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Macroalgal detritus: Physical variables and impacts on the benthic macrofaunal community

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Marine Coastal Development

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Abstract

Marine primary productivity by micro- and macroalgae in Norway, limited to the photic zone (0 – 200 m depth), controls the amount of organic carbon (food) available to higher trophic levels, and is the basis for marine biodiversity and productivity. Recent studies have revealed new habitats dominated by “kelpfalls” (concentration zones with macroalgae detached from their hard substrate, including kelp detritus/fragments), and indications that these may play an important part in the vertical transport of organic carbon and energy to the aphotic zone. Macroalgal fragments has been documented on the seabed (ranging from shallow waters to the deep sea), and there is an increased focus by researchers to investigate the impact of the detritus on the benthic organisms in the deep sea and fjord environments. Physical parameters impact the transport of organic carbon to the marine benthic organisms in the deep. High current speed can have an impact on the size of particles that reach the seabed, and high variation in seafloor morphology has been linked to a build up of organic content on the seafloor.

The study aimed to document the occurrence of macroalgae fragments, its impact on the benthic macrofaunal biodiversity, and occurrence of phytoplankton pigments on the seabed. Furthermore, investigate the impact of physical parameters and assess the use of a Remotely Operated Vehicle (ROV) as a mapping tool. The study was conducted 6 km south of the mouth of the Trondheimsfjord, Norway. Macroalgal fragments and benthic macrofaunal biodiversity where documented by video transects following the European Standard for visual seabed surveys. Sediment grain size and occurrence of potential phytoplankton pigment were investigated from box core sediment samples. A link was found between higher variation in seafloor morphology, an increase in biodiversity, coarser grain size of bottom surface sediment and a higher occurrence of macrofaunal fragments. Results indicate an increase in taxa biodiversity, especially with respect to occurrence of macroalgal grazers, with the presence of macroalgal fragments. Biofilm from sedimented phytoplankton were not found in surface of bottom sediments (HPLC analysis of pigments). The ROV video transects allowed for identification and distribution of taxa on the seabed, but several problems were encountered with species identification due to low image resolution and using external morphology for identification. Additionally, the need to develop alternatives within the European Standard depending on baseline data available and ecosystems of interest was identified. Macroalgal fragments may play a large role in carbon sequestration and in supplying food to benthic organisms in the deeper parts of the ocean. Further studies, with a multidisciplinary approach, is needed to identify the pathways of transport to the deep and its impact on the life below.

Sammendrag

Mengden organisk karbon (næring) som er tilgjengelig for trofiske nivåer langs norskekysten er kontrollert av primærproduksjon av mikro- og makroalger i lyssonen ned til 200 m. Tilgangen til organisk karbon er en driver for utbredelse og diversitetene for biologiske mangfold i mange marine økosystemer. Studier har påvist habitater som tarenedfall i form av algebiter på havbunnen også kan ha en viktig påvirkning på transporten av organisk karbon og energi til den afotiske sonen. Makroalger er en gruppe fototrofe organismer som finnes i tempererte marine områder, og er svært viktige for mange marine økosystemer. Biter fra makroalger har blitt funnet på havbunnen, både på grunt og dypt vann, og forskere har begynt å spørre hvilken påvirkning bitene har på bunnlevende organismer i dyphavet og i fjordsystemer. Fysiske variabler påvirker transport av organisk materiale til dypere lag. Stor strømhastighet kan føre til at små partikler ikke når havbunnen, og sammenhenger har blitt funnet mellom større variasjon i bunnmorfologien og større forekomst av organisk materiale.

Målet med studien var å dokumentere makroalgebiter og fytoplanktonpigmenter på havbunnen, og påvirkningen dette har på den bentiske biodiversiteten. Jeg ville også undersøke hvordan fysiske faktorer påvirker distribusjonen av organisk karbon og vurdere bruken av en fjernstyrt undervannsfarkost (ROV) til å kartlegge habitater. Studiet ble utført 6 km sør for munningen av Trondheimsfjorden. Makroalgebiter og bentisk biodiversitet ble logget ved hjelp av videotransekter europeisk standard for visuelle bunnundersøkelser. Boxcore sedimentprøver ble brukt til å undersøke kornstørrelse på sediment og tilstedeværelse av pigmenter fra fytoplankton. En sammenheng ble funnet mellom høyere antall algeobservasjoner, høyere bentisk biodiversitet, grovere sediment og høyere variasjon i bunnmorfologien. Dette indikerer at det er økning i biodiversitet, spesielt algebeitere, ved høyere forekomst av algebiter. Det ble ikke funnet noen fytoplanktonpigmenter i sedimentprøvene (HPLC analyse). Videotransektene gjorde det mulig å se på fordeling av organismer på havbunnen, men det var problemer med artsidentifikasjon på grunn av videooppløsning og restriksjonen med å kun bruke ekstern morfologi til å identifisere arter. Det er tydelig at den europeiske standarden burde ha flere alternativer slik at man kan tilpasse metoden basert på området man skal undersøke, tilgang på data og hvilke økosystemer og organismer man vil undersøke. Rollen til makroalgebiter når det kommer til karbontransport til bentiske organismer i dypet er uvisst, men kan være større enn tidligere antatt. Det er behov for flere undersøkelser med en tverrfaglig sammensetning, for å identifisere transportmåter av algene, og dermed karbon, og hvilken påvirkning de har på de bentiske økosystemene.

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Abbreviations

% Retained	Percent sediment retained in sieve
AUR-lab	Applied Underwater Robotics Laboratory
DP	Dynamic Positioning
DTM	Digital Terrain Model
E	Evenness
EMODnet	The European Marine Observation and Data Network
GIS	Geographic Information System
H'	Shannon Index of Species Diversity
HPLC	High Performance Liquid Chromatograph
MBE	Multi Beam Echo Sounder
NTNU	Norwegian University of Science and Technology
P_i	The proportion of the <i>i</i> th species
POC	Particular Organic Carbon
R/V Gunnerus	Research Vessel Gunnerus
ROV	Remotely Operated Vehicle
S	Numbers of species in the transect
TBS	Trondhjem Biological Station
W_{sieve}	Sediment sample retained in sieve
W_{total}	Weight of the total sample

1. Introduction

1.1. Transport of Organic Carbon to the Deep Sea

The aphotic zone was long thought to be a lifeless abyss, with the lack of sunlight disabling it from photosynthesis, and thus lack of food for marine organisms (Eizaguirre, 2016). Since then, researchers have discovered that these lightless areas of the oceans, which comprises the majority of all marine ecosystems, contain a vast array of marine life sustained by particular organic carbon (POC) sinking down from the photic zone to the deep – commonly referred to as “marine snow” (Druffel et al., 1999). In more recent time, a study using newly developed hyperspectral imaging techniques, found phytoplankton pigments at 3000 m depth (Dumke et al., 2018).

Primary production control the amount of organic carbon (food) available to the different trophic levels in the ocean, thus driving the biodiversity and productivity of many marine ecosystems (Pauly and Christensen, 1995, Costanza et al., 2007). The main organisms in marine primary production are phytoplankton, marine plants and macroalgae, and is restricted to the upper 200 m due to the rapid absorption of light by the water column (Falkowski et al., 1998, Gattuso et al., 1998, Gattuso et al., 2006, Ramirez-Llodra et al., 2010). However, as the mean depth of the ocean is 3,796 m (Garrison, 2010, p.11) most marine ecosystems depend on carbon being produced elsewhere as sustenance for the food web, with the exception being chemo-auto-trophic communities found for instance around hydrothermal vents (Falkowski et al., 1998). In temperate zones the vertical transport of organic carbon from the surface waters to the deep sea is closely connected with the spring bloom of phytoplankton, which provides a temporary surplus of food to the benthic organisms (Yang et al., 2008, De Bettignies et al., 2013, Billett et al., 1983, Platt et al., 1989, Smith et al., 1994).

Research on the transport of organic carbon from the photic zone to the deep ocean has mainly been focused on phytoplankton, and the seasonal pulse of organic matter from the sea surface to the deep (Billett et al., 2001, Smith et al., 2008, Smith et al., 2006). However, with the rapid development of technology and increased focus on exploring the deep ocean researchers have documented numerous new ecosystems such as whalefalls, which are hosts to unique organisms (Aronson et al., 2016). Whalefalls – dead whales that sink to the seafloor – serve as an oasis for benthic marine life, as they provide large amounts of carbon to an ecosystem that is otherwise energy-limited (Baco and Smith, 2003, Dubilier et al., 2008, Hartmann and Levin, 2012, Aronson et al., 2016, Smith and Baco, 2003). Several studies have shown similar

occurrences with macroalgae, often referred to as kelpfalls, and these may play a significant role in energy transport and food supply to the benthic organisms in the deep sea (Garden and Smith, 2015, Ramirez-Llodra et al., 2016, Dierssen et al., 2009, Bustamante et al., 1995, Bernardino et al., 2010, Renaud et al., 2015, Sampaio et al., 2017, Wernberg et al., 2006).

1.2. Macroalgae

Macroalgae, commonly referred to as seaweeds, are a diverse group of photoautotrophic organisms, comprised of Phaeophyceae (brown algae), Chlorophyceae (green algae) and Rhodophyceae (red algae), that are of vital importance for marine ecosystem functions as they provide food, shelter and habitat to an array of species. Although they only cover one percent of all ocean areas, marine macroalgae are responsible for 5 – 10 % of the total oceanic production (Wiencke, 2012). Macroalgae depend on photosynthesis and are therefore limited by light availability for their distribution. However, the algae have been found to survive extended period without sunlight and can be found in the Arctic and Antarctic enduring through the polar night (Gomez et al., 2009, Zacher et al., 2009, Wiencke and Wiencke, 2011).

Kelp forests, large brown macroalgae from the order Laminales, are one of the most diverse ecosystems in the world, more diverse than terrestrial forest (Steneck et al., 2002). In Norway, kelp forest is estimated to cover more than 18 000 km² containing a total biomass of 180 million tonnes (Gundersen, 2011). These forests can often be found in areas with high current activity, and as a result fragments of the algae are often ripped off. Additionally, many macroalgal species found in kelp forest shed their blade (lamina) annually, and combined these factors result in a high amount of detritus produced in these ecosystems, which functions as food for many organisms (Taylor, 1998, Carlsen et al., 2007).

1.2.1. Transport of Macroalgae to the Seafloor

The occurrence of macroalgal detritus on the seafloor is not a recent discovery and was first described by the Challenger Expedition in the later part of the 19th century (Murray et al., 1895). In Norway, a study shows that only 3 – 8 % of kelp produced in the kelp forest is consumed directly by secondary consumers on site. This leaves approximately 90% of the kelp to be consumed elsewhere, and where this goes is poorly understood. Documented presences of macroalgal detritus in marine sediments are relatively few, but the ones that exist show a huge spread of detritus extending from the shallow to the deep zones and spanning across polar to

tropical regions (Krause-Jensen and M. Duarte, 2016). Macroalgae are also found in several oil shales, further evidence that they have been sequestered into marine sediments (Xie et al., 2014, Sun et al., 2013).

Previous studies have documented macroalgal detrital production rates as well as their introduction to nearby benthic habitats, and there is an increased awareness of the importance of linking these ecosystems with the deep sea benthos, including deep fjord systems (Wernberg et al., 2006, Britton - Simmons et al., 2012, Filbee-Dexter and Scheibling, 2016, Filbee-Dexter and Scheibling, 2014, Filbee-Dexter and Scheibling, 2017, Filbee-Dexter et al., 2018, De Bettignies et al., 2013, Krumhansl and Scheibling, 2012, Renaud et al., 2015). A recent study looking at a deep fjord system in Norway indicated that large quantities of macroalgal fragments from kelp forests enter the surrounding subtidal benthic habitats (Filbee-Dexter et al., 2018). Studies on transport of macroalgae to deep sea ecosystems have mainly been focused on kelp species, while other macroalgal species perhaps have been overlooked (Vetter and Dayton, 1998, Harrold et al., 1998, Krause-Jensen and M. Duarte, 2016).

Studies have shown that floating fragments of macroalgae can be transported vast distances by the ocean currents. Hobday (2000) found drifting kelp could travel over 300 km offshore. Moreover, air bladders commonly found in many species of brown algae have been found to function as buoys, enabling the macroalgae to be transported further (Trevathan - Tackett et al., 2015) (Figure 1.1). Potential evidence of this can be found on deep sea soft sediment where stones have been deposited, most likely a result from having been ballasted by macroalgae with airbladders, and when the air bladders deflate and deposit the rocks, and supposedly the macroalgae, on the seabed (Garden and Smith, 2015).

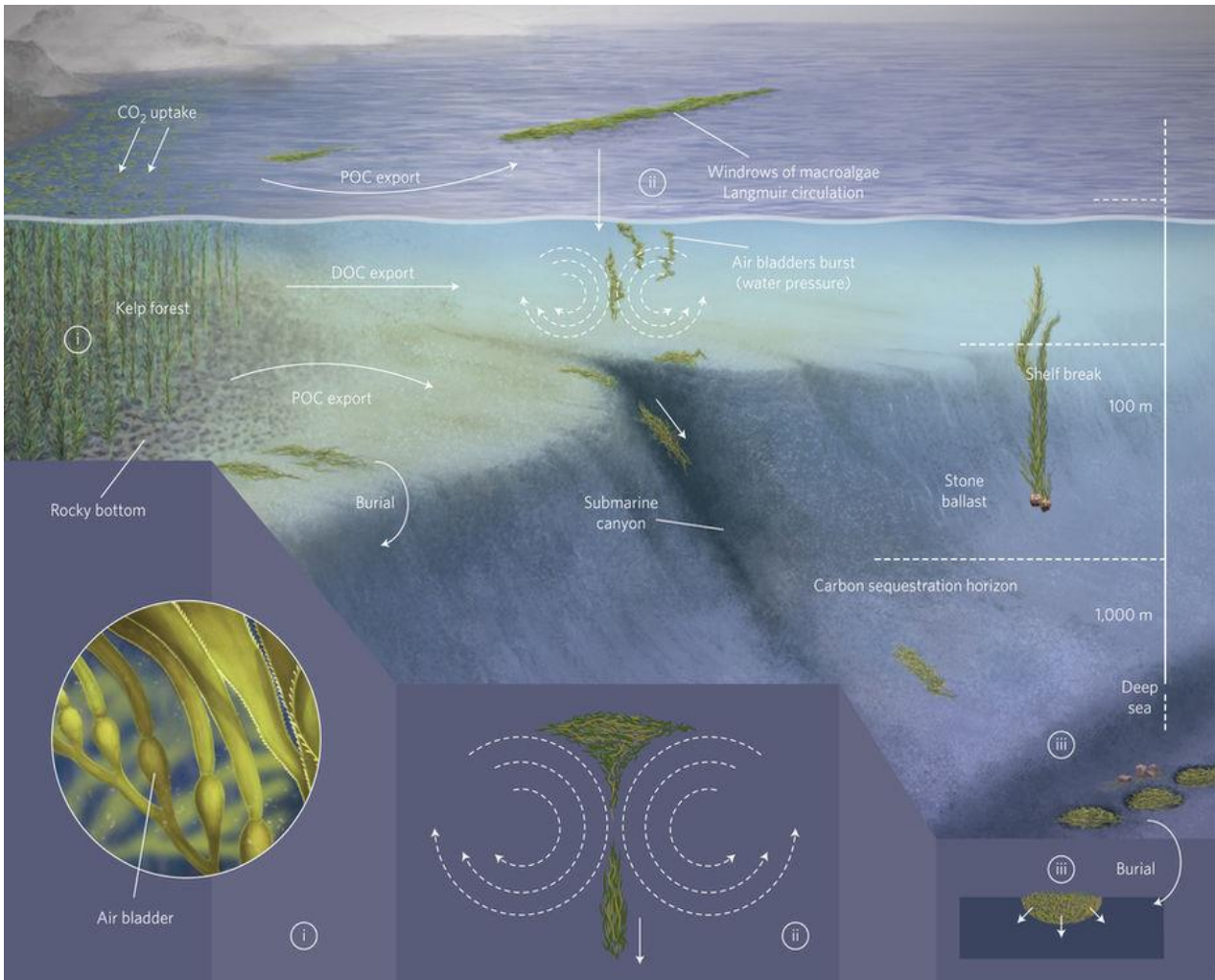


Figure 1.1: Diagram displaying export, sequestration and transport of macroalgae. Air bladders, common in many brown macroalgae can enable the macroalgae to be transported far away from the original site (i) Langmuir circulation can form windrows of macroalgae (ii) and can furthermore push the algae to depths where the water pressure bursts the air bubbles making the algae sink. From there the algae can be sequestered by burying into the sediment or (iii) transported to the deep sea where it will be sequestered. Figure from Krause-Jensen and M. Duarte (2016).

1.3. Physical Parameters

Abiotic conditions play a large role in marine ecosystems by for instance linking ecosystems together by the transport of organic material. High current speed can result in a more horizontal transport of smaller particles due to a slower sinking rate, thus leaving them suspended in the water column for longer periods of time, and potentially resulting in larger deposits of these particles in areas with less current speed (Simpson, 1982). If current speed is not known, grain size can also be an indication, as larger grain size usually indicates a higher current speed (McCave et al., 1995). Additionally, grain size has an impact on the benthic fauna, as some organisms prefer certain a particle size, for instance burrowing organisms may prefer sediments comprised of smaller grain size such as clay and silt where they can construct holes and burrows (Ramirez-Llodra et al., 2010). Moreover, the seafloor morphology can have an impact on the accumulation of organic debris, including macroalgae and POC, and studies have shown fjord basins and submarine canyons have higher accumulation of organic material (Vetter, 1994). These accumulations of organic material could affect the food web in the community and the functioning of the marine ecosystem by increasing the amount of food available (Renaud et al., 2015).

1.4. The Aim of the Study

The aim of this study was originally to create a predictive model of marine habitats in the study area, but because of lack of data publicly available, the aim was changed in March 2018 to focus on macroalgae detritus and energy transport to the deep. However, the data collection was already completed, so the study design may not be optimal for the new aim.

This study is only an investigative study to reveal potential patterns and areas of interest to conduct further study, it is therefore important to keep in mind that this is a pilot study and did not collect enough data to make any definite conclusions.

This aim of the study was to (1) document the occurrence of macroalgae detritus on the seabed (2) investigate the impact of physical parameters such as ocean current speed, seafloor morphology and sediment grain size on the occurrence of macrofauna detritus on the seabed; (3) investigate the occurrence of phytoplankton pigments on the seabed; (4) evaluate the use of a Remotely Operated Vehicle in the study.

2. Materials and Methods

2.1. Study Site

The location was chosen as research cruises in previous years have made observations of macroalgae detritus at greater depths at the site from Agassiz trawling (Figure 2.1). However, these observations have not systematically been examined thus it was of interest to investigate the area further. The study was conducted 6 km south of the inlet of the Trondheimsfjord located in central Norway (Figure 2.2).



Figure 2.1: Pictures of macroalgae detritus found from Agassiz trawling taken on different field cruises in the study site 6 km south of the mouth of the Trondheimsfjord in Norway. Photo: Torkild Bakken, 2016.

After a study of the seabed data available, using a bathymetry map with 50 m spatial resolution from the Norwegian Mapping Authority, two locations were chosen. Location A was thought to have little variance in seafloor morphology and Location B was thought to have a greater variance in seabed morphology.

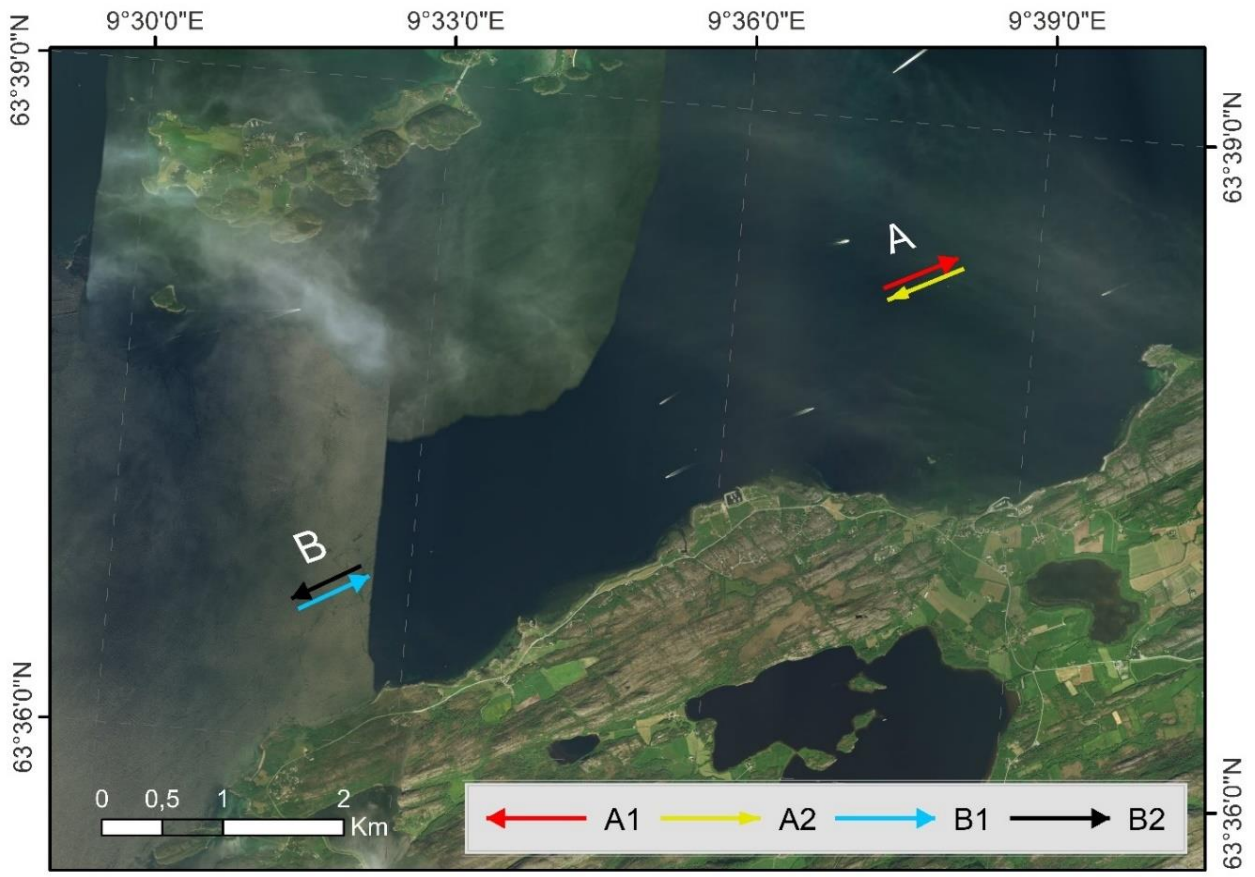


Figure 2.2: Map of the study site 6 km south of the mouth of the Trondheimsfjord in Norway. The smaller maps on the bottom is showing the area of the study marked with the red square. The two study sites are marked with Location A (white A) and Location B (white B). The arrows display the direction and location of four transect lines completed by the Remotely Operated Vehicle (ROV) at approximately 400 m depth during field work on February the 22nd 2017. Source: ESRI Imagery Basemap 2016, the Norwegian Mapping Authority 2017 & USGS 2018. Datum: WGS 84, Projection: UTM Zone 32N.

2.2. Data Collection

2.2.1. The Research Vessel Gunnerus

The data for this master thesis was collected during a cruise with the Research Vessel Gunnerus (R/V Gunnerus) on the 22st of February 2017 from where the instruments were deployed. R/V Gunnerus is equipped with a dynamic positioning (DP) system allowing for very accurate navigation such as path following of ROV used in this survey (Sørensen et al., 2012).

2.2.2. Video Transects from the Remotely Operated Vehicle

The Remotely Operated Vehicle (ROV) used for all transects was a SUB-fighter 30 K ROV (Figure 2.3) from Sperre AS (Notodden, Norway). The ROV was equipped with two light sources, comprising of 250 W halogen lights and HMI gas lights of 200 and 400 W, providing light for a high definition video camera with a laser-ruler (seen as two red points in images 10 cm apart) to enable a scale to be made for the images (Ludvigsen et al., 2014).



Figure 2.3: The Remotely Operated Vehicle used for the transects was a Sperre SUB-fighter 30k equipped with halogen lights, HMI gas lights and a high-resolution video camera with a laser ruler (distance=10cm) to enable a scale for the images. Photos: Kaja Lønne Fjærtøft.

Two video transects of a minimum of 600 m distance along the seafloor were collected from each of the locations (Table 2.1). The transects were conducted according to the European Standard for visual seabed surveys (NS-EN16260:2012) (Standard Norge, 2012). The ROV video transects will hereby be referred to with Location and the transect number (A1, A2, B1, B2).

Table 2.1: Table describing video transects taken at the field cruise in the study area 6 km south of the mouth of the Trondheimsfjord, Norway.

Transect	Time		Position		Depth (m)	Length (m)
	Start	End	Start	End		
A1	15:27	16:19	63.637426, 9.624931	63.640131, 9.636661	394 – 398	638
A2	16:31	17:47	63.639383, 9.637780	63.636626, 9.625766	393 – 399	650
B1	11:34	12:30	63.612571, 9.543258	63.609666, 9.531945	399 – 418	689
B2	12:51	13:47	63.610420, 9.530821	63.613209, 9.541582	390 – 419	641

The ROV video camera altitude was at 1 – 1.5 m distance from the seafloor and moved at a speed of approximately 0.4 knots. During the video transects, biological objects of interest and habitat types were live logged with exact location by the help of the software Urd developed by the Applied Underwater Robotics Laboratory lab (AUR-lab) at the Department of Marine Technology at the Norwegian University of Science and Technology (NTNU) (Figure 2.4) (Nornes, 2018).



Figure 2.4: The control room for the Remotely Operated Vehicle (ROV), with the joystick on the bottom left. The screen displays live footage from the ROV transmitted by optical fibres to the surface via the umbilical, and biological objects of interest and habitat types can be live logged with exact location utilising the software Urd. Photo: Kaja Lønne Fjærtøft

2.2.3. Box Core Samples

Box core samples were collected as close to the transect lines as possible (Table 2.2). The area of the box core was 30x30 cm, with a volume of 0.117cm³ (Figure 2.5). The box core was lowered to one meter above the seabed and held there for one minute to limit sideways movement, before it was lowered slowly to seabed and raised to the surface. The box corer was required to be fully closed when reaching the surface to be deemed a usable sample.

On deck the sediment samples were emptied into a clean plastic box. The top of the sediment sample was scraped off and separated into two small bags and frozen on board for the High Performance Liquid Chromatography (HPLC) analysis to identify potential microalgal pigments from biofilm layer that may be on surface of seafloor substrate. Two samples of approximately 1 kg were put in a large plastic zip lock bag for grain size analysis.



Figure 2.5: Box core with 30x30 cm area and a volume of 0.117cm³ for sediment samples the 22nd of February 2017. Photo: Kaja Lønne Fjærtøft.

Table 2.2: Table showing depth and location of the box core samples taken at the study site 6 km south of the mouth of the Trondheimsfjord, Norway. Location is displayed in decimal degrees.

Box Core sample	Location	Depth (m)
1	63.633889, 9.617222	405
2	63.633611, 9.618056	405
3	63.633889, 9.617778	404
4	63.601806, 9.536944	417

2.3. Data Processing

2.3.1. Physical Parameters

Bathymetric Model

Due to depth restrictions of 200 m for the Kongsberg EM 3002s multi beam echo sounder (MBE) onboard the R/V Gunnerus it was not possible to obtain bathymetric data from the vessel's MBE. Instead, bathymetric data with 10 m resolution collected in 1999, the best available in the region, was released by the Norwegian Mapping Authority after a successful application on the 27th of September 2017. After receiving information from the Norwegian Mapping Authority that the backscatter data was unreliable due to bad quality, no application was sent to acquire this data.

The data received contained point-measurements of depth in the region and utilising a Geographic Information System (GIS) a model of the seabed was created – hereby referred to as the Digital Terrain Model (DTM). The DTM was created using the GIS NaviModel 4 (EIVA, 2005) by using the “Create DTM” function.

Seafloor Morphology

This study uses slope as a proxy for variance in seafloor morphology. After the creation of the DTM, the “slope along line” function in NaviModel 4 (EIVA, 2005) was used to get the slope measurements in degrees along the four individual transects.

Ocean Current Speed Model

SINTEF Ocean ran a simulation in their SINMOD ocean current model¹ and provided data on modelled current speed for 1 m, 50 m and 200 m below sea surface and bottom current speed in the study area. For detailed description of the mathematical model behind SINMOD see Slagstad and McClimans (2005).

Grain Size Analysis

The grain size analysis was conducted on the four marine sediment samples collected by the box core during the field work. The samples were weighed, and finer sediments were washed out utilising the finest sieve in the sieve set. Afterwards, they were put in a sediment oven at 70° C to remove moisture overnight (approximately 10 hours). The sediment samples were then shaken through a series of seven grain size sampling sieves for 10 minutes, with the following

¹ The simulation was run by Ole Jacob Broch, SINTEF Ocean

size mesh; 4.0 mm, 2.0 mm, 1.0 mm and 500 μm , 250 μm , 125 μm , 63 μm with a pan at the bottom (Figure 2.6).

Afterwards each fraction was weighted using an analytical balance, and the weight of the empty sieve subtracted.

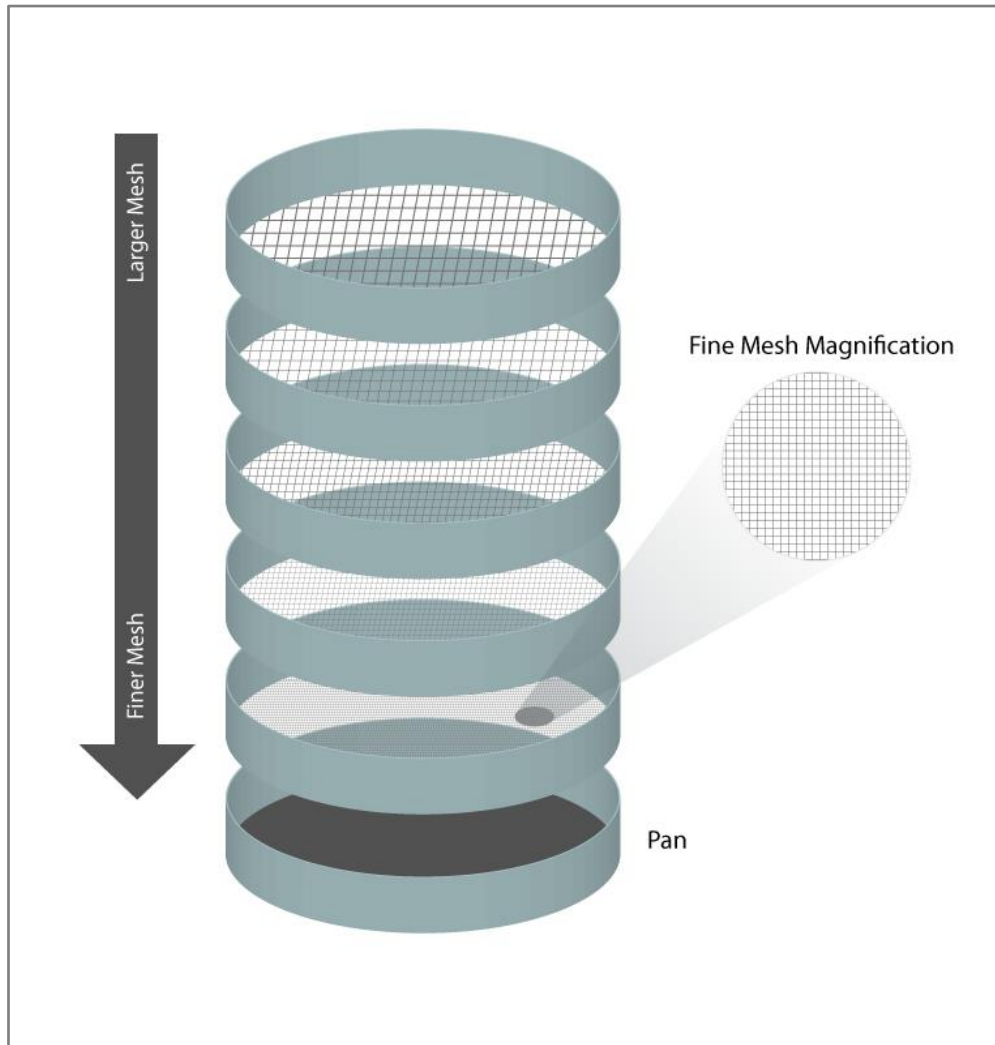


Figure 2.6: Diagram of the workings of the grain size analysis. Sieves ranging from 4 mm – 63 μm are arranged on top of each other. A dried sample of ~1 kg was poured into the top of the sieve set and the sieve set is shaken for 10 minutes. Then each sieve is weighted and then the total mass retained in each sieve is noted down. Figure from Particle Technology Labs, 2018.

The following formula was used to calculate the sediment retained in each sieve:

$$\% \text{ Retained} = \frac{W_{\text{Sieve}}}{W_{\text{Total}}} \times 100$$

% Retained = percent sediment retained in sieve

W_{total} = weight of the total sample

2.3.2. Biological Parameters

High Performance Liquid Chromatography

High Performance Liquid Chromatography (HPLC) was used to identify the occurrence of phytoplankton pigments, specifically looking for taxonomic markers belonging to the pigment groups chlorophylls, xanthophylls and carotenes in the sample (Roy et al., 2011).

The samples were immediately frozen at -20° C prior to arrival back at the laboratory (3 days) and further stored at -20° C until the time of laboratory work (~13 months). The samples were then extracted for pigment analysis by taking ~ 7 grams of frozen matter and mixing with methanol as solvent, before an electric mixer was used to ensure proper extraction of the sample. Afterwards, the sample was put back in the freezer for 72 hours. HPLC analyses for identification and quantification of pigments were performed by a lab technician at Trondhjem Biological Station (TBS) according to the protocol by Rodríguez et al. (2006).²

Remotely Operated Vehicle Video Transect Analysis

Macroalgae

Video of the seabed was continuously filmed along the transect line and macroalgal specimens observed along each transect line were noted with position and depth. For each macroalgae specimen an estimated length was noted and identified to lowest taxonomic level based on “A Key for Seaweed Identification (South Norway)” (Sjøtun, 2017) and “Alger I Farger” (Rueness and Knispel, 1998).

Biodiversity

Frame grabs, extracted from the continuous video footage that was filmed along the transect line, were taken with Adobe Premier Elements 2018 (Adobe, USA). Two intervals between frame grabs were used. One following with 8 m between frame grabs based on recommendations from previous study with ROV video analysis (Jakobsen, 2016), and a second based on the recommendations of a minimum frame grab interval of 20 m made by the European Standard for visual seabed surveys (NS-EN 16260:2012) (Standard Norge, 2012). To reduce the workload every third photo extracted for the initial analysis was used, resulting in 24 m between frame grabs

² HPLC analyses was conducted by senior engineer Kjersti Andresen at Trondhjem Biological Station (TBS)

All frame grabs were analysed per the European Standard NS-EN 16260:2012 for visual seabed surveys thus all living organisms in the frame grabs were identified to the lowest taxonomic level (Standard Norge, 2012).

2.4. Statistical Analysis

2.4.1. The Shannon Index of Species Diversity

The Shannon Index of Species Diversity (H'), also referred to as the Shannon's Diversity Index, the Shannon-Weaver Index or the Shannon Wiener Index (Spellerberg and Fedor, 2003), is used in the biological sciences as a statistical measure of how much information is needed to predict the species diversity in this case found in the transect. All living organisms in each transect was used as a basis for calculating H' , macroalgae observations were excluded due to difficulty in species identification and identifying if fragments were living or dead. H' can be described as (Shannon et al., 1950):

$$H' = - \sum_{i=1}^S (P_i \log P_i)$$

S = numbers of species in the transect

P_i = the proportion of the i th species

It is assumed that a random sample is used thus evenness of the sample can be calculated. Evenness (E) is the ratio of the calculated H' value to the maximum value (thus ranging from 0 to 1) (Hill, 1973):

$$E = \frac{H'}{H_{max}}$$

A scale defined by Jakobsen was used to measure equitability (Table 2.3) (Jakobsen, 2016).

Table 2.3 : Equitability scale of evenness of biodiversity as defined by Jakobsen (Jakobsen, 2016).

<i>E</i> value	Equitability
0	Not present
0.10 – 0.29	Low diversity
0.3 – 0.49	Medium diversity
0.5 – 0.9	High diversity
1	Perfect diversity/evenness

3. Results

3.1. Physical Parameters

3.1.1. Bathymetric Model

A Digital Terrain Model (DTM) with 10 m spatial resolution was created using the software NaviModel 4.0 (EIVA, USA), and the track from the ROV overlaid. (Figure 3.1). The DTM shows that Location A was in a relatively flat area, while Location B was located on a downhill slope finishing in the deepest section of the study section (~430 m). Furthermore, in an email correspondence on May 25th, 2018, Senior Marine Geologist Øivind Lønne informed me that indications of sediment slides can be seen along the shore, marked with white arrows in Figure 3.1.

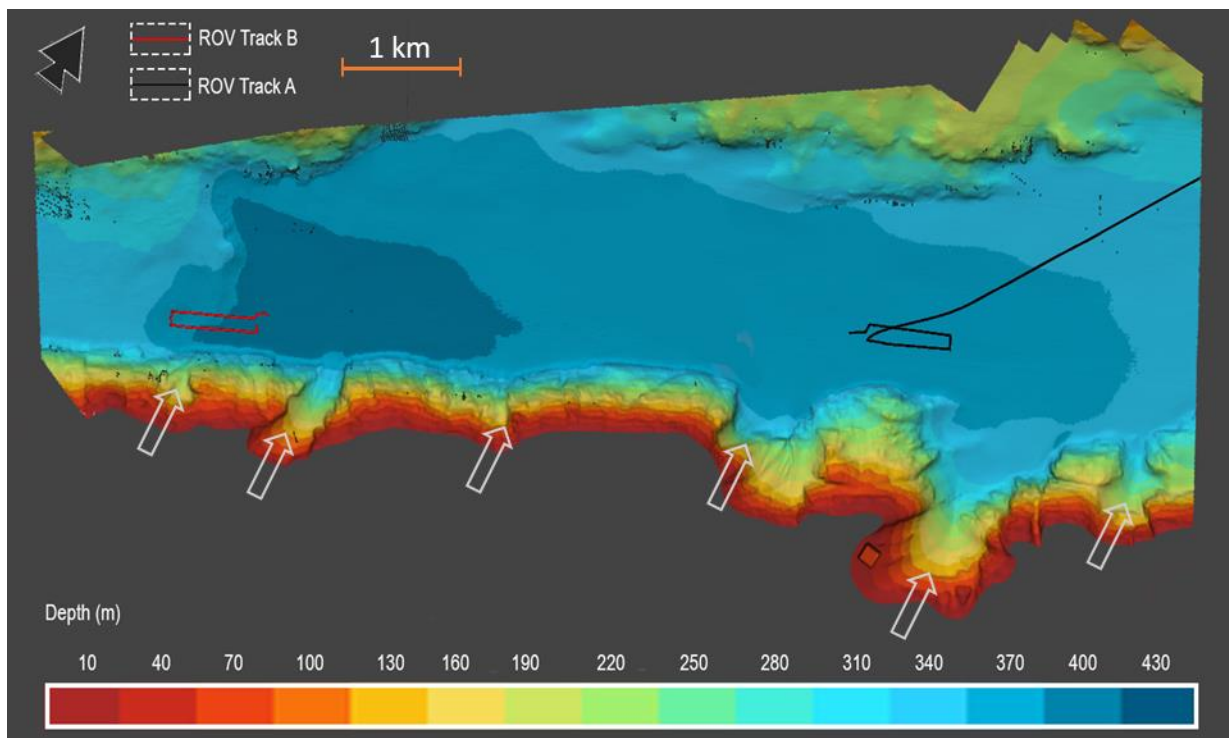


Figure 3.1: The bathymetric Digital Terrain Model create in NaviModel 4.o (EIVA, USA) of the seabed in the study location approximately 6 km south of the Trondheimsfjord, Norway, displayed in the NaviModel 4 software (EIVA, USA). Black arrow in top left-hand corner indicates north. The lines are the track of the Remotely Operated Vehicle (ROV), displayed in red for Location B and black for Location A. The white arrows represent possible sediment slides. Datum: World Geodetic System 84, Projection: Universal Transverse Mercator Zone 32 North.

3.1.2. Seafloor Morphology

Figure 3.2 shows the slope in degrees along the transect line for the four ROV video transects calculated in NaviModel 4 based on the DTM. Both transects in Location A were relatively flat with a slope of <1 degrees along the whole transect line. B1 had a relatively flat section with a slope of <2 degrees along the first 500 m, but with the slope steepness increasing up to 6 degrees from 500 m and onwards. Transect B2 had the steepest slope, with an increasing slope steepness from 7 – 9 degrees the first 100 m, decreasing down to 3.5 degrees until the 200 m along the transect line. From 200 m the slope steepness increased to 7 degrees until 390 m along transect, and from there the slope steepness decreased down to 1.5 degrees at 500 m and then flattened out onwards with a slope below 1.5 degrees.

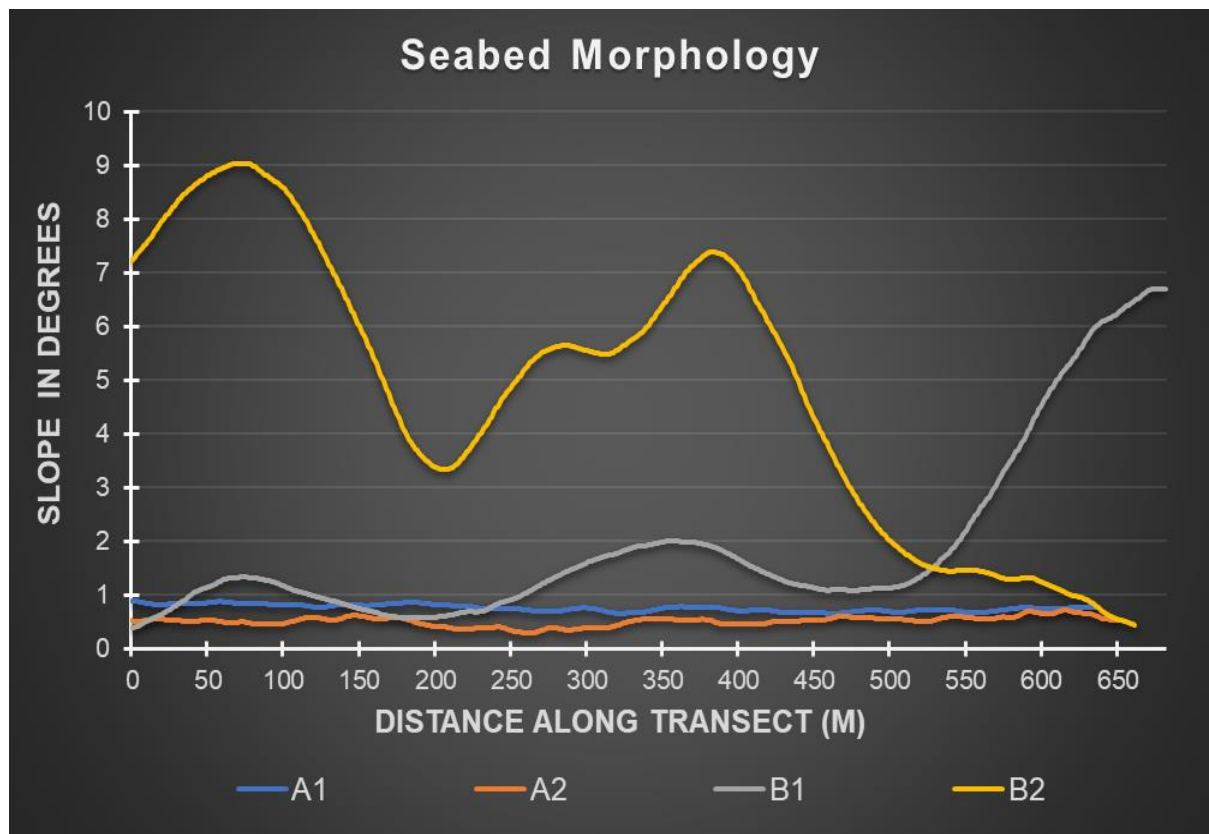


Figure 3.2: Slope along the four Remotely Operated Vehicle (ROV) transects from the study site 6 km south of the mouth of the Trondheimsfjord in Norway. The vertical axis is showing the slope of the transect in degrees, and the horizontal axis is displaying the distance along the transect in m. The slope is calculated from the 10 m resolution Digital Terrain Model created in NaviModel 4 (EIVA, USA).

3.1.3. Ocean Current Speed Model

Modelled ocean current speed from depths of 1 m (hereby referred to as surface), 50 m, 200 m and seafloor (hereby referred to as bottom) from the ocean current model SINMOD created by SINTEF Ocean (SINTEF, 2018). For a detailed description of the mathematical model behind SINMOD see Slagstad and McClimans (2005). Surface current speed is relatively high (approximately 0.25 ms^{-1}), while 50 m current speed was medium (0.15 ms^{-1}) in both Location A and Location B. However, the 200 m modelled current speed shows a stronger current speed around Location B (approximately $0.05 - 0.15 \text{ ms}^{-1}$) than in Location A (approximately $0.0 - 0.05 \text{ ms}^{-1}$). Bottom current speed surrounding Location B is similar to that found on the surface (between $0.25 - 0.15 \text{ ms}^{-1}$) while at Location A the current speed is much less ($0.05 - 0.1 \text{ ms}^{-1}$) (Figure 3.3).

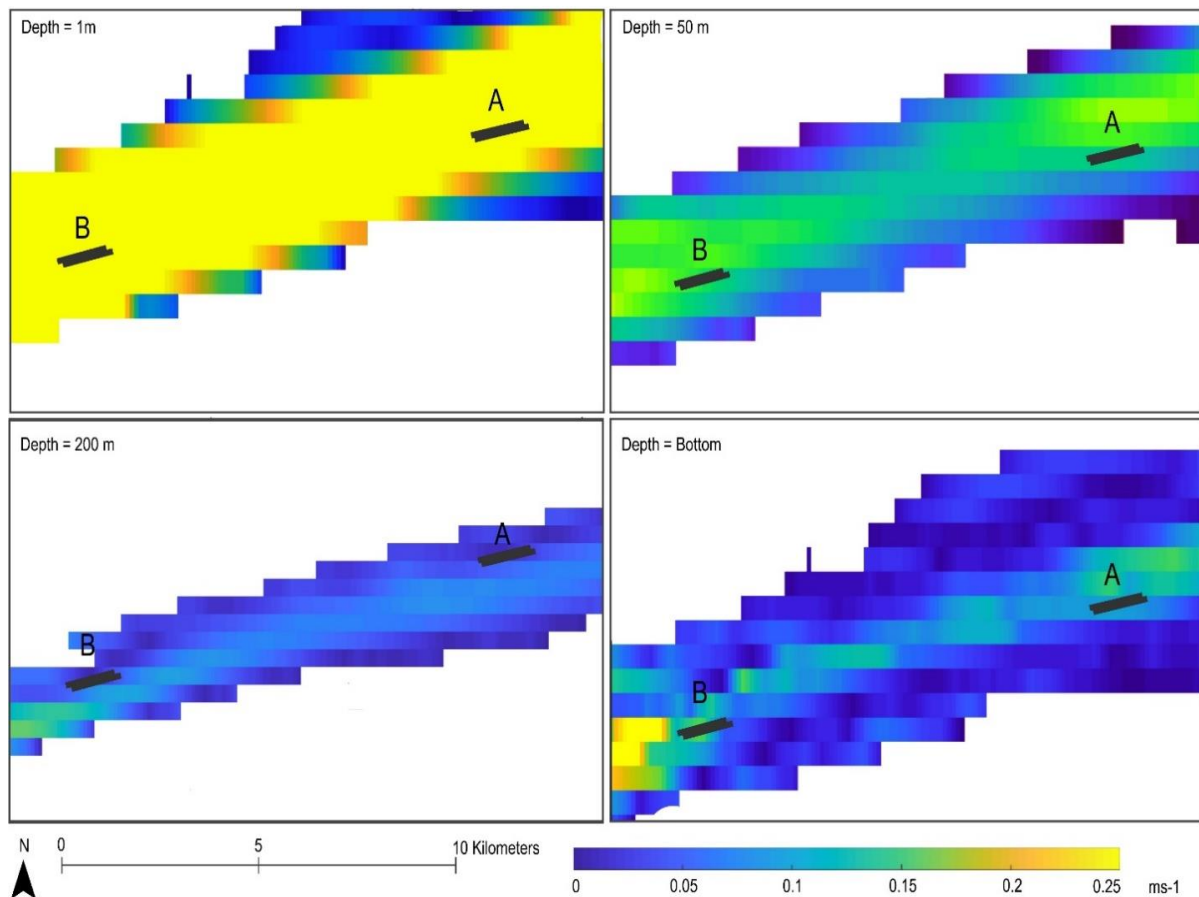


Figure 3.3: Modelled ocean current speed at 1 m, 50 m, 200 m depth and corresponding seafloor (bottom) from the mathematical current model SINMOD developed by SINTEF Ocean in the study site 6 km south of the mouth of the Trondheimsfjord in Norway. The modelled current speed is displayed as dark blue (low current speed) to yellow (high current speed). The two study locations are displayed as Location A (A) and Location B (B) see section 2.1.

3.1.4. Grain Size Analysis

There was a distinct difference between the sediment samples from Location A and Location B. Over 95% of the grains found in Location A were smaller than 250 μm , while most of the grains in Location B were above 1 mm (Figure 3.4). Box core samples in Location B were difficult to obtain, plausibly due to high current speed or hard bottom. Eight unsuccessful box core samples were taken before the successful box core sample was acquired.

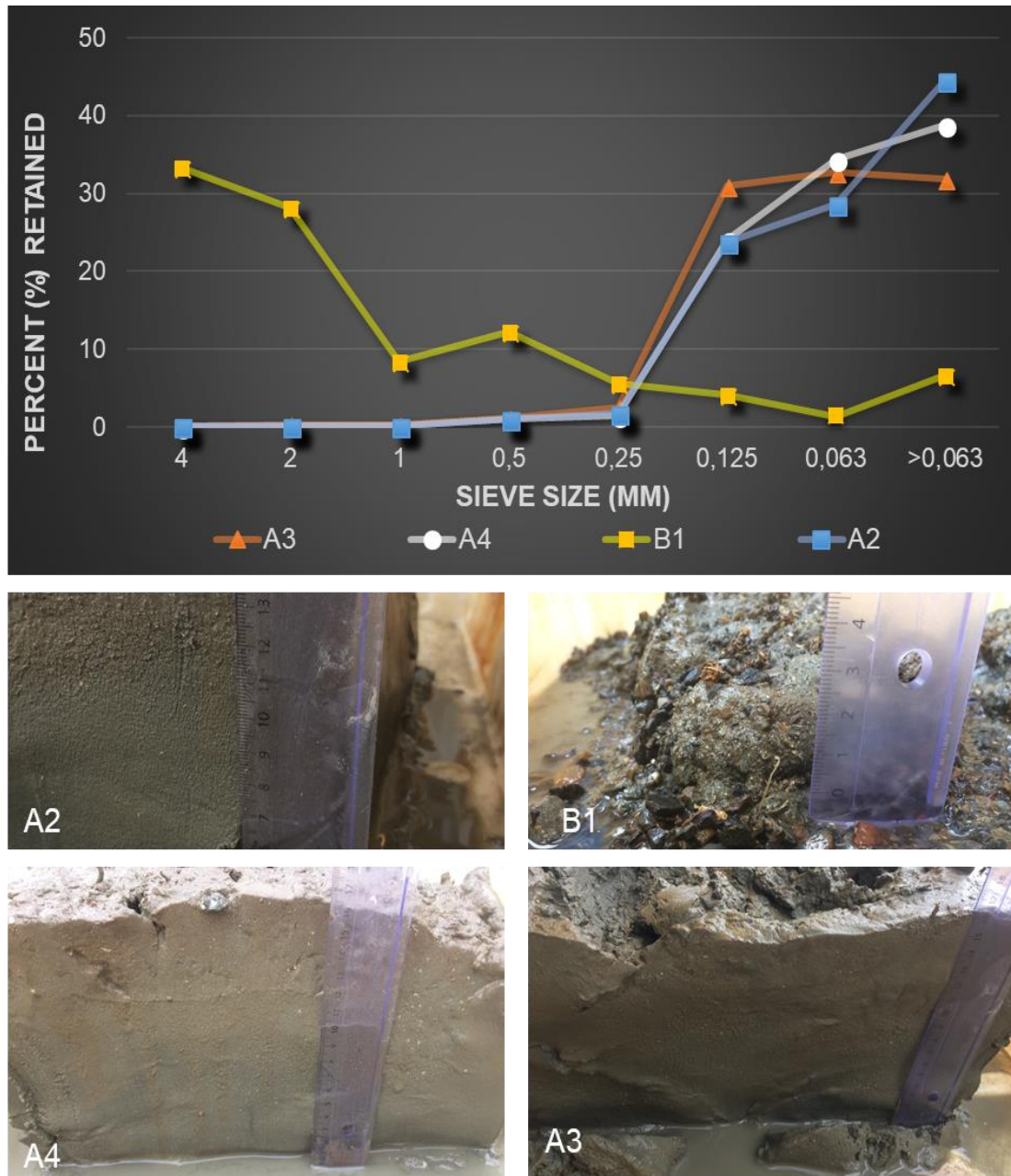


Figure 3.4: Graph showing results of grain size analysis and pictures from box core samples in Location A (A2-4) and Location B (B1) from the study site 6 km south of the mouth of the Trondheimsfjord in Norway. The horizontal axis shows the percent retained in each sieve and the vertical axis displays the sieve size. Photos: Kaja Lønne Fjærtøft.

3.2. Biological Parameters

3.2.1. High Performance Liquid Chromatography

High Performance Liquid Chromatography (HPLC) analyses was used to elucidate if there were a sedimentation of phytoplankton particles to the seafloor as a potential source for organic carbon (food) source for benthic organisms. There was no evidence found in the sediment samples of phytoplankton cells from the upper water column. A representative graph displaying the results of the HPLC analysis can be found in Figure 0.1 in Appendix 1.

3.2.2. Remotely Operated Vehicle Video Transects

A complete list of species identified in the four video transects can be found in Table 0.3 Appendix 3. The following terms as per Sigovini et al. (2016) were used when organisms have not been described to species level; indet. for when it is was not possible to identify species to genus level, spp. – the presence of several species of the same genus not identified to species and sp. – specimen of one genus where species identification was not achieved.

Macroalgae Observations

95 observations of macroalgal fragments or clusters (sometimes comprising several species and specimens) from eight taxa were found along the transect line Location A and B combined (Figure 3.5; Figure 3.6). My observations showed noteworthy differences in macroalgal observations in Location A (n=32) compared to Location B (n=63) (Figure 3.5). The most macroalgae was observed in B2 (n=42), and the largest macroalgal specimens were found in B2 (average 24 cm) followed closely by A1 (average 23 cm) (Table 0.1; 0.2; Appendix 2).

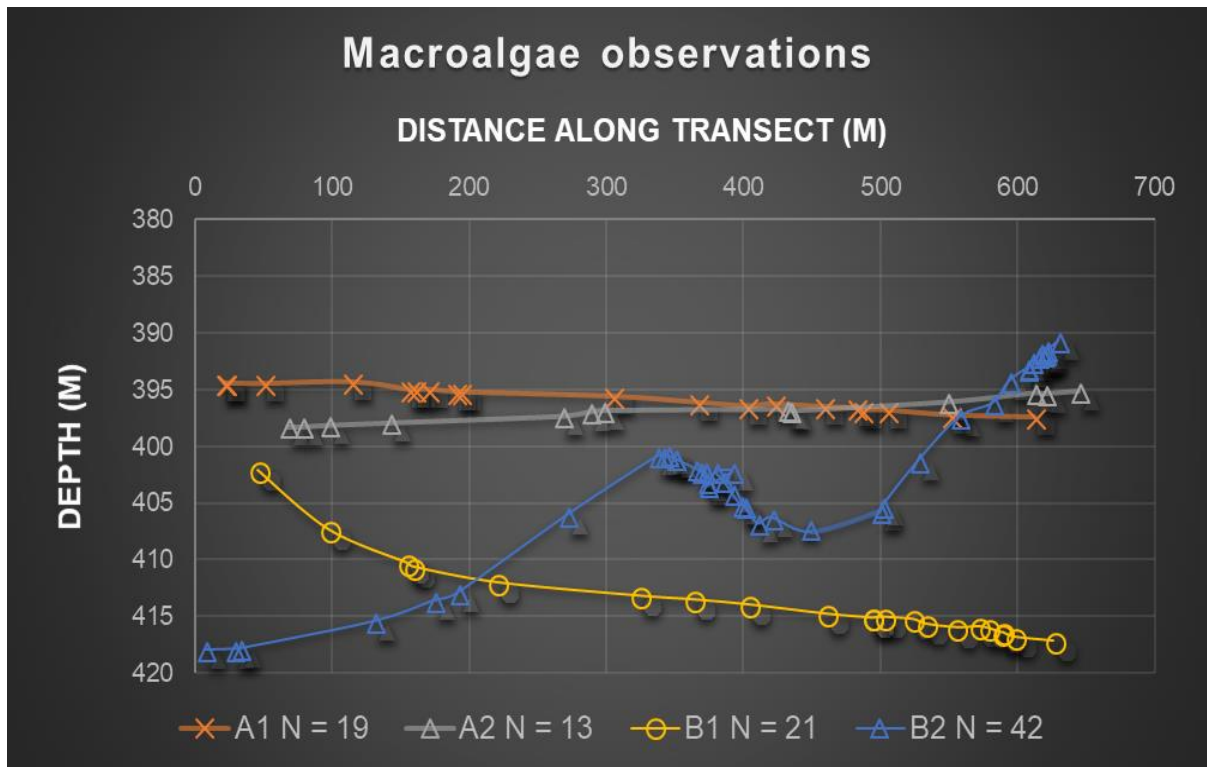


Figure 3.5: Macroalgae observations along the four transects from the study site 6 km south of the mouth of the Trondheimsfjord in Norway. Each point marks an observation of a macroalgal fragment or cluster (sometimes comprising several species and specimens) where the depth and the distance along the transect has been recorded. The line shows the depth on the y axis and distance along transect in m on the x-axis.

Eight different taxa were found in the study with the highest diversity found in A1 (n=9), followed by B2 (n=7), B1 (n=7) and A2 (n=3) (Figure 3.6). The dominant taxa found were *Ascophyllum nodosum* (16%) and *Desmarestia aculeata* (16%). Due to the difficulty in identifying some of the specimens due to size and condition of the specimens (32% of all observed occurrences) these were classified into a larger group named “Kelp” comprised of specimens from either *Laminaria digitata/hyperborea*, *Saccharina latissima*, *A. nodosum* or *Saccorhiza polyschides*. A complete list with number of specimens identified can be found in Table 0.1 in Appendix 2.

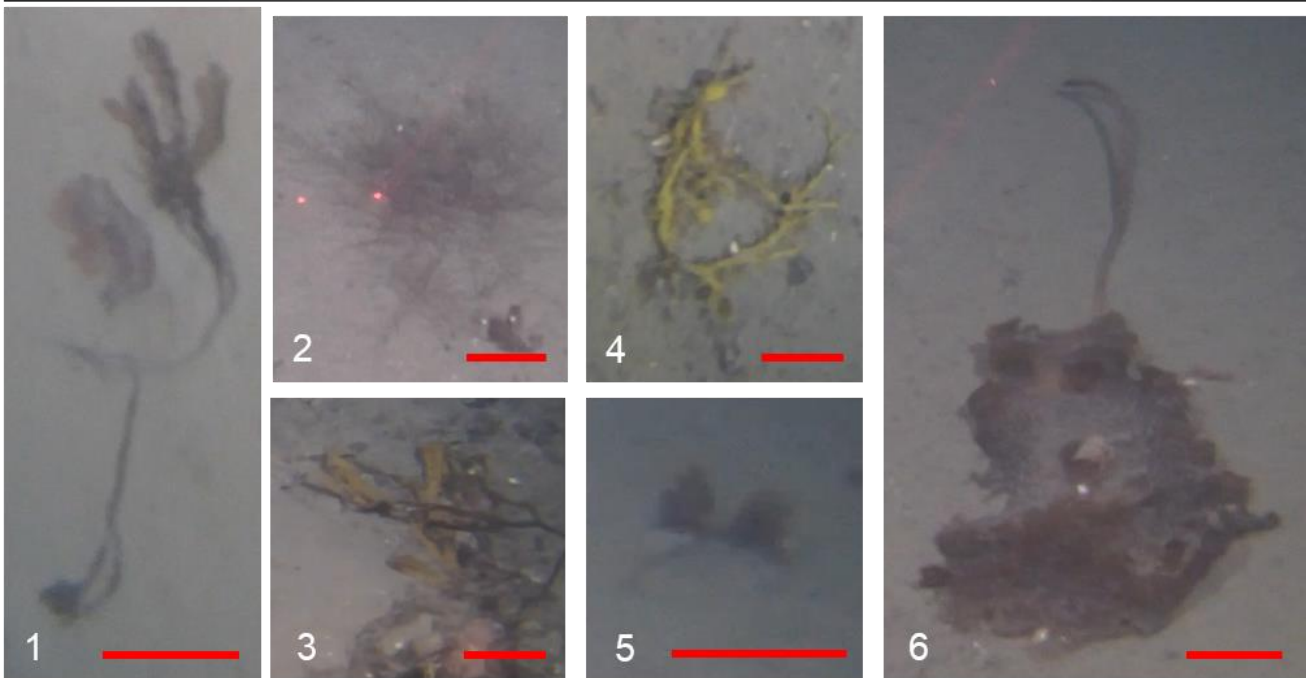
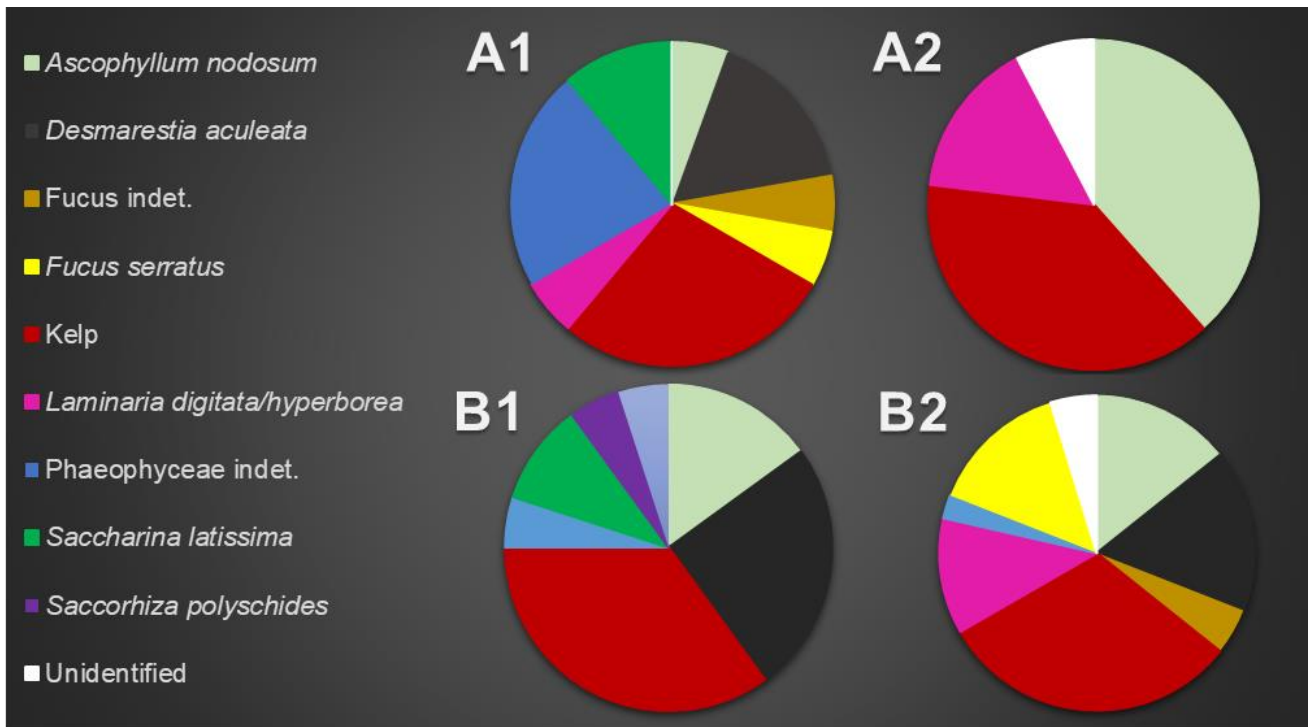


Figure 3.6: Macroalgal taxa observed in the four transects conducted in the study site 6 km south of the mouth of the Trondheimsfjord in Norway at 395 – 420 m depth. Scale bar in red = 10 cm. The most taxa observed where in A1 (n=9), followed by B2 (n=7), B1 (n=7) and A2 (n=3). Taxa in the pictures: (1) *Laminaria digitata/hyperborea* (2) *Desmarestia aculeata* (3) *Fucus serratus* (4) *Fucus indet.* (5) *Saccorhiza polyschides* (6) *Saccharina latissima*.

3.2.3. Biodiversity

A total of 317 individuals from 19 taxa were observed in Location A and B combined, with eight taxa identified as possible macroalgae grazers (Table 3.1; Figure 3.7).

Table 3.1: The total number of taxa identified in the four ROV video transects conducted at the study site 6 km outside of the Trondheimsfjord in Norway. Taxa identified as possible macroalgae grazers are marked with *.

Taxa	A1	A2	B1	B2	Total
<i>Antho dichotoma</i>				1	1
<i>Bolocera tuediae</i>	1		1	5	7
<i>Brisaster fragilis</i> *	36	90		11	137
Buccinidae indet. *	1		9	8	18
<i>Chimaera monstrosa</i>	13	17	7	8	45
Demospongiae indet.				32	32
Echinoidea indet. *				4	4
<i>Geodia baretii</i>				3	3
<i>Henricia</i> sp.*	2			2	4
<i>Hippasteria phrygiana</i>			1		1
<i>Kophobelemnon stelliferum</i>	4	3		8	15
<i>Lithodes maja</i>				1	1
<i>Molva molva</i>				2	2
<i>Munida</i> sp.*			1	1	2
<i>Nephrops norvegicus</i>	1				1
Paguroidea indet. *			1	18	19
<i>Psilaster andromeda</i>		2			2
<i>Pteraster</i> sp.*			1	1	2
<i>Stichopus tremulus</i> *	7	7	3	4	21
Total	65	119	24	109	317

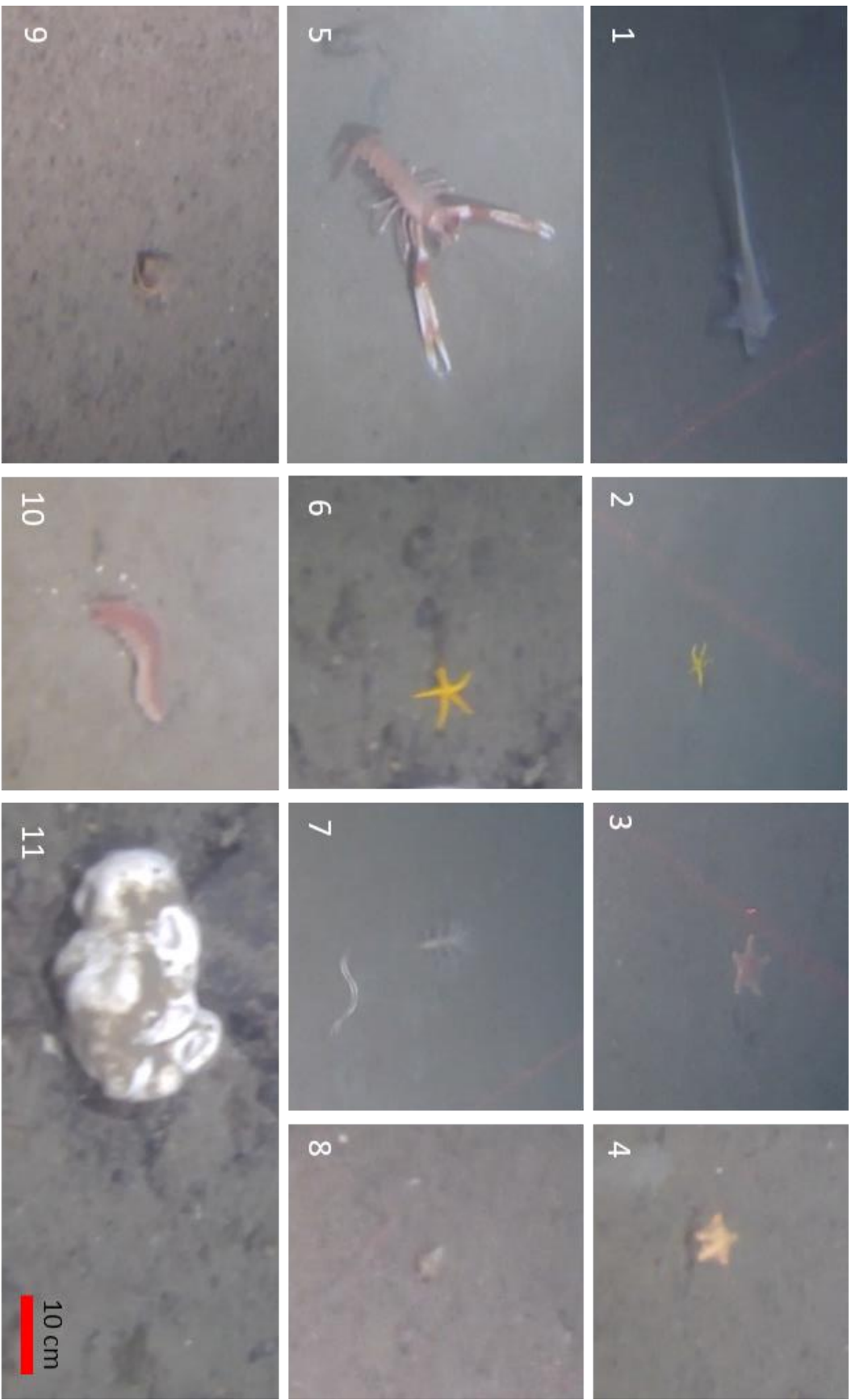


Figure 3.7: Pictures of some of the organisms identified along the transect. Red line represents 10 cm in all images. The following taxa are in pictures (1) *Chimnaera monstrosa* (2) *Henricia sp.* (3) *Hippasteria phrygiana* (4) *Pteraster indet.* (5) *Nephrops norvegicus* (6) *Henricia sp.* (7) *Stichopus tremulus* (8) *Geodia baretti* (9) *Paguroidea indet.* (10) *Buccinidae indet.* (11) *Koplobelemon stelliferum*.

Transect A1

8 m Frame Grab Interval

A total of 81 frame grabs were taken from the 8 m frame grab interval in transect A1, which had a total length of 638 m. Eight taxa were found with a combined total of 65 individuals. The most commonly observed species was *Brisaster fragilis* (n=36) (Table 3.2; Figure 3.8).

24 m Frame Grab Interval

A total of 27 frame grabs were taken from the 24 m frame grab interval in transect A1, which had a total length of 638 m. Four taxa were found with a combined total of 127 individuals. The most commonly observed species was *B. fragilis* (n=21) (Table 3.2; Figure 3.9).

Table 3.2: Taxa observed in transect A1 in the study site 6 km south of the mouth of the Trondheimsfjord, Norway.

Taxa	Number of individuals	
	8 m interval	24 m interval
<i>Bolocera tuediae</i>	1	N/A
<i>Brisaster fragilis</i>	36	21
<i>Chimaera monstrosa</i>	13	4
<i>Henricia</i> sp.	2	1
<i>Stichopus tremulus</i>	7	N/A
<i>Kophobelemnion stelliferum</i>	4	1
<i>Nephrops norvegicus</i>	1	N/A
Buccinidae indet.	1	N/A
Total	65	27

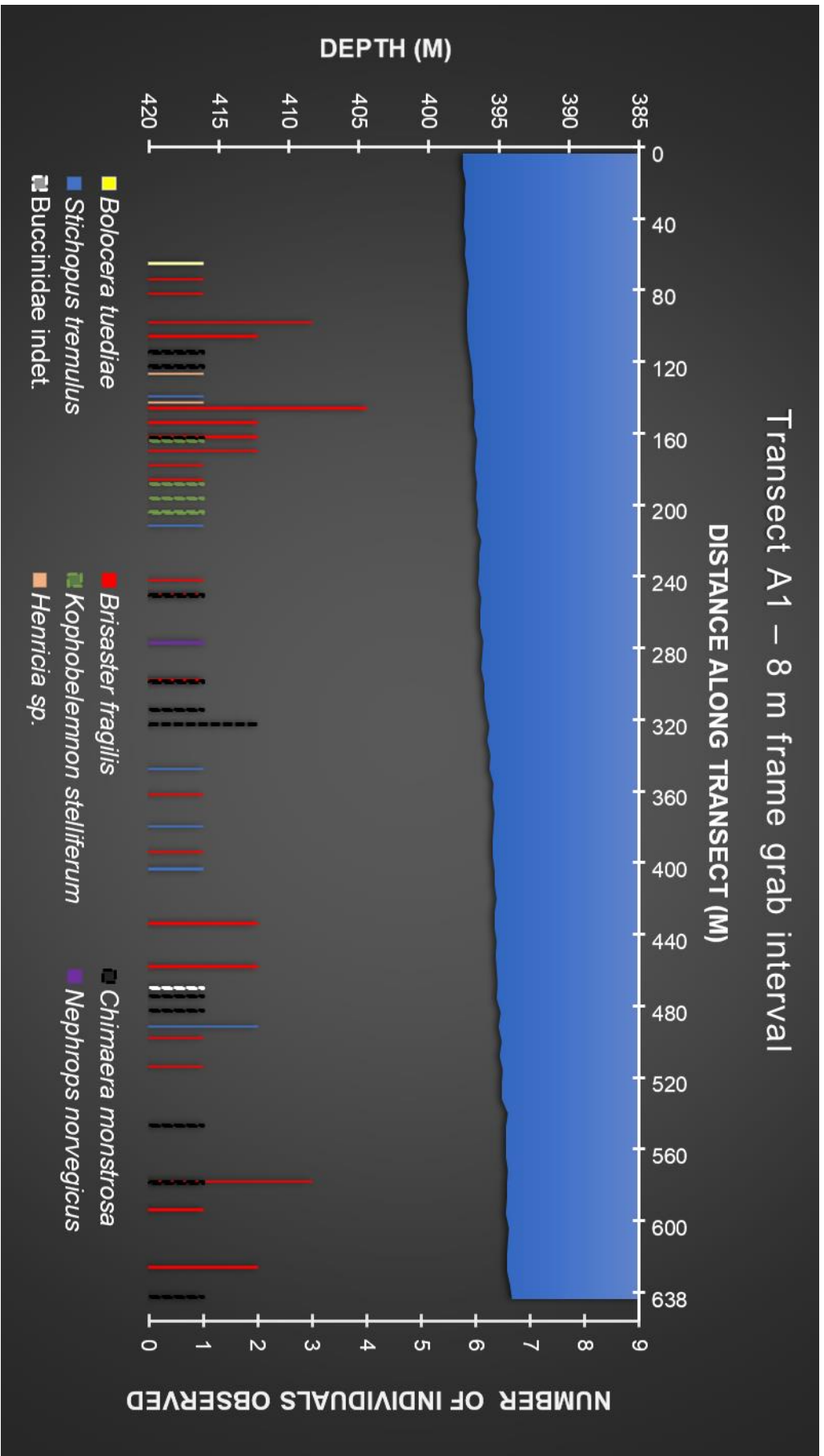


Figure 3.8: Taxa identified along the transect A1 with frame grabs intervals of 8 m. The primary vertical axis shows depth in m, the secondary vertical axis shows number of individual observed and horizontal axis shows distance along the transect line in m. The blue area on the graph represents the water column. The following species were identified: *Bolocera tuediae* (n=1), *Brisaster fragilis* (n=36), *Chimaera monstrosa* (n=13), *Henricia sp.* (n=2), *Stichopus tremulus* (n=7), *Kophobelemnion stelliferum* (n=4), *Nephrops norvegicus* (n=1) and *Buccinidae indet.* (n=1).

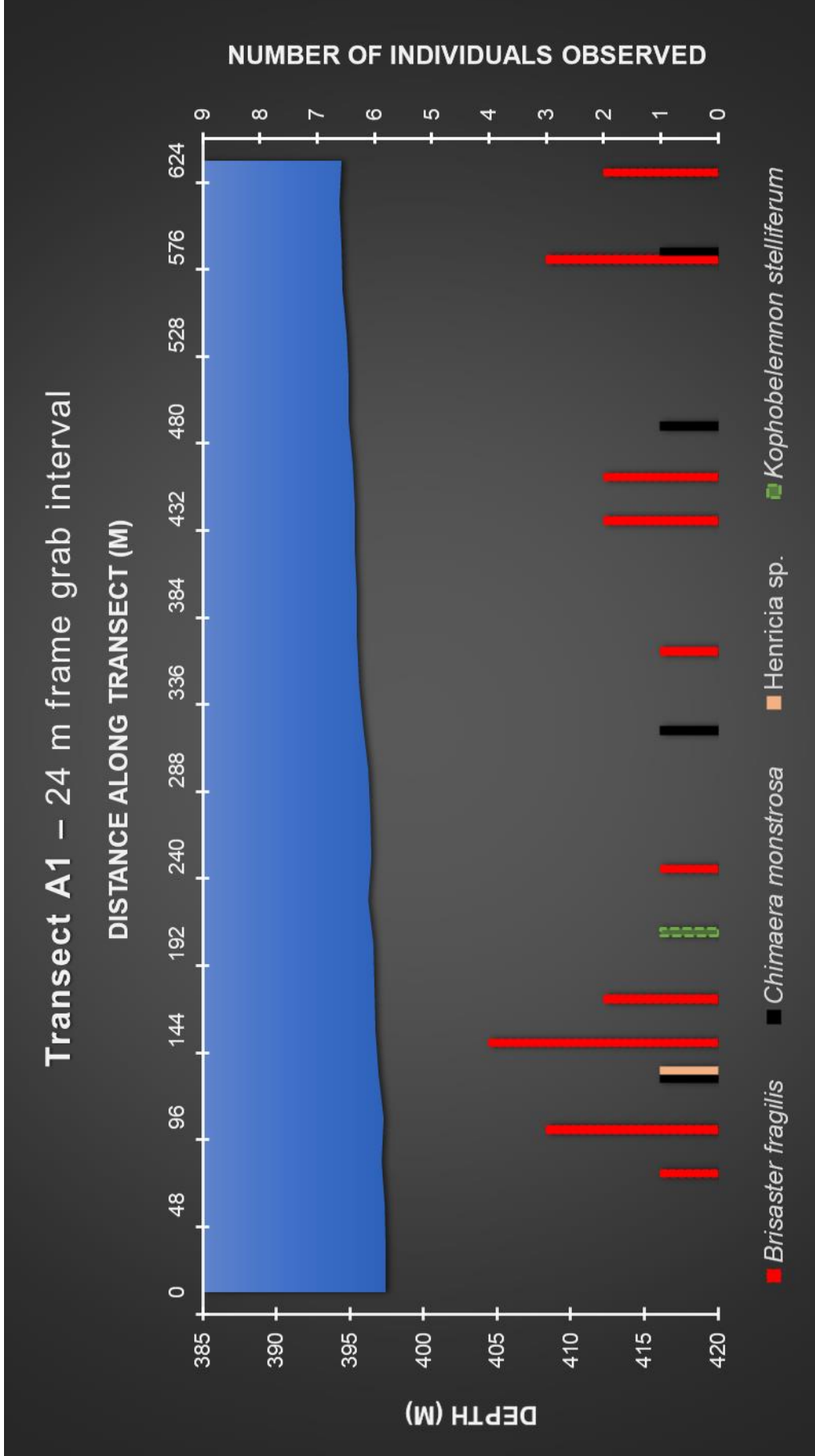


Figure 3.9: Taxa identified along the transect A1 with frame grab interval of 24 m. The primary vertical axis shows depth in m, the secondary vertical axis shows number of individuals observed, and the horizontal axis shows the distance along the transect line in m. The blue area on the graph represents the water column. The following taxa were identified; *Brisaster fragilis* ($n=21$), *Chimaera monstrosa* ($n=4$), *Henricia sp.* ($n=1$) and *Kophobelemnion stelliferum* ($n=1$).

Transect A2

8 m Frame Grab Interval

A total of 82 frame grabs were taken in the 8 m frame grab interval in transect A2, which had a total length of 650 m. Five species were found with a combined total of 119 individuals. *B. fragilis* (n=90) was the most commonly observed species (Table 3.3; Figure 3.10).

24 m Frame Grab Interval

A total of 28 frame grabs were taken in the 24 m frame grab interval in transect A2, which had a total length of 650 m. Four species were found with a combined total of 35 individuals, with *B. fragilis* (n=26) being the most commonly observed species (Table 3.3; Figure 3.11).

Table 3.3; Taxa observed in transect A2 in the study site 6 km south of the mouth of the Trondheimsfjord, Norway.

Taxa	Number of individuals	
	8 m interval	24 m interval
<i>Brisaster fragilis</i>	90	26
<i>Chimaera monstrosa</i>	17	4
<i>Psilaster andromeda</i>	2	N/A
<i>Stichopus tremulus</i>	7	3
<i>Kophobelemnion stelliferum</i>	3	2
Total	119	35

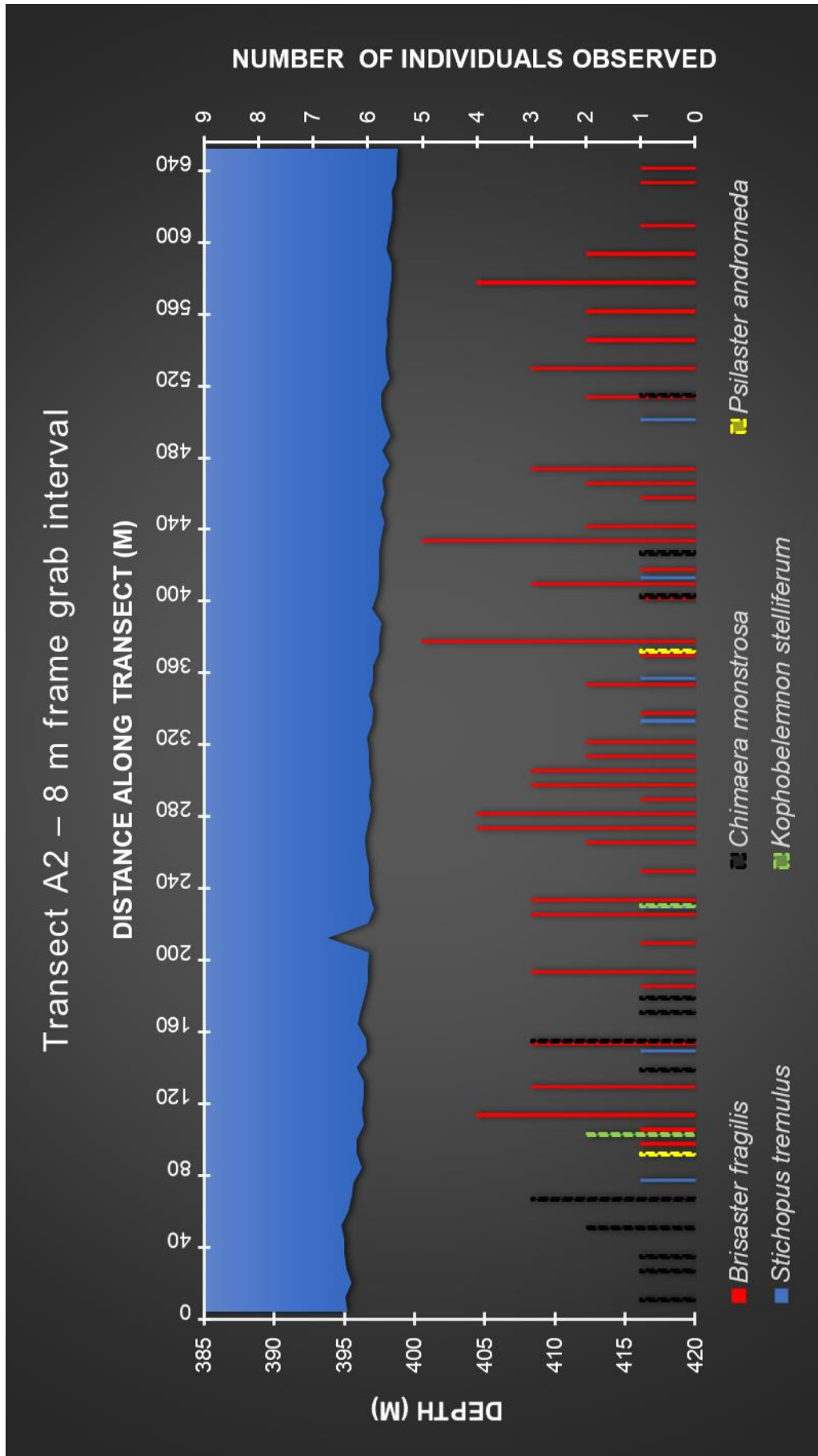


Figure 3.10: Taxa identified along the transect A2 with 8 m frame grab interval. The primary horizontal axis shows depth in m, the secondary horizontal axis shows number of individuals identified in transect and vertical axis shows the distance along the transect line in m. The blue area on the graph represents the water column. The following taxa were identified; *Brisastrer fragilis* ($n=90$), *Chimaera monstrosa* ($n=17$), *Psilaster andromeda* ($n=2$), *Stichopus tremulus* ($n=7$), and *Kophobelemnion stelliferum* ($n=3$).

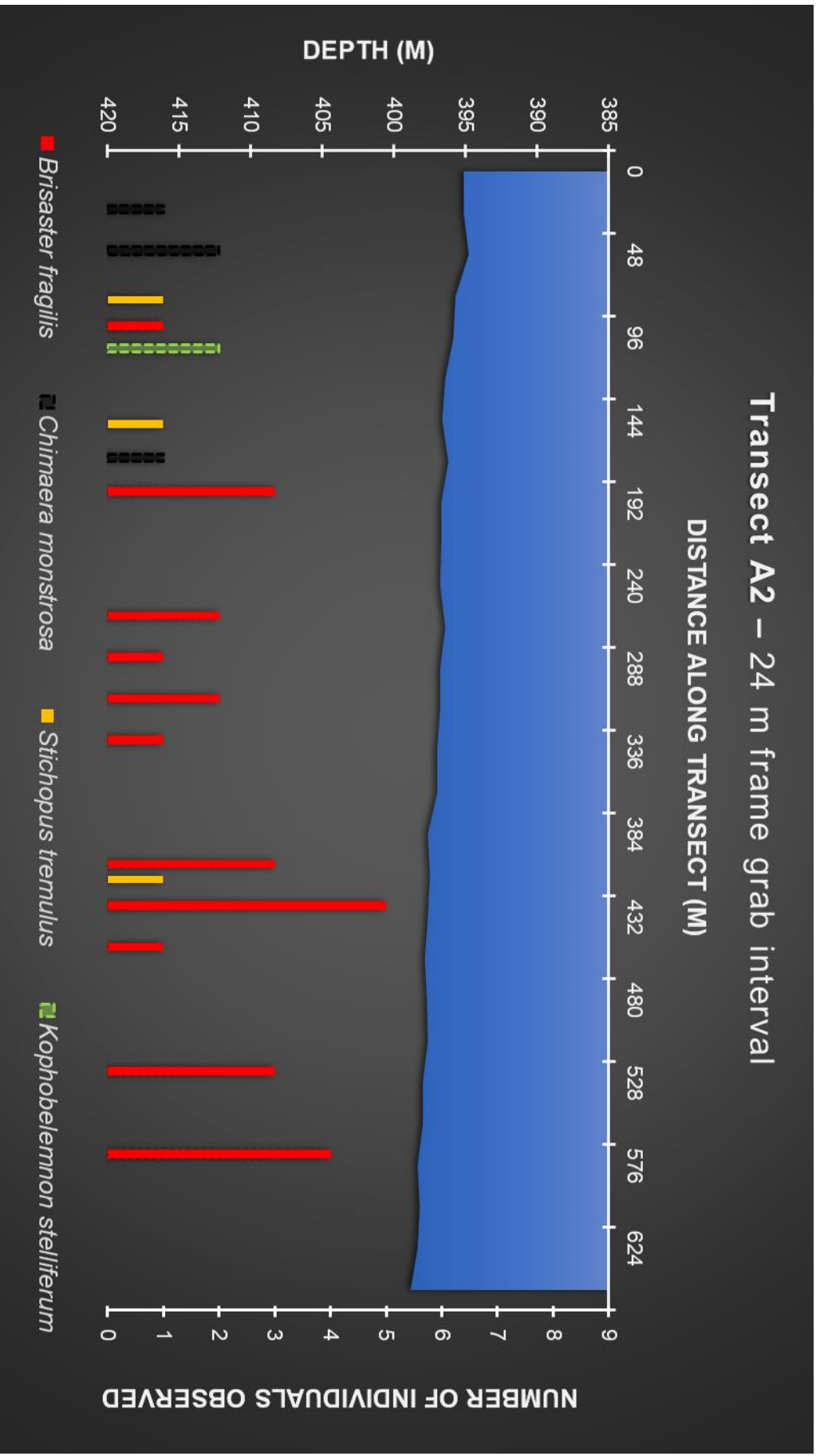


Figure 3.11: Taxa identified along the transect A2 with 24 m frame grab interval. The primary horizontal axis shows depth in m, the secondary horizontal axis shows number of individuals identified in transect and vertical axis shows the distance along the transect line in m. The blue area on the graph represents the water column. The following species were identified; *Brisaster fragilis* ($n=26$), *Chimaera monstrosa* ($n=4$), *Stichopus tremulus* ($n=3$) and *Kophobelemnion stelliferum* ($n=2$).

Transect B1

8 m Frame Grab Interval

A total of 86 frame grabs were taken in the 8 meter frame grab interval in transect B1 which had a total length of 689 m. Eight taxa were found with a combined total of 27 individuals, with three individual organisms left as unidentified. Buccinidae indet. (n=9) was the most commonly observed taxa (Table 3.4; Figure 3.12).

24 m Frame Grab Interval

A total of 29 frame grabs were taken in the 24 m frame grab interval in transect B1 which had a total length of 689 m. Five taxa were found with a combined total of six individuals and one organism left unidentified. All species were observed equally (Table 3.4; Figure 3.13).

Table 3.4: Taxa observed in transect B1 in the study site 6 km south of the mouth of the Trondheimsfjord, Norway.

<i>Taxa</i>	<i>Number of individuals</i>	
	<i>8 m interval</i>	<i>24 m interval</i>
<i>Bolocera tuediae</i>	1	N/A
<i>Chimaera monstrosa</i>	7	1
<i>Stichopus tremulus</i>	3	1
<i>Munida</i> sp.	1	1
<i>Pteraster</i> sp.	1	N/A
<i>Hippasteria phrygiana</i>	1	1
Buccinidae indet.	9	1
Paguroidea indet.	1	N/A
Unidentified	3	1
Total	27	6

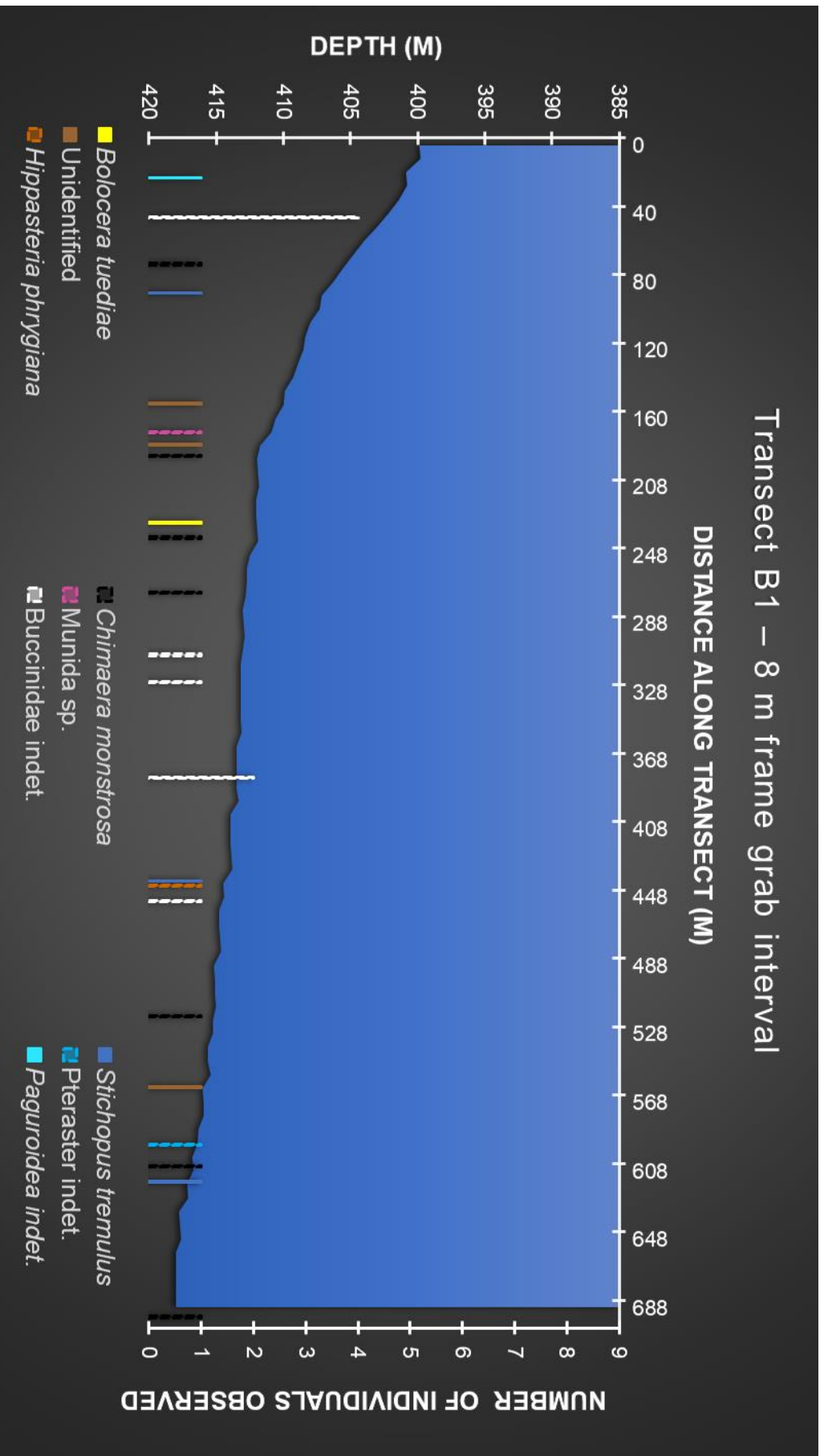


Figure 3.12: Taxa identified along the transect B1 with 8 m frame grab interval. The primary horizontal axis shows depth in m, the secondary horizontal axis shows number of individual individuals identified in transect and vertical axis shows the distance along the transect line in m. The blue area on the graph represents the water column. The following species were identified; Bolocera tuediae (n=1), Chimaera monstrosa (n=7), Stichopus tremulus (n=3), Munida sp. (n=1), Pteraster indet. (n=1), Hippasteria phrygiana (n=1), Buccinidae indet. (n=9), Paguroidea indet. (n=1) and Unidentified (n=3).

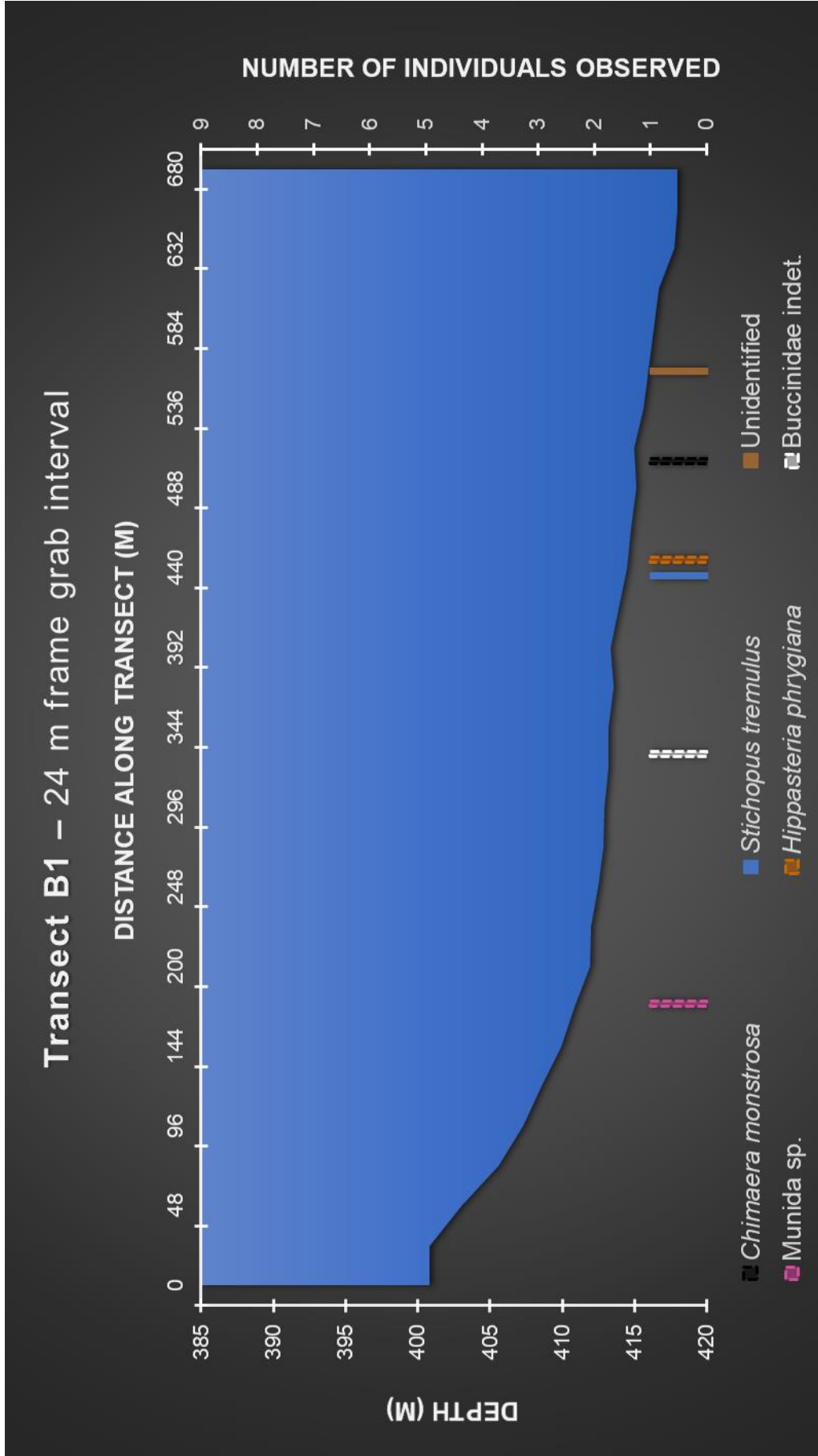


Figure 3.13: Taxa identified along the transect B1 with 24 m frame grab interval. The primary horizontal axis shows depth in m, the secondary horizontal axis shows number of individuals identified in transect and vertical axis shows distance along the transect line in m. The blue area on the graph represents the water column. The following species were identified; Chimaera monstrosa (n=1), Stichopus tremulus (n=1), Munida sp. (n=1), Hippasteria phrygiana (n=1), Buccinidae indet. (n=1) and Unidentified (n=1).

Transect B2

No data is available between 285 and 321 m along transect B2 as the ROV had to move up in the water column due to strong currents.

8 m Frame Grab Interval

A total of 81 frame grabs were taken from the 8 m frame grab interval in transect B2, which had a total length of 641 m. 16 taxa were found with 109 individuals combined. The most commonly observed taxa was Demospongiae indet. (n = 32) (Table 3.5; Figure 3.14).

24 m Frame Grab Interval

A total of 27 frame grabs were taken from the 24 m frame grab interval from transect B2, which had a total length of 641 m. 13 taxa were found with a total of 36 individuals. The most commonly observed taxa were Demospongiae indet. (n=10) and Paguroidea indet. (n=10) (Table 3.5; Figure 3.15).

Table 3.5: Taxa observed in transect B2 in the study site 6 km south of the mouth of the Trondheimsfjord, Norway.

Taxa	Number of individuals	
	8 m interval	24 m interval
<i>Bolocera tuediae</i>	5	N/A
<i>Brisaster fragilis</i>	11	3
<i>Chimaera monstrosa</i>	8	1
<i>Stichopus tremulus</i>	4	2
Pteraster indet.	1	N/A
<i>Henricia</i> sp.	2	1
<i>Kophobelemnion stelliferum</i>	8	2
<i>Antho dichotoma</i>	1	1
<i>Munida</i> sp.	1	N/A
Buccinidae indet.	8	2
Echinoidea indet.	4	1
Demospongiae indet.	32	10
<i>Geodia baretii</i>	3	1
Paguroidea indet.	18	10
<i>Molva molva</i>	2	1
<i>Lithodes maja</i>	1	1
Total	109	36

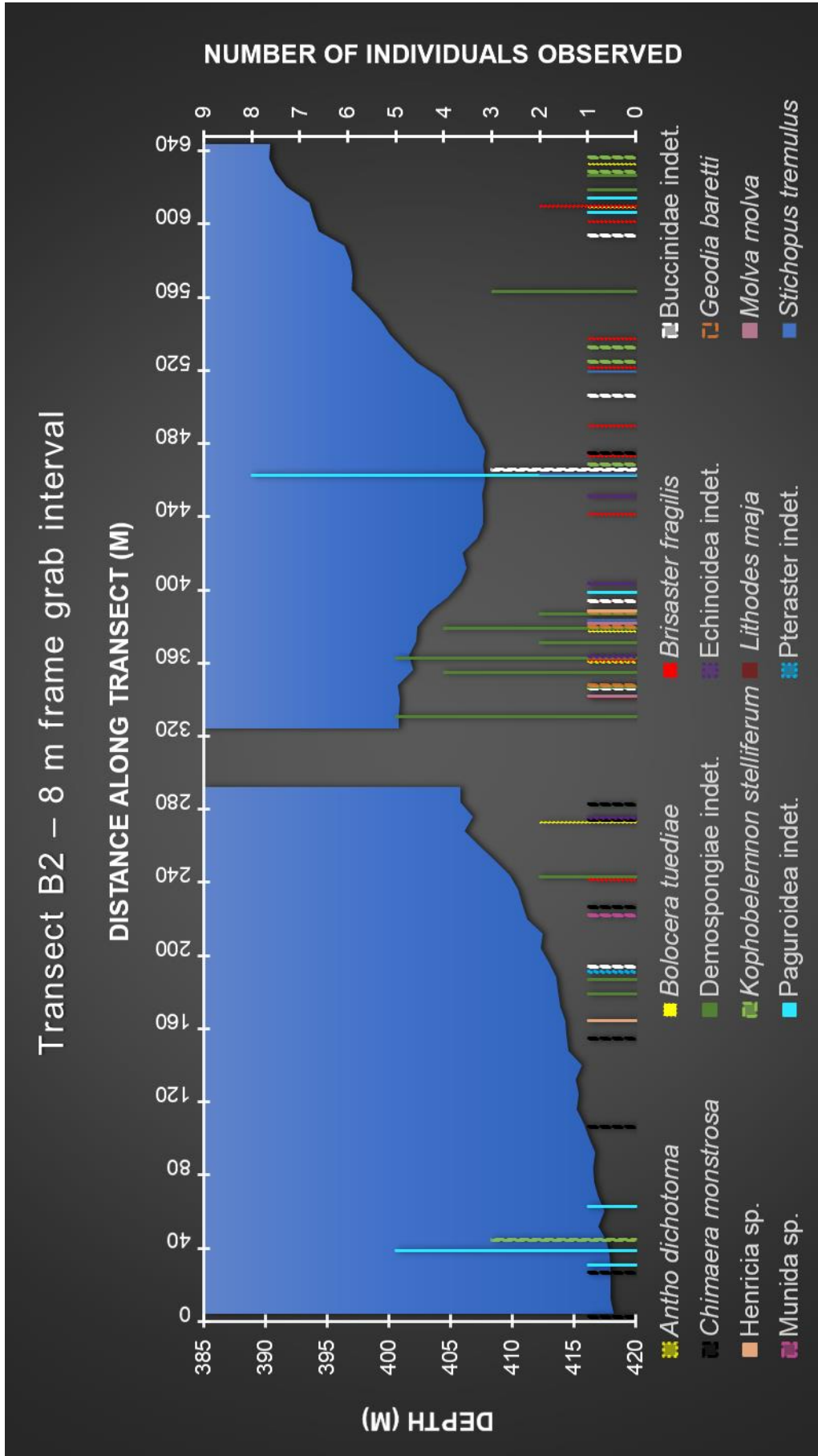


Figure 3.14: Taxa identified along the transect B2 with 8 m frame grab interval. The primary horizontal axis shows depth in m, the secondary horizontal axis shows number of individuals identified in transect and vertical axis shows the distance along the transect line in m. The blue area on the graph represents the water column. The following taxa were identified; Bolocera tuediae (n=5), Brisaster fragilis (n=11), Chimaera monstrosa (n=8), Stichopus tremulus (n=4), Pteraster indet. (n=1), Henricia sp. (n=2), Kophobelemnion stelliferum (n=8), Antho dichotoma (n=1), Munida sp. (n=1), Buccinidae indet. (n=8), Echinoidea indet. (n=4), Demospongiae indet. (n=32), Geodia baretii (n=3), Paguroidea indet. (n=18), Molva molva (n=2) and Lithodes maja (n=1).

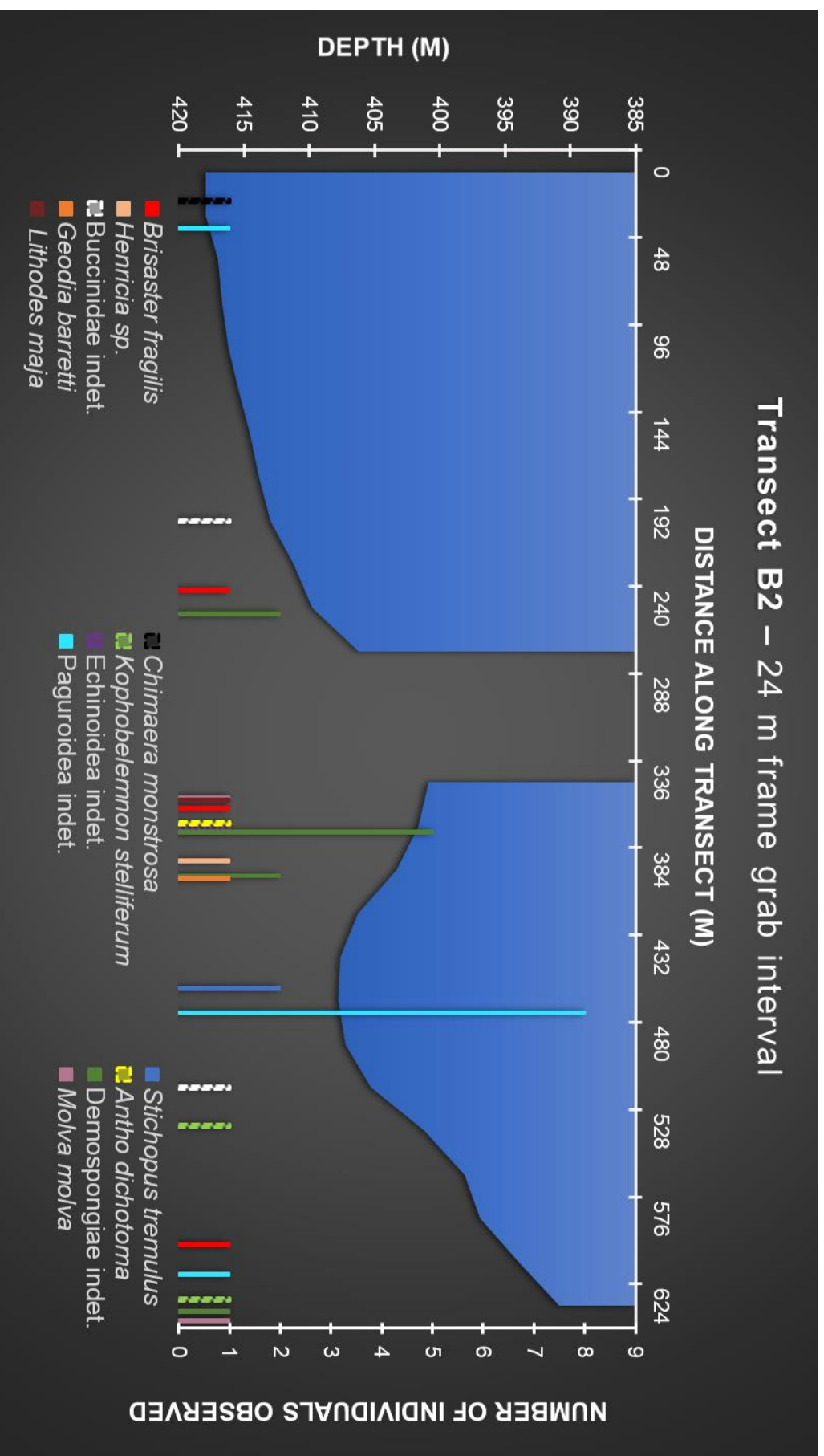


Figure 3.15: Taxa identified along the transect B2 with 24 m frame grab interval. The primary horizontal axis shows depth in m, secondary horizontal axis shows number of individuals identified in transect and vertical axis shows the distance along the transect line in m. The blue area on the graph represents the water column. The following species were identified; *Brisaster fragilis* ($n=3$), *Chimaera monstrosa* ($n=1$), *Stichopus tremulus* ($n=2$), *Henricia* sp. ($n=1$), *Kophobelemnion stelliferum* ($n=2$), *Antho dichotoma* ($n=1$), *Buccinidae* indet. ($n=2$), *Echinoidea* indet. ($n=1$), *Demospongiae* indet. ($n=10$), *Geodia barretti* ($n=1$), *Paguroidea* indet. ($n=10$), *Molva molva* ($n=1$) and *Lithodes maja* ($n=1$).

3.2.4. Statistical Analysis

The Shannon Index of Species Diversity

8 m Frame Grab Interval

The highest biodiversity score was found in transect B2 ($H'=1.27$), and the score was found in A2 ($H'=0.17$), while A1 and B1 had H' scores of 0.59 and 0.42 respectively. The equitability reflects the results with B2 classified as Perfect Diversity/Evenness, B1 and A1 as Medium Diversity and A2 as Low Diversity (Table 3.6).

24 m Frame Grab Interval

The highest biodiversity score was found in transect B2 ($H'=1.05$), and the lowest H' score was found in B1 ($H'=0.33$), while A1 and A2 had H' scores of 0.31 and 0.33 respectively. The equitability classified B2 as High Diversity while A1, A2 and B1 was classified as Low Diversity (Table 3.6).

Table 3.6: The results of Shannon's Index of Species Diversity (H'), Evenness Score and Equitability from the four ROV video transects from the study site 6 km south of the mouth of the Trondheimsfjord, Norway. The score is displayed both for the 8 m interval frame grabs and the 24 m interval frame grabs.

Transect	H'		Evenness Score		Equitability	
	8 m	24 m	8 m	24 m	8 m	24 m
A1	0.59	0.31	0.46	0.25	Medium diversity	Low Diversity
A2	0.17	0.33	0.13	0.26	Low diversity	Low Diversity
B1	0.42	0.27	0.33	0.21	Medium Diversity	Low Diversity
B2	1.27	1.05	1	0.82	Perfect Diversity	High Diversity

4. Discussion

Transects A1 and A2 had low variation in seafloor morphology with a fine grain size indicating lower current speed (Figure 3.2; Figure 3.4). The lack of phytoplankton pigment in the sediment surface sample indicates a low degree of vertical transport of small particles such as phytoplankton, in contrast to macroalgae. 19 macroalgal specimens were found in Transect A1 from nine different taxa (Figure 3.5; Figure 3.6). In transect A2, 13 macroalgal specimens were identified from three different species (Figure 3.5; Figure 3.6). Transect A1 and A2 had medium and low diversity respectively (Table 3.6).

Transects B1 and B2 had medium and high variation in seafloor morphology respectively and both had sediment with coarse grain sizes, indicating higher current speed in Location B relative to Location A (Figure 3.2; Figure 3.4). The coarser grain size may also be due to sediment slides as Location B is located closer to these occurrences (Figure 3.1). At Location B, no phytoplankton pigments were observed in the sediment surface sample, indicating no significant transportation of small particles to the seafloor from surface waters. In contrast, 21 and 42 macroalgal observations were made respectively in transect B1 and B2, and seven macroalgal taxa were identified in each of the transects, indicating a vertical transport of larger phototrophic algae from surface waters to the seafloor (Figure 3.5; Figure 3.6). Transect B1 was found to have medium biodiversity and transect B2 have high biodiversity (Table 3.6).

4.1. Linking Physical Parameters and Macroalgae Observations

4.1.1. Seafloor Morphology

Location B was thought to have a higher variation in seafloor morphology, which was supported by our findings, and both Transect B2 and B1 had higher variation in seafloor morphology than the transects from Location A (Figure 3.2). Interestingly, B2 had a significantly higher variation in seafloor morphology, being the only transect where the slope was more than seven degrees, and the highest number of macroalgal observations was seen here with 42 observations – over 20 observations more than in any of the other transects (Figure 3.5).

When looking at the larger scale seafloor morphology Location B is situated on a downwards slope towards a depression in the seafloor (from 340 to 430 m depth), with a continuous upwards slope towards Location A (Figure 3.1). Harrold et al. (1998) found higher occurrences

of organic detritus in canyons. As Location B is located at greater depths and at the bottom of this slope, the macroalgae may be collected in this depression in a similar manner. Additionally, as many macroalgal species shed their lamina in the fall, it may be optimal to sample in early winter to get a better picture of the amount of detritus that is transported to seafloor (Taylor, 1998, Carlsen et al., 2007). Further, as Location B is situated closer to the possible sediment slides, it may be that the coarser grain size is originating from such slides, and that macroalgal detritus from shallower waters are transported to Location B in these slides. It is not possible to separate the larger seafloor morphology and the small scale seafloor morphology in this study; however, it is an interesting observation that could be worth further studies and shows the benefits of a multidisciplinary approach. The results show that higher variation in seafloor morphology is linked with a higher number of macroalgal observations.

4.1.2. Modelled Ocean Current Speed

The modelled ocean current speed from SINMOD showed a higher current speed at Location B than Location A. Additionally, the presence of larger grain size and the several unsuccessful box core attempts likely due to hard substrate indicate a higher current speed in Location B than Location A (McCave et al., 1995). Location B is located closer to the known areas of kelp forest on the coast, and perhaps the number of macroalgal observations in the region could be explained by these being deposited here first. Consequently, this would have meant that the detritus would slowly making their way to Location A, so that larger fragments would be found in Location B, as the smaller fragments (including phytoplankton) would be unable to sink to the seafloor with the high current speed and would be deposited in an area with reduced current speed (as in Location A). However, the average size of the macroalgal fragments in the different locations were not noticeably different from one another, with the largest detritus found in transect B2 (24 cm) and transect A1 (23 cm). The size of the macroalgal fragments therefore do not indicate that this process is occurring in the study location. Nevertheless, as the macroalgal distribution of the regions are poorly mapped, it may be that there are larger macroalgal occurrences close to Location A as well.

Most macroalgae have few components in their cell walls and may therefore be almost completely broken down (Enríquez et al., 1993). Thus, there is a chance that there are a higher number of macroalgal occurrences in Location A, but of a smaller size, making them undetectable in the video transects (Enríquez et al., 1993). This may be an indication that the macroalgal fragments are either transported away from the site once they are too small,

completely consumed by the organisms preying upon them or less excitingly, that the pigments were too degraded by the time the samples reach the lab as they are very sensitive to sunlight and oxygen exposure.

Macroalgal detritus, especially containing air bladders, have been shown to travel far distances through a variety of mechanism (Figure 1.1). Note that kelp may survive for several months in complete darkness, such as during the polar night, growing heterotrophically on available nutrients and using stored sugar from previous photosynthetic activity (Aamot and Johnsen, 2018, unpublished). In further studies it would be interesting to investigate the degradation state of the macroalgal fragments as this may tell us if the fragments at Location A are older compared to fragments in Location B. However, as this study was initially not intended to focus on macroalgal fragments, physical samples along the transect lines of the fragments were not collected. The detrital state can tell us what state these fragments are when they reach the during sedimentations.

4.2. Macroalgal Observations and Benthic Biodiversity

Eight of the taxa identified in the area are thought to be grazers on macroalgae (Table 3.1). In Transect A1 three of eight groups were observed, with a total of 46 individuals, in A2 97 individuals from two groups were observed. The number of individuals per transect in Location B were lower with B1 having 15 individuals and B2 having 40 individuals. However, five organism groups were observed in B1 and all eight of the macrofaunal grazer groups were found in transect B2. Although the number of individuals observed were higher in A1, the range of potential macroalgal grazers were higher in Location B2, in correlation with the high number of macroalgal observations. Considering the species identified in Location A; *B. fragilis*, Buccinidae indet. and *Sticophus tremulus* are all omnivorous (Hudson et al., 2004, Ziegler et al., 2010, Zapata-Hernández et al., 2014, Bowden et al., 2016), there is an indication that the higher amount of macroalgal detritus in Location B, particularly in Location B2, may have had an impact on the organisms comprising the benthic community in Location B.

Several studies have shown an impact of macroalgal detritus on the species composition in benthic communities. In Western Australia, Vanderklift and Wernberg (2008), found that kelp fragments function as the primary food source for sea urchin located on reefs with no kelps. In the Norwegian Arctic, a study conducted by Renaud et al. (2015) utilising stable isotope technique to find trace the carbon uptake of organisms, found that bivalves in the region got

50% of their carbon uptake from kelp and rockweeds. Hence, when linking the biodiversity in the region with the macroalgal occurrence, it is important to not just to look at species diversity, but also which species we find and their role in the food web.

The degradation state of the macroalgae can also influence the species composition found in the region. Ramirez-Llodra et al. (2016) conducted an experimental study where fragments from three different macroalgal species were put on plates and left on the seafloor for 48 hours under monitoring. They found that the first species to arrive were amphipods, followed later by shrimp and linked a possible explanation to the bacterial composition rate in the macroalgae (Norderhaug et al., 2003). Highly degraded macroalgae is thought to be easier to consume, and thus will attract a different composition of organisms, and possibly a higher number of individuals (Ramirez-Llodra et al., 2016). Thus, if macroalgae in Location B are older, and hence more degraded, than the ones in Location A, this may also be a possible explanation for the pattern found.

A higher number of *Chimaera monstrosa* individuals were found in Location A (A1=3, A2=17) compared to Location B (B1=7, B2=8) (Table 3.1). This may be an indication that there are more bottom living invertebrates in Location A, as this is the main food source of *C. monstrosa*. However, our understanding of the light pollution in the darker parts of the ocean is increasing and has shown that artificial light changes the nature of an organism's behaviour (Marchesan et al., 2005, Ludvigsen et al., 2018). Hence, it is hard to know if the counted *C. monstrosa* are separate observations, and not the same individuals just simply drawn to the ROV due to its artificial light.

Moreover, in addition to attract fish, the artificial light as well as the sound and shadow of the ROV may have caused other species that are not sessile, such as worms, etc. to retreat into their burrows, hideouts or leave the area all together (Ludvigsen et al., 2018). There were indications of this happening in some of the transects where there were clear indications of burrowing species, most likely a crustacean, but no organism to be found. This may have meant that in areas with more burrowing species, most likely the ones with finer grain size (Location A), the identified species number may be too low, because the species in this area are more likely to be living within the sediments, using the fine particles as hiding ground. A previous study looking at macroalgal detritus and biodiversity found a high number of polychaete worms linked with areas with high detritus, as well as amphipods and bivalves (Vetter and Dayton, 1998). Grain size has in multiple studies been linked closely to the distribution of soft-sediment

infaunal invertebrates, finding more individuals in areas with finer grained sediments (Scheltema, 1974, Butman, 1987, PVR Snelgrove, 1994). In conclusion, benthic macrofaunal diversity was the focus in this study, excluding meio-, meso and microfauna, and this may limit our understanding of the overall biodiversity at the study site.

Previous studies have linked complex seabed structure, i.e. higher variation in seafloor morphology, with an increase species richness provided by more options due to high diversity in micro-habitats which enhances the chance for a greater number of niches (Daniela et al., 2016, Ramirez-Llodra et al., 2010). When looking at the data and linking macroalgal occurrence with biodiversity, it is therefore also important to consider the seabed morphology. The study indicates that areas with more heterogenous seafloor morphology have a higher biodiversity and a higher number of macroalgal observations.

4.2.1. Shannon's Diversity Index

The results of the Shannon's Diversity Index indicate a link between macroalgae observations and biodiversity scores. Transect B2 had the highest score for H' score (1.27) and the only transect classified as "Perfect Diversity" and had the highest number of macroalgal observations (n=42), 20 more observations than found in Transect B1 (n=21) (Table 3.6). Although my data is not sufficient to state a significant difference, it indicates that areas with higher occurrence of macroalgal detritus have a higher biodiversity. Furthermore, the absence/presence of macrofaunal debris, such as whalefalls, can have an impact on the diversity in the system, and this was found in transect B2 where what is presumably a skull from a small whale was found along the transect, with numerous crustaceans on it (Figure 4.1). This outlier will have an impact on the biodiversity score and is most likely not representable for the region.



Figure 4.1: Skull likely from a small whale species, with macrofaunal diversity surrounding it. This skull was identified along transect B2 and may have skewed the biodiversity numbers for that transect, as it is unlikely that the skull is representative for the study area.

Relatively little is known about the expected biodiversity in the region in the depths where the study was located, and thus stating an expected ratio and number of individuals from species along the transects is challenging. It is highly unlikely that the survey captured the range of species present in the area, and thus these diversity results are only an indication of the patterns, as the data is not sufficient to establish a baseline for the area. Consequently, the findings from the Shannon's Diversity Index only show relative biodiversity comparatively to the other transects, not overall biodiversity in these ecosystems. The European Standard NS-EN 16260:2012 has no definition of a biodiversity measurement, and hence H' was selected based on a previous study (Jakobsen, 2016). Other video surveys use other surrogates for diversity, making it hard to compare between surveys when there is no standardised method for this (Hankinson and Ulvestad, 2014). A recommendation from this study would be to include a standardised measurement for diversity in the European Standard.

4.3. Occurrence of Phytoplankton Pigments

No phytoplankton pigment signatures, such as chlorophyll a and fucoxanthin, were detected in either location in the HPLC analysis of the potential biofilm of surface sediment from the seafloor obtained from the box corer. However, these samples were taken in February before the annual phytoplankton spring bloom whose maximum biomass usually occurs in late March (Volent et al., 2011). Since the sedimentation rates in the region are not known, it is uncertain how deep into the sediment the samples should be collected to detect previous years' spring bloom. Possibly, the optimal timing for sampling of potential phytoplankton biomass

contribution to the seafloor in the area should be in May, allowing time for cells to settle on the seafloor. Furthermore, if there was only a small layer of biofilm, it is possible that the water plume from the box core may have pushed the biofilm layer off and resultingly it may not have been included in the sample. The results may also indicate that the current speed is too high in the study site for these small particles to be deposited. In conclusion, the results do not indicate the presence of a biofilm consisting of phytoplankton particles.

4.4. Study Design and Challenges

4.4.1. Frame Grab Intervals

The 8 m interval between frame grabs was recommended from a previous study that recommended the interval for the mapping when looking at coral cover in a cold-water coral reef in the Trondheimsfjord (Jakobsen, 2016). The European Standard NS-EN 16260:2012 recommend that a minimum of 20 m between each frame grabs is kept ensuring that these are separate areas (Standard Norge, 2012). The European Standard NS-EN 16260:2012 applies to a wide range of ecosystems, not only to video surveys conducted in the coastal zone but also video transects done offshore, in shelf regions or abyssal plains.

Results from the video transects analysis showed that organisms were patchily distributed, and that a smaller interval between frame grabs enabled me to better encapsulate the biodiversity, than the larger 24 m intervals. It was found that changing the interval from the 8 m to 24 m had a large impact on the findings. For instance, the equitability rating for A1 and B1 was changed from “Medium Diversity” to “Low Diversity” when looking at the 24 m intervals between frame grabs. The spread of individuals and species along the transects were larger than the study done by Jakobsen, thus it is possible that a frame grab interval in between the 8 m and 24 m may have encapsulated similar results in terms of biodiversity. A better understanding of the pattern and distribution of the organisms would be necessary to establish the best frame grab intervals. Regions with high variance of benthic diversity, or high variance in seafloor morphology, or unknown diversity a smaller frame interval would be necessary to get a proper picture of the pattern on the seafloor.

The European Standard NS-EN 16260:201 is often used for baseline studies aimed at identifying vulnerable species before commencing offshore activity (Hankinson and Ulvestad, 2015, Hankinson and Ulvestad, 2014, Fjukmoen et al., 2014). These studies are mostly aimed

at identifying potential vulnerable ecosystems before initiating commercial activity in offshore areas such as shelves or abyssal plains. However, fjord systems are highly dynamic and as the results indicate that a large interval between the frame grabs can have a tremendous impact on the results of the study. One recommendation from this thesis would be to have different alternatives to choose from depending on the areas where the study will be conducted, as it is not the same to conduct a survey on an abyssal plain or shelf areas as it is in a fjord system, and furthermore, it is different to conduct a study in an area where knowledge of species distribution and patterns exists, versus a completely unexplored region. These variances should be reflected in the European Standard.

4.4.2. Species Identification

Species identification based on morphology from underwater images is difficult, and this is reflected in the results where I was unable to identify 25% of the organism which therefore had to be grouped in a higher taxonomic group. One percent of the organisms were left unidentified all together. The same pattern can be found in the macroalgal observations, where 39% of the specimens were too small or the spatial resolution not high enough to identify the organism down to species level. There are several factors that determine the taxonomic level one can identify species to.

Occurrence of cryptic species with significant differences in their morphological appearance may result in wrongful species identification (Bickford et al., 2007, Mark, 2003, Hebert, 2013). This is well illustrated in a study done by Korshunova et al. (2017) who looked at external diversity in three nudibranch species, where external variance in morphology makes the three species undistinguishable based on external morphology (Korshunova et al., 2017). Furthermore, small specimens are totally overlooked as they cannot be identified with ordinary camera techniques but shows a need for physical sampling and taxonomic identification followed by molecular identification. However this is dependent that the species in the DNA database are correctly identified in the first place, and with a recent estimate stating that up to 91% of the species remain undiscovered, this is a major problem using DNA barcoding databases (Mora et al., 2011).

Several aspects effect the quality of the image, and thus can impact the ability to identify organisms in the video transects. Firstly, the transparency in the water can have an effect on the sharpness, contrast and colours which may cause features of the organisms to be difficult to detect, change its apparent colour or blur the image (Johnsen et al., 2009). Secondly, the

light exposure can cause over- or underexposure of the image (Johnsen et al., 2009). Lastly, if the spatial resolution (pixels per area of image) is too low, coarseness of the image can limit the details in the picture making it hard to correctly identify the organism (Johnsen et al., 2009). The distance from the seafloor will also affect what spatial resolution is required to identify the organisms of interest. Additionally, due to the setup of the light source on the ROV in this study the organisms situated at the edges of the frame were harder to identify because of the difference in illumination. A previous study found that due to the aforementioned individuals without any distinctive colours or patterns are difficult to spot if they are less than 0.5 mm in size (Andersen, 2011). Therefore, if the aim is to identify organisms smaller than this size, a different approach is needed.

The difficulty in using external morphology in species identification is well established and can for instance be seen in reports from baseline surveys offshore Norway, where most baseline surveys have trouble identifying taxa to species level based on video footage and stillimages (Hankinson and Ulvestad, 2015, Fjukmoen et al., 2014, Hankinson and Ulvestad, 2014). Some reports also state that according to their findings the still photos provided a better basis for species identification than the video footage which is more suitable for covering large areas and density estimation (Hankinson and Ulvestad, 2015, Hankinson and Ulvestad, 2014).

In this study, species were only classified down to the taxonomic level where there was a high certainty of correct identification (highly dependent on spatial resolution of images). There is always a level of uncertainty for this, and thus human error must be considered. The ROV was equipped with two laser pointers 10 cm apart which gave me a scale for all the frame grabs. This was a great help in the identification of the species. Overall, the study provided good data that can be used for further studies in the area, to help plan areas of further investigation, and can serve as an indication of which taxa one is likely to find.

4.4.3. The use of a Remotely Operated Vehicle

A few challenges were faced during the ROV video transects. Firstly, we encountered an area with high current speed in the collection of transect B2 which led to a section of the transect without data as the ROV had to ascend a few meters to get away from the strong bottom current.

Furthermore, due to currents and local conditions the ROV may not have kept a constant speed and distance from the seafloor, and there are times when the camera looks like it is too far from the seafloor to enable a good video image. We tried to keep a maximum of 1.5 m distance from the seafloor, which even in some cases was too far. In the European Standard NS-EN

16260:2012 sets a maximum distance of 3 m kept from the seabed, however in my opinion this distance makes it extremely difficult to identify species as discussed in the below section (Standard Norge, 2012).

The mapping of biodiversity using ROV video transects has both advantages and disadvantages. Firstly, the method is non-invasive so it is possible to conduct a long term survey in an area, without the confounding effects caused by removal of biomass via grab sampling or trawling (Kollmann and Stachowitsch, 2001). Traditional sampling methods using the removal of physical samples give us a better foundation for identifying species, but often do not show the patterns or distribution of the species on/in the seabed. This is especially relevant in this study where my findings were able to show clusters of macroalgae, which, if the study had been conducted with traditional method such as bottom trawling, would be lost. Additionally, the video and images can be stored without quality being lost, thus enabling the raw data to be re-examined or used in other studies if relevant. In recent times several organisations doing research on the seabed, most notably the National Office of Ocean Exploration and Research (NOAA), have live streamed the ROV video transect with live commentary from scientists allowing this captivating footage to be reach demographics that otherwise would not have access to such footage, possibly resulting in increased awareness and protection of these ecosystems that we know little about (Figure 4.4) (NOAA, 2018).



Figure 4.2: Short clip from one of the live video streams from one of the National Office of Exploration and Research (NOAA) with live commentary from expedition scientists. The videos are used for science communication and research purposes (NOAA, 2018).

4.5. Impact of Findings

As the region of this study area is surrounded by areas with high primary production from phytoplankton and macroalgae at surface waters, it is unlikely that there is a food limitation for the benthic species in the area. However, my findings indicate that the benthic species composition, especially the number of algae grazer species, may be impacted by the macroalgal fragments present, and that in areas with high variation in seafloor morphology there is a build-up of such fragments, thus making the areas more diverse. Further, the results from the thesis supports the findings of Filbee-Dexter et al. (2018) who found that deep fjord habitats and macroalgal systems such as kelp forests, are closely linked.

There are several impacts of these findings which are relevant for the broader range. Firstly, with climate change and carbon storage being high up on the agenda, the contribution of macroalgae to the sequestration of carbon in the deep sea may be higher than previously thought. Along video transects there were some indication that this process is occurring, as some specimens looked to be partially buried under the sediment. Krause-Jensen and M. Duarte (2016) did a rough estimate trying to quantify the role of macroalgae detritus in carbon sequestration and reached a number of 173 TgC yr (range: 61–268 TgC yr), where 88% is sequestered the deep sea. This is only an estimate and more data are needed to get a more accurate idea of the role macroalgae plays in the sedimentation process. However, it is an indication that macroalgae play a much larger part in energy transport and carbon sequestration to deeper water than previously thought. Additionally, the importance of understanding the geological processes such as sediment slides and sedimentation rates and their importance in the transport of organic material to the seabed highlight the importance of a multidisciplinary approach.

Another impact of climate change and global warming is thought to be larger and more frequent storms. Previous studies have linked storms and high wave action to more production of macroalgal fragments (De Bettignies et al., 2015, Krumhansl and Scheibling, 2012). These storms have also previously been found to be able to transport a large influx of carbon to the deep sea (Dierssen et al., 2009). With an increase in storm severity and frequency in the deep ocean we can therefore predict that more macroalgal fragments end up in deep ocean system, and deep fjord system, thus amplifying their role on benthic communities and carbon sequestration.

Furthermore, with global warming the temperature in our oceans is thought to increase, which can shift the ranges of the different macroalgal species (Wernberg et al., 2011, Krumhansl et al., 2016, Steneck et al., 2002). Shift in macroalgal species diversity have already been observed in Norway with the distribution of *L. hyperborea* increasing along the west coast (Fagerli et al., 2013), and in the southwest and Skagerrak coast *Saccharina latissima* is on the decline (Moy and Christie, 2012). On a larger scale, predicted sea surface temperature increase ~2°C compared to 1990 will most likely decrease southern distribution of the macroalgae (Wernberg et al., 2011, Smale et al., 2013, Philippart et al., 2011), and temperate macroalgal species may expand towards the poles, however due to the lack of shallow waters the expansion to the north pole may be limited (Elvira et al., 2013, Dorte and Carlos, 2014, Krumhansl et al., 2014). With the shift both in the distribution of the macroalgae, and the increase in abundance with the global rise in cultivation of seaweed, also seen regionally in Norway (Olsen, 2015), the amount of fragmented and distribution of macroalgae that reaches the deeper parts of the ocean will be changing.

Cultivation of macroalgae for commercial industry is growing in popularity and will increase the amount of biomass of macroalgae along the coast and as a result detritus from these systems. A new project lead by the Norwegian Institute for Water Research (NIVA) is aimed at looking at potential impacts on the coastal ecosystems due to industrial kelp production. One of their aims is to quantify the potential export of detached kelp biomass from cultivation facilities and use the previously mentioned ocean current model SINMOD to map out transport pathways and deposit areas for the kelp detritus. Furthermore, they wish to study the impact this detritus has on the marine habitats in the area (Hancke, 2017). The results of this study indicate that the project should investigate benthic habitats in a large radius around the cultivation sites and investigate the degradation level of the algae as well as the shifts in benthic community species composition. Furthermore, seabed morphology should be included in the predictive mapping of possible deposit areas.

Moreover, a clear finding of this study is the need for up to date standards that take into consideration the variation of the benthic fauna, so that impacts can be better identified. As stated by the Nature Diversity Act (Naturmangfoldsloven 2009), which all biodiversity in Norway is protected under. This act implies the precautionary principle – which means that if there is a lack of knowledge this should not lead to a risk of serious and irreversible damage to the biodiversity. If we are to ensure that this damage does not happen, we need to establish

good standards that consider the varying levels of baseline data available for study design and the variation that the expansive marine area belonging to Norway contains.

4.5.1. Knowledge Gaps

One might think that the marine areas of Norway are well understood and that lots of data exists along the Norwegian Coastline (Sakshaug and Sjøtun, 2002), but this study has indicated there is a strong need for more basic mapping to gain a better understanding of the ecosystem patterns and trends. Our knowledge of our marine areas has increased significantly since the start of Norway's marine mapping program MAREANO that commenced in 2006 (Buhl-Mortensen et al., 2015). However, this program has not focused on the coastal zone, but the continental shelf and slope mapping marine sediments and habitats.

The knowledge from the MAREANO project has been of great help to the Norwegian Environment Agency when processing applications for further petroleum activity on the Norwegian shelf (Iversen et al., 2015, Havforvaltning, 2016), but basic mapping of our coastal zone is highly lacking. Most of the data that the Norwegian Environment Agency bases their assessment of marine areas on area modelled data based on data existing of the ecosystems. As of yet, no comprehensive map exists with distribution of macroalgae, and management of this in many areas are based on predictive mapping of individual kelp species (Bekkby and Moy, 2011, Bekkby et al., 2009). To further be able to study the impact of these kelp on other ecosystems, and to identify where kelp fragments originate from, further data is needed. A new country wide mapping program, titled "Kyst-MAREANO" in Norwegian (translated to Coast – MAREANO) has been proposed to gain a better understanding of our coastal systems (Longva, 2015). Furthermore, as data from the inner coastal zone is lacking it is hard to know what type of variation can be found on the seabed.

4.5.2. Data Availability

Within the 12 nautical mile zone from the coast, bathymetry data with higher resolution than 50 m will not be made available to the public unless special permission is granted from the Norwegian Mapping Authority, due to military restrictions. Offshore these restrictions do not exist, and high resolution seabed data are available from projects such as the previously mentioned MAREANO project, and also from industry activities (Buhl-Mortensen et al., 2015). This implies that offshore studies have better baseline data than in the coastal zone. The availability of baseline data may help improve a study by identifying areas with high variation in seabed morphology, interesting bathymetric areas (that could for instance indicate colony

organisms) and enable better planning and reflect the level of variation present. Thus, the amount of preliminary data should affect how the study is conducted and should be reflected in the European Standard.

Numerous surveys have been conducted along the Norwegian coast, both scientific research cruises and navigation charter surveys. In Norway, data from projects such as the MAREANO project are freely available for download and use, moreover, a regional project in Europe is working towards centralising all marine data in Europe through the European Marine Observation and Data Network (EMODnet) (EMODnet, 2017). The project funded by the European Union works towards gathering all marine related data in Europe into one central data base where it is freely available for download for the public sector, civil society, private sector and the research community. In Norway, many industries such as the aquaculture industry or the petroleum industry, as well as the public sector, collect huge amounts of data every year, which is highly costly and time consuming. By centralising marine data either by participating in the EMODnet project, or through a Kyst-MAREANO project, freely available marine data from the coastal zone should be centralised to save time and money and create and share insights.

5. Conclusion and Future Prospects

Understanding the biodiversity and corresponding transport pattern of carbon (food and energy) from the photic zone to the deeper parts of the ocean is vital to ensure that our ecosystems are preserved, and to mitigate climate change and global warming. It has long been thought that the primary production and thus food availability in the deep ocean is heavily reliant on the spring bloom for temperate zones, and that these pulses of particles provide food for the organisms below. However, my findings indicate that perhaps other key processes also come into play in the food web of the aphotic zone, especially during the stormy winter time providing macroalgal fragments to sink to the seafloor. Additionally, time of year is also of essence here. To track the organic carbon from spring bloom of phytoplankton, sampling should be started before, under and after a bloom event to quantify the vertical flux of organic C to deeper waters. However, as many algae shed their lamina in the fall, another sampling may be necessary in early winter to get measure the amount of detritus that is transported to the deep. Macroalgal detritus may play an important role, both in sequestering carbon in marine sediments, but also in supplying food for benthic organisms outside of the spring bloom. Degradation state of the marine algae may be an important factor and should be included in future studies, and a multidisciplinary approach is needed to fully understand all processes that come into play in the transport of carbon to the deep.

With the oceans warming due to climate change, the geographical distribution of macroalgae will most likely shift, with species distributions shifting poleward due to increased sea surface temperatures. Coupled with a potential increase of algal biomass due to the increasing interest in cultivating macroalgae for commercial use, it is important to understand the processes and impact of macroalgal detritus on the benthic communities. Furthermore, proper mapping standards and sampling techniques for marine habitats, considering the organisms of interest and the parameters of the study location, must be used to allow for comparison between studies, to give us a better understanding of the temporal change in our marine areas. Lastly, data collected from our marine environment should be stored in common databases, for instance through the EMODnet project, and made available in an easy to use platform to allow for the public sector, civil society, private sector and the research community to have the best possible baseline data of marine regions when creating marine plans, planning surveys and research studies or conducting activity in the Norway Exclusive Economic Zone and Extended Continental Shelf.

6. References

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Appendix 1: Representative results of HPLC analysis



Figure 0.1: Results of the High Performance Liquid Chromatography (HPLC) analysis conducted to identify phytoplankton pigments from the sediment samples from the study site 6 km south of the mouth of the Trondheimsfjord, Norway. The x axis shows time in minutes and the y axis shows area at 440 nm absorbance. The results show no peaks hence indicating no presence of phytoplankton pigment in the sample. The result of this sample is representative for all samples conducted.

Appendix 2: Macroalgae observations

Table 0.1: Overview of taxa identification in the macroalgal observations with number of macroalgal observations per taxa and percent of total macroalgal observation. Due to the difficulty in identifying some of the specimens due to size and condition, these specimens were classified into a larger group named “Kelp” comprising of specimens from *Laminaria digitata/hyperborea*, *Saccharina latissima*, *Ascophyllum nodosum* or *Saccharina polyschides*.

Taxa	Number of macroalgal observations	Percent of total (%)
<i>Ascophyllum nodosum</i>	15	16
<i>Desmarestia aculeata</i>	15	16
<i>Fucus</i> sp.	1	1
<i>Fucus serratus</i>	3	3
<i>Laminara digitata/hyperborea</i>	8	9
Kelp	30	32
Phaeophyceae indet.	6	6
<i>Saccharina latissima</i>	10	11
<i>Saccorhiza polyschides</i>	2	2
Total	95	

Table 0.2: Macroalgal observations with number and average size found along four transect lines in an area 6 km south of the Trondheimsfjord in Trøndelag county, Norway.

Transect	Number of macroalgal observations	Average length (cm)
A1	19	23
A2	13	17
B1	21	19
B2	42	24

Appendix 3: List of all taxa observed in the study

Table 0.3: Overview of all taxa identified in the study 6 km south of the mouth of the Trondheimsfjord in Norway.

Group	Common Name	Latin Name	Described by
Arthropoda	King crab	<i>Lithodes maja</i>	(Linnaeus, 1758)
	Plated lobster	<i>Munida</i> sp.	Leach, 1820
	Norway lobster	<i>Nephrops norvegicus</i>	(Linnaeus, 1758)
	Hermit crab	Paguroidea indet.	Latreille, 1802
Chordata	Rabbit Fish	<i>Chimaera monstrosa</i>	Linnaeus, 1758
	Common ling	<i>Molva molva</i>	(Linnaeus, 1758)
Cnidaria	-	<i>Bolocera tuediae</i>	(Johnston, 1832)
	-	<i>Kophobelemnion stelliferum</i>	(Müller, 1776)
Echinodermata	Heart Urchin	<i>Brisaster fragilis</i>	(Düben & Koren, 1844)
	Sea Urchin	Echinoidea indet.	Leske, 1778
	-	<i>Henricia</i> sp.	Gray, 1840
	Cushion Star	<i>Hippasteria phrygiana</i>	(Parelius, 1768)
	-	<i>Psilaster andromeda</i>	(Müller & Troschel, 1842)
	-	Pteraster indet.	Müller & Troschel, 1842
	Red Sea Cucumber	<i>Stichopus tremulus</i>	(Gunnerus, 1767)
Mollusca	True whelk	Buccinidae indet.	Rafinesque, 1815
Phaeophyceae	Rockweed	<i>Ascophyllum nodosum</i>	(Linnaeus) Le Jolis, 1863
	Witch's hair	<i>Desmarestia aculeata</i>	(Linnaeus) J.V.Lamouroux, 1813
	-	Fucus indet.	Linnaeus, 1753
	Toothed wrack	<i>Fucus serratus</i>	Linnaeus, 1753
	Oarweed/tangle	<i>Laminaria digitata/hyperborea</i>	(Hudson) J.V.Lamouroux, 1813/ (Gunnerus) Foslie, 1884
	Brown Algae	Phaeophyceae indet.	Kjellman, 1891
	Sugar kelp	<i>Saccharina latissima</i>	(Linnaeus) C.E.Lane, C.Mayes, Druehl & G.W.Saunders, 2006
	Furbellow	<i>Saccorhiza polyschides</i>	(Lightfoot) Batters, 1902
Porifera	-	<i>Antho dichotoma</i>	(Linnaeus, 1767)
	-	Demospongiae indet.	Sollas, 1885
	-	<i>Geodia barretti</i>	Bowerbank, 1858