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The Tautra Cold-Water Coral Reef

Mapping and describing the biodiversity of a cold-water coral reef ecosystem in the Trondheimsfjord by use of multi-beam echo sounding and video mounted on a remotely operated vehicle

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List of Abbreviations:

AOI – Area of interest

AUV – Autonomous underwater vehicle

CWC – Cold-water coral

DKNV - Det Kongelige Norske Videnskabers Selskab

DP – Dynamic positioning system

E – Equitability of Shannon’s diversity index

GPS – Geographical positioning system

H’ – Shannon’s diversity index

KP – Kilometre point

NGU – Norwegian geological surveys

NM4 – NaviModel 4, EIVA

MBES – Multibeam echo sounder

OOI – Object of interest

ROV – Remotely operated vehicle

RV – Research vessel

USBL – Ultra short baseline

Abstract:

The Tautra sill is one of three sill dividing Norway's third largest fjord, the Trondheimsfjord. Knowledge of cold-water corals in the fjord has been known for centuries and has been a popular object of interest in regards to research. As anthropogenic impact on the oceans world-wide is increasing, an urgent need to gain knowledge about the many habitats is a necessity. The three-dimensional reef structures formed by the cold-water coral *Lophelia pertusa* are considered a biodiversity hotspot and important for many commercial fish stocks. By combining non-invasive technology in the form of video and multibeam echo sounder, mounted on a remotely operated vehicle, to map the seabed and the cold-water corals in the Trondheimsfjord, new biological information was gathered. Two surveys were performed, at the Tautra sill and at Hoøyskjæret in the Beitstadfjord. The surveys aimed to gain knowledge about the *Lophelia pertusa* reef as a habitat and to map cold-water coral occurrence in relation to topography and biodiversity. To illustrate how biodiversity may change along a 1 km long transect, a spatial resolution of 2 m was analysed for megafauna taxa diversity. High correlations between sponge occurrences and *Lopehlia pertusa* were found, as well as higher biodiversity located around the reefs. The combination of the two non-invasive mapping techniques was used to further suggest areas of interest for future inspection and management.

Sammendrag

Tautraryggen er en av tre rygger som deler Trondheimsfjorden inn i tre basseng. Kunnskap om kaldtvannskoraller i fjorden har vært tilstede siden 1700-tallet og har vært et populært objekt for forskning opp til i dag. Ettersom menneskelig påvirkning på verdenshavene øker, blir et økende behov for kunnskap om flere typer marine habitater en nødvendighet for å utføre kunnskapsbasert forvaltning. En tredimensjonal struktur dannet av kaldtvannskorallen *Lophelia pertusa* er ansett som det som kan kalles en biodiversitets-«hotspot» for mange kommersielle fiskebestander. Ved å kombinere miljøvennlig teknologi som ikke skader habitatet i form av video og multistråle-ekkolodd montert på en fjernstyrt undervannsfarkost (remotely operated vehicle) for å kartlegge havbunnen og kaldtvanskoraller i Trondheimsfjorden, ble ny biologisk kunnskap innhentet i denne oppgaven. To undersøkelser ble utført ved Tautraryggen og i Beitstadfjorden ved Hoøyskjæret. Undersøkelsen hadde som mål å innhente kunnskap om Lophelia pertusa-revene som habitat og å kartlegge kaldtvannskorallenes forekomst i relasjon til topografi og biodiversitet. For å illustrere hvordan biodiversiteten kan variere langs et transekt av betydelig størrelse, i dette tilfellet 1km, ble en romlig oppløsning på datapunkt for hver 2 m analysert for megafauna taksa-diversitet. Høy korrelasjon mellom svamper og Lophelia pertusa-forekomster ble funnet. Det ble også funnet høyere biodiversitet rundt korallrevene. Kombinasjonen av de to miljøvennlige kartleggingsmetodene ble brukt til å videre foreslå områder av interesse for fremtidig undersøkelse og forvaltning.

Introduction:

The Tautra sill is one of three sills dividing the Trondheimsfjord into 3 main basins. The sill ridge is a morainic deposit from a glacier, which has created a threshold in the fjord, which alters the tidal current system and provides a source of upwelling of nutrients. Because of this, the ridge may provide favourable conditions for certain organisms thriving in locations with tidal driven and exposed to high current speed providing ample amounts of food in form of phyto- and zooplankton (Tiller et al., 2014). On top of the sill, there is located cold-water coral reefs build by the stone coral *Lophelia pertusa.* The presence of the coral has been described as early as in the 18th century by bishop Gunnerus (Gunnerus, 1768). The reef has been known as a good location for fishing redfish (*Sebastes viviparous*) and is thought to be a biodiversity hotspot, important to many species in the Trondheimsfjord. Because of the cold water coral reefs importance to the biodiversity, the Tautra sill was deemed a marine protected area in 2013 (Miljødirektoratet, 2016). The Tautra sill and the Trondheimsfjord has been the site for research for many decades (Gunnerus, 1768, Storm, 1879, Dons, 1927, Ludvigsen et al., 2013) and is still an area of interest today. The development of marine sampling methods have moved from physical sampling methods (Flannery and Przeslawski, 2015), which are still used today (Kuklinski, 2013), to include a more non-invasive technological development with the use of acoustic and visual sampling, in contrast to sampling of species using destructive sampling devices (Ludvigsen, 2010, Hansen, 2013, Johnsen et al., 2009) to describe the marine habitat on different levels. The importance of knowledge about cold-water coral reefs as a habitat for anthropogenic resources and the effect anthropogenic impact has on them has an increasing urgency as many cold-water coral reefs have already been found to be heavily or completely damaged by fishing methods such as trawling (Løkkeborg, 2005, Fosså et al., 2002). This thesis combines a widely used acoustic mapping method, multibeam echo sounding, and visual information in the form of video mounted on a remotely operated vehicle. The data will be used to describe the cold-water coral reef on the Tautra sill as a habitat and map a topographical elevation in the Beitstadfjord called Hoøyskjæret and to locate cold-water coral occurrences at the elevation.

Theory

The geology of the fjord

The fjord as we know it, started to emerge after the deglaciation of the last ice age, in the first half of what is called the Pre-Boreal period. This period lasted from about 10 000 to 9000 radiocarbon (^{14}C) years before present (BP) (Rise et al., 2006). Glaciers have followed the same paths during several glaciations over the past 3 million years to carve out the present Norwegian fjord systems. Some paths reflect older river systems that can be traced back to the Tertiary time period. Because glaciers have followed the same carved out paths, the topography of the fjord has been slowly enhanced over hundreds of thousands of years, making it what it is today (Rise et al., 2006)

Large parts of the fjord south of the Tautra ridge was most likely ice free after 14 500 ^{14}C years BP. Between the Tautra ridge and Ytterøya, a sedimentary succession of ca. 300 metres has been mapped from seismic surveys performed by Norwegian Geological Surveys (NGU) (Bøe et al., 2003)

Colder climate during the younger Dryas (11 000 to 10 600 ^{14}C years BP) resulted in the glacier re-advancing southwestwards in the fjord. This resulted in glaciofluvial (sediment deposit from glacial run-off) and till (sediment deposit by melting glaciers) deposits on the Tautra ridge. During surveys, NGU has found that east of the ridge there are till and glaciofluvial deposits with a thickness of 150 to 200 m beneath glaciomarine sediments, which again is covered by a thin layer of Holocene sediments (Bøe et.al 2003).

Glaciofluvial deposits occur when melted ice water run under the ice and deposit substrate when stream velocity decreases. In figure 1, glaciofluvial deposits are seen on the Tautra ridge together with till deposits and some exposed bedrock. The till was deposited through glacial erosion and transport. The till deposits consists of a mixture of many grain sizes and bedrock fragments.

Current systems in the fjord

The topography of the fjord as a result from earlier glacial erosion allows for a complex current system. The tidal forces in the fjord are the main driving force of the current system in the fjord. With a mean mixed tidal elevation of 1.8 m (Volent et al., 2011), the current speed at the sills may reach up to 0.7 to 1.04ms^{-1} (Tiller et al., 2014). Inflowing water goes along the southeast side of the fjord, while outflowing water to the north-west side. Between these main currents of in- and outflowing water, eddies are created (Bakken et al., 2000). As Atlantic water flows in to the fjord during the period of late winter to summer, it brings with it planktonic species important as feed for the coral reefs and the general ecosystem of the fjord (Tiller et al., 2014).

The plankton, arriving together with the oxygen rich Atlantic water, flows along the sill slopes and downward to the deep-water masses. On the outer fjord side of the Tautra sill, cyclonic, meso-scale eddies often appears as a result from the tidal currents. These eddies created from tidal currents provide an upwelling force of the deep-water masses, helping to distribute planktonic food upwards to the surface layers of the fjord. These types of eddies are also found in the Beitstadfjord. The distribution of *Calanus finnmarchicus, Periphylla periphylla* and Cod larvae has shown a connectivity of the fjord to the coast. The sills in the fjord, except of the Agdenes sill, inhibits a quick exchange of water masses between the fjord and the coast, allowing for plankton to reside in the basins of the fjord for a prolonged time, together with the deep water masses. Some planktonic species, such as *C. finnmarchicus*, have even been found to spend their entire life cycle in the basins (Tiller et al., 2014).

The annual mean salinity of the fjord is at or above 34 and the temperature in the deep water masses are usually at 7 – 7.5 ^{o}C. In the outer fjord, the temperature will reach a low point, with inflowing deep-water with a temperature of 7 ^{o}C, and surface temperatures between 3 and 6 ^{o}C in February along with a high salinity from the inflowing Atlantic water. During May, the surface (0 - 50 m) temperature will rise as a result from a rising air temperature, leading to heat spreading downwards to deeper layers (Bakken et al., 2000).

As Norwegian coastal water (NCW) flows in to the fjord during autumn, the isocline of 7 ^{o}C will start to sink. With the inflowing of the NCW, the isohaline border sinks as well. The outer fjord and the middle fjord basin has a similar seasonal shift in isohaline and isocline positions. Only in the middle fjord basin, the isocline of 7 ^{o}C will sink to a lower point of 270 m depth, compared to the outer fjord basin where the isocline will reach a depth of 125 m. In the Beitstadfjord the changes lags behind the changes in middle fjord and outer fjord (Bakken et al., 2000). This may relate to the slight rediction of water exchange that the Tautra and Verrasundet sill provides.

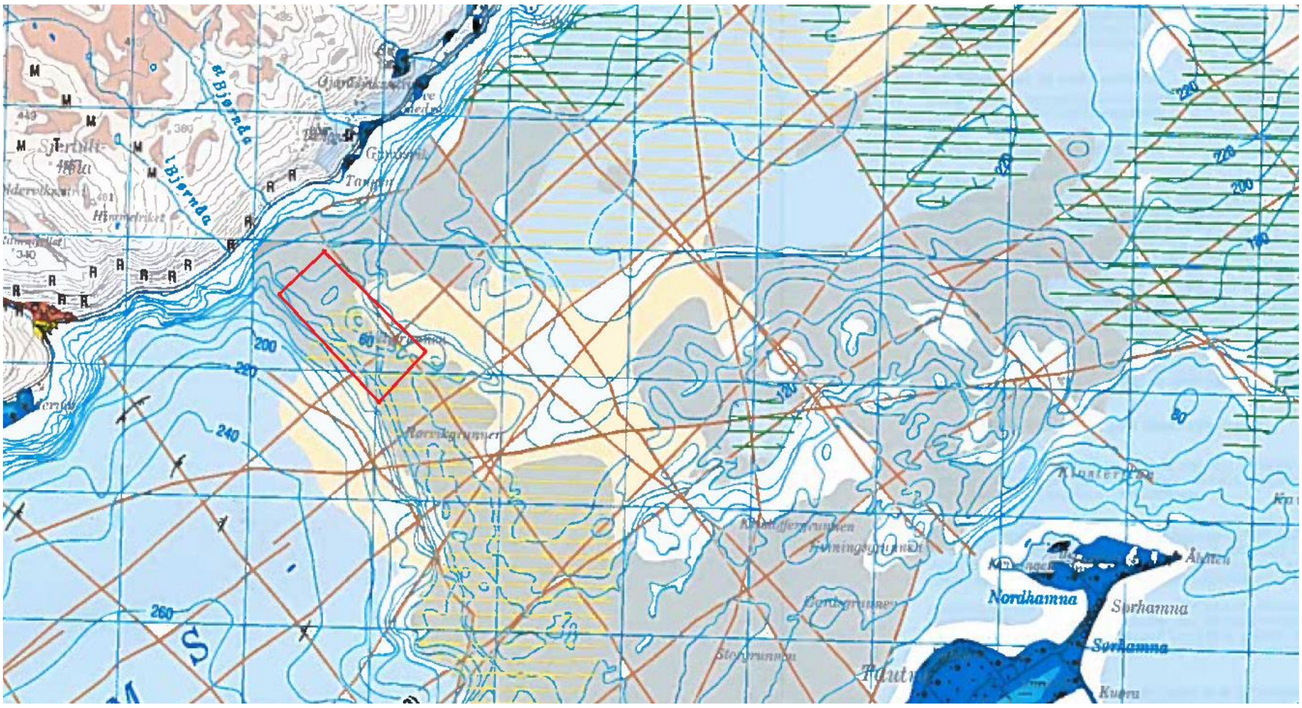

Figure 1: Geological map over the Tautra ridge provided by NGU. Scale 1:50 000. The red box indicates the area surveyed during the cruises 25th and 26th of June 2015. The colours within the box indicates a seafloor covered in till deposits in a relatively thin layer (grey/green colour) and glaciofluvial deposits (light yellow). White areas indicates bedrock. Source: (Reite and Olsen, 2002).

Lophelia pertusa – an important part of marine habitats and ecology

The scleractinian (stony coral) *Lophelia pertusa* was first described as *Madrepora pertusa* by Linné in 1758 (Wilson, 1979), and is a common reef building coral in cold and deep waters (Järnegren and Kutti, 2014). The distribution of *L. pertusa* is spread along the European continental margin, reaching from Norway in the north to the south-west of Ireland. *L. pertusa* is also reported found in the Gibraltar strait, off the west coast of Africa, and in the Indian and

Pacific oceans (Costello et al., 2005). *L. pertusa* seems to thrive in varying temperatures and depths. The coral is found at temperature ranges of 4 – 14ºC (Brooke and Jarnegren, 2013) and at depths ranging from 37m in the Beitstadfjord (Sneli, 2014) down to 3000m depth in the Atlantic ocean (Fosså et al., 2002).

Norwegian waters has a high abundance of *L. pertusa* reefs with a more defined depth, 200 – 400m, where it is abundant (Buhl-Mortensen et al., 2015). The 2 largest reported *L. pertusa*-reefs in the world (the Røst reef and the Sula reef), as well as the worlds shallowest located colonies of *L. pertusa* (in the Trondheimsfjord) are located in Norwegian waters (Costello et al., 2005). Being an azooxanthellate coral meaning that it does not contain endosymbiotic microalgae (zooxanthellae), *L. pertusa* depends on good conditions for filtering zooplankton out of the water (Järnegren and Kutti, 2014). *L. pertusa* is usually found located on sites of topographical heights (Mortensen et al., 2001) where flow-patterns are favourable for a good access to food. Other factors contributing for a thriving *L. pertusa* reef or colony could be the presence of a suitable seabed substrate (hard-bottom), physical and chemical properties of the water masses and seabed topography affecting current system around the coral. It has been suggested that in mid-Norway morainic deposits are a favourable substrate for the scleractinian to colonize (Mortensen et al., 2001).

The coral reef creates a 3-dimensional habitat for surrounding fauna. An increased complexity in the structure built by the scleractinian has been noted to have a positive correlation to increased diversity and abundance (Demopoulos et al., 2014). *L. pertusa* reefs are found to have a high associated biodiversity and provides a shelter and habitat for cold-water species in an often otherwise flat environment with little hiding opportunities (Fosså et al., 2002). The *L. pertusa* reefs has been found to have a high importance to many commercial fish species. *Pollachius virens* (saithe), *Sebastes* spp. (redfish/rockfish), *Brosme brosme* (cusk), *Gadus morhua* (cod) and as much as 21 other species has been found in relation to *L. pertusa* reefs in the NE Atlantic (Costello et al., 2005). At the Tautra reef in the Trondheimsfjord saithe, poor cod and redfish have been found to be the dominating fish species. The reef is thought to work as a nursing habitat, habitats for food sources and as spawning sites (Costello et al., 2005, Järnegren and Kutti, 2014). Other megafauna often found to be associated with and around a *L. pertusa* reef are the sponges *Mycale lingua* and *Geodia baretti (Hansen, 2013).*

Other corals common in cold-water areas that are also associated with *L. pertusa* are *Paragorgia arborea*, *Primnoa resedaeformis* and *Paramuricea placomus (Purser et al., 2013).* Approximately 1300 species has been found in relation to the *L. pertusa* reef (Järnegren and Kutti, 2014), making the reef an important ecosystem in cold-water and deep areas of the ocean.

L. pertusa reefs and ecosystems can be categorised into 4 types of macro habitats:

1. Live corals, usually at the top of the reef.
2. Dead coral structure, usually under the live coral. This contributes to reef building structure.
3. Dead coral rubble. Eroded dead coral structure creating a gravel-like substrate under and around coral reefs.
4. Underlying sediment. Reef-building scleractinians usually attach to hard bottom substrate. Surrounding sediment may be anything such as hard-bottom, sand or gravel.

L. pertusa has two genders and can reproduce both sexually and asexually. The formation of reefs takes place through asexual replication of polyps by unequal intratentacular budding (Brooke and Jarnegren, 2013). The growth rate of linear polyp extension has been reported to reach almost 10mm year^{-1}, while a *L. pertusa* reef can grow up to 5mm year^{-1} (Järnegren and Kutti, 2014), but favourable conditions may give a thought maximum growth of 25mm year^{-1} (Costello et al., 2005). The slow growth of the reefs introduces a resilience and survival of *L. pertusa* that is highly dependent on fecundity and post-settlement survival of planulae (larvae from sexual reproduction) (Brooke and Jarnegren, 2013).

Increasing rates of discovery of coral reefs in the deep sea as a result from increasing use of modern technology such as remotely operated vehicles (ROV) (Costello et al., 2005) shows that there might be many cold-water coral (CWC) reefs not yet discovered. Because of slow growth rate, it takes time for a thick and considerable reef to build. Some of the oldest and largest reefs in Norwegian waters are thought to have started to settle and grow after the last glaciers retreated some 8000 – 10000 years ago (Costello et al., 2005, Mortensen et al., 2001). In addition to scientific surveys to map *L. pertusa* reefs on the Norwegian coast, many of the reported records of *L. pertusa* reefs in Norway comes from fishermen (Fosså et al., 2002). This may relate to the importance the reefs has to many commercial fish species.

Anthropogenic impacts to *L. pertusa* reefs could have been inflicted before the reefs are even discovered and put on the map. Many reefs are shown to be partly or completely destroyed through trawling activity, especially in shallower waters around 200m depth (Fosså et al., 2002). Other threats to the *L. pertusa* reef are climate change, mariculture operations, and even a highly localised nutrient input from terrestrial discharge. There is not yet enough information to accurately predict how the reef ecosystems would react and cope with environmental and physical changes as a result from anthropogenic activity (Brooke and Jarnegren, 2013). The damage done to *L. pertusa* reefs may even cause significant alterations to the biodiversity hotspots and the distribution of biodiversity on CWC (Fosså et al., 2002).

Early coral research of the fjord

Many researchers have contributed to research in the Trondheimsfjord. Knowledge of the fauna living in and surrounding the fjord has been described and noted down since the mid-18th century. Researchers have an important role to play in gaining knowledge about the fjord and even if there are many more questions to be answered about what is out there and how it all connects, some of the researchers in the fjord had to have started the task. Reaching from Gunnerus through Storm to Dons and up to today, the research history of the Trondheimsfjord is rich and full of knowledge.

Johan Gunnerus.

Gunnerus was bishop in Trondheim from 1758 to 1773 (Bakken, 2011). When Gunnerus was ordained as bishop in Trondheim in 1758, he immediately sent out a letter to the clergymen of the diocese inviting them to be a member of the "Trondhjemske Selskab". The scientific society founded by Gunnerus, together with Gerhard Schøning and Peter Friedrich Suhm, was the beginning of a long and still evolving research history and environment in Trondheimsfjorden (Nissen and Berglund, 2000).

The diocese was large, reaching from the border of Romsdal in the south to Vardø in the north. A large diocese left Gunnerus large amounts of fauna to explore and describe both from own journeys, the first one taking place in 1759 (Bakken et al., 2011), and from collected specimens sent from clergymen and laymen. On one of his journeys in 1761, around the western part of the fjord (Ørlandet), Gunnerus opened his eyes for the fjord's fauna. It was after this journey he started to collect and describe the animals he could get his hands on from the fjord (Nissen and Berglund, 2000).

Because of limited available methods of collecting marine fauna, Gunnerus mostly described what was given to him from anglers and what he could pick up from the shoreline (Nissen and Berglund, 2000). Gunnerus managed to describe the important reef building scleractinian *Lophelia pertusa* already in 1768 (Gunnerus, 1768). He even published a description and an illustration of its morphological traits and stated that it could not be mistaken for anything else based on this illustration (see figure 2) (Bakken et al., 2011).

Figure 2: *Madrepora pertusa*, presently named *Lophelia pertusa* as published by Gunnerus in 1768. The illustration was the first published of the species (Bakken, 2011).

Gunnerus mentioned that the corals he got from anglers were from the same area as where they usually fished for S*ebastes viviparus* or *Sebastes norvegicus*, Norwegian redfish (Gunnerus, 1768). The equipment used at the time to fish in the fjord was of the traditional kind, this included hook and line, gillnets and longlines (Olsen, 2008). When anglers got too close to the coral reefs, gillnets mostly would be entangled into the corals and either the anglers would lose the equipment or fish up the cnidarians.

Gunnerus described 15 species new to science, of which 10 are valid names today. His contribution to information about species biodiversity in Norwegian fauna and botany are esteemed as an important primary source for research today (Bakken et al., 2011).

Vilhelm Ferdinand Johan Storm

It wasn't until Storm was hired as curator at "Det Kongelige Norske Videnskabers Selskabs Museum" (DKNVS) from 1856 to 1913, that the research in the fjord again prospered. Storm started to collect and describe the fauna on the bottom of the fjord systematically. Storm used a hard bottom dredge to take samples and he systematically mapped several areas of the fjords benthic fauna. Storm described fauna in the fjord in works published in DKNVS' journal, areas in the fjord such as Stadsbygd, Rissa, areas around the Tautra ridge and in Skarnsundet. (Bakken, 2014, Nissen and Berglund, 2000, Storm, 1879). Storm charted where he found different corals and sponges. This he plotted into a map published in 1901, as shown in *Figure 3* (Storm, 1901).

The work Storm performed through DKNVS and in Trondheim as curator of the museum was inspired by Gunnerus' writings in DKNVS' "Skrifter". Because of Storms' research and excellent management of DKNVS' museum, Trondheim became acknowledged early in international research groups as an exquisite destination for research of marine fauna (Mork and Sneli, 2011).

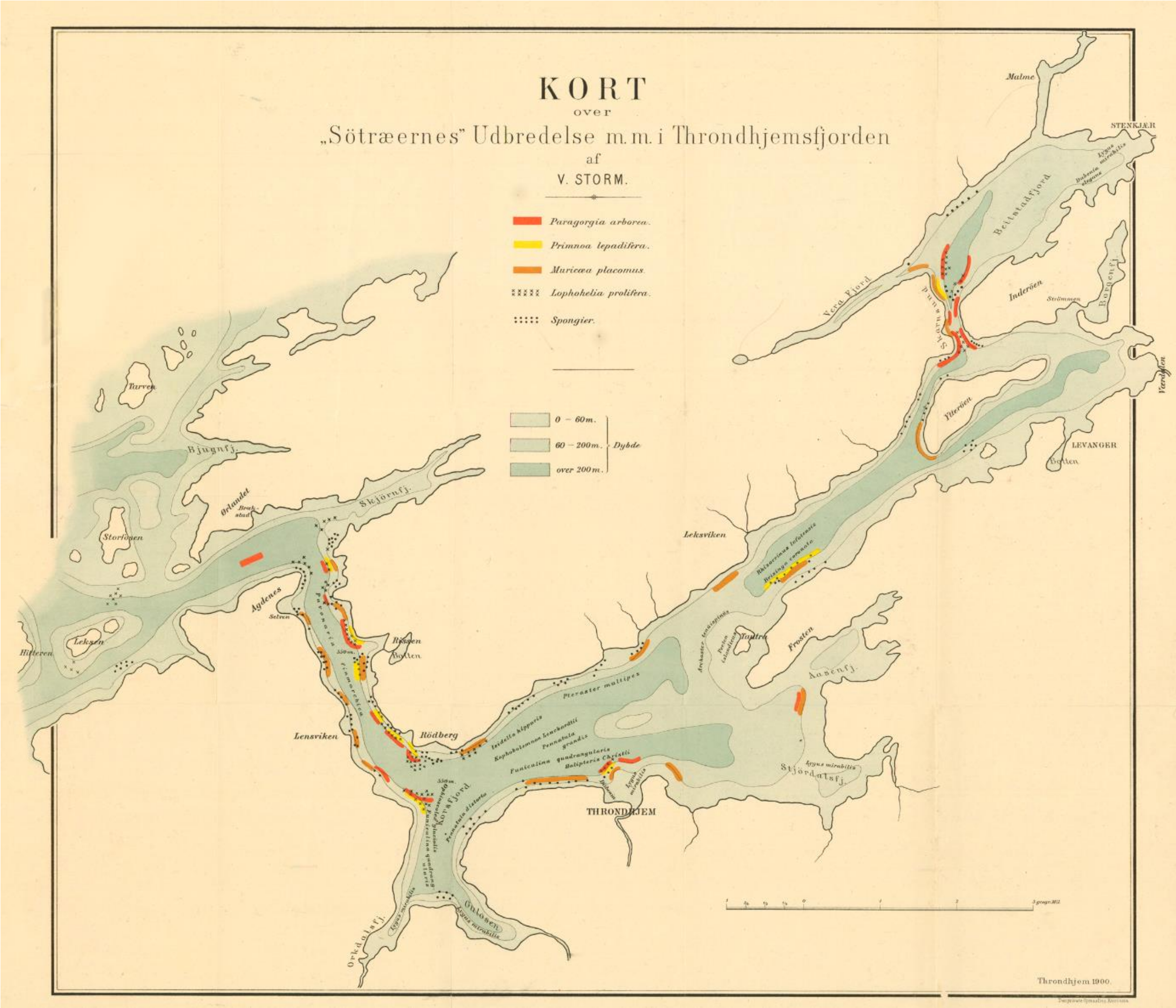

Figure 3: Storm made a map of cold-water coral occurences in the Trondheimsfjord in 1900. Red indicates *Paragorgia arborea*, yellow indicates *Primnoa lepadifera* (Now: *Primnoa resedaeformis*), brown indicates *Muricea placomus* (Now: *Paramuricea placomus*), x's indicate *Lophelia prolifera* (now *Lophelia pertusa*) and dots indicate sponges (porifers). Lightest blue indicates depths of 0 – 60m, mid-dark blue indicates 60 – 200m, and dark blue indicates more than 200m depth. Source: (Storm, 1901)

Carl Frederik Lindeman Dons

Dons was curator at the DKNVS museum from 1920 (Sakshaug and Mosby, 1976) and worked in relation to DKNVS for 29 years. He performed survey cruises along much of the Norwegian coast, and even went north to Finnmark. This resulted in large amounts of material for the museum. Dons contributed much to scientific literature about marine invertebrate fauna. Between "Zoologiske notiser", which consisted of 40 publications, and "Norges strandfauna" Dons described and included research of just about every group of marine invertebrates (Nissen and Berglund, 2000). Dons was one of the first curators to systematically describe fauna *associated* with the cold-water corals found in and around the Trondheimsfjord and Mid-Norwegian waters (Fosså et al., 2002, Dons, 1927, Dons, 1944). In his work "Sjøen", Dons refers to Storms description of the seabed fauna, but is particular to mention in detail what he found with his survey and sampling methods (Dons, 1927).

Common traditional benthic sampling methods in marine biology

There have been many traditional ways of sampling the benthic fauna and many of the methods are still used today. Some of the most commonly used traditional methods include: grabs, dredges, bottom sleds, trawls and box corers. Most of the methods are mentioned in publications by biologists from the Trondheimsfjord such as e.g. Dons and Storm (Dons, 1927, Storm, 1878).

Dredges, sledges and trawls

The triangular dredge can be put in the same category as sledges and trawls of different kinds. The common denominator for these methods is the towing of the equipment from a vessel by a chain or wire. They also have a metal frame to which a net is attached to capture whatever is in the way of the frame. These methods are designed to capture epibenthic fauna, but at different substrate types. While the trawl and the sledge are more suitable for softer sediments, the dredges is especially robust and suited for hard bottom substrates and are often used to scrape off epifauna with a hard attachment to the substrate (Flannery and Przeslawski, 2015). Triangular sledge are still in common use (illustrated in *Figure 4*). An advantage of these towing methods is the area coverage it provides compared to other physical sampling techniques such as box corers and grabs (Flannery and Przeslawski, 2015). The trawling and dredging methods for fishing and sampling are thought to have a possibly severe effect on the epibenthic fauna with slow growth, such as cold-water coral (CWC) reefs (Løkkeborg, 2005). This may lead to an assumption that research on CWC reefs before remote sensing started to take place, would be damaging to the very object studied, the CWC reefs.

Figure 4: On the left is a box corer, this particular boxcorer is from the manufacturer KC Denmark A/S. It has a typical design for the type of bottom substrate sampling gear. On the right is a triangular bottom dredge also from the manufacturer KC Denmark A/S. The sledge also has a typical design with a triangular metal fram to scrape benthic fauna from the seabed. (KC Denmark A/S, 2016b, KC Denmark A/S, 2016a)

Grabs and boxcorers.

Grabs consists of two facing boxes lowered vertically to the seafloor. Upon hitting the seafloor, the grab is closed, enclosing sediment and hence infauna. A boxcorer works as a cubicle without a bottom, which is lowered into the sediment and is closed at the bottom before being retrieved to the vessel (*Figure 4*). One of the main differences between them are that the boxcorer will not disturb and mix the sediment layers, and therefore it is possible to do geochemical analysis of the sample as well as in situ observations from the samples. The disadvantage of these methods is the low area coverage and time-consuming sample analysis (Flannery and Przeslawski, 2015).

Seabed mapping

Multi-Beam Echo Sounding

When mapping the seabed a topographical knowledge of the survey area is important to identify areas of interest for ground-truthing. Acoustic waves (“echosounders”) are widely used and very suitable for this particular purpose since it does not attenuate in the seawater as quickly as e.g. electromagnetic waves (Vangen, 2007). The use of acoustic signals to map the seabed has been around for decades, and has been used both by the industry (Hovland et al., 2002) and by science on several topics such as archaeology, marine biology and geology (Ludvigsen, 2010). Today one of the most widely used types of acoustic mapping is Multi-Beam Echo-Sounding (MBES). MBES has been used since the end of the 1970s. It works in principle that an acoustic pulse (a sound of a given frequency) is sent from an acoustic transducer mounted on an instrument-carrying platform such as the hull of a ship, ROV or an Autonomous Underwater Vehicle (AUV). The acoustic signal hits the seabed and is bounced back to hydrophones, which is recording the pulse as several smaller beams. The angle and strength of the beams are registered and used to construct a topographical image of the seabed (Vangen, 2007). MBES is a swift way of getting the corner stone knowledge of an area and to quickly identify areas of interest (AOI). It has been shown that MBES data can identify possible coral reefs (Hovland et al., 2002, Wilson, 1979). By using the MBES wisely, areas of interest can be quickly identified and efficiently ground truthed. This may lead to measures taken to protect important habitats.

Optical sea floor mapping

MBES is a good way to gain basic knowledge over a large area due to high areal coverage, but further ground-truthing is important to verify what is physically present at the survey site. To perform ground-truthing, physical methods as sampling in the AOI may be used. Recently, non-invasive optical methods, giving specific information in contrast to acoustic sensors, have become more and more useful for the purpose of ground-truthing. Often are cameras mounted on AUVs or ROVs manoeuvred around the AOI (Ludvigsen, 2010). More and more studies have combined the acoustic information data and video/optical surveys to map and describe the seafloor (Touria et al., 2015, Hovland et al., 2002, Hansen, 2013). Visible light is heavily attenuated by the seawater and its inherent optical properties such as phytoplankton coloured dissolved organic matter and suspended matter (Johnsen et al., 2009), additional lights are needed when optical ground-truthing is performed at depths with little light penetrating and reaching the seabed.

Optical sensors has several uses and can be combined with a diverse range of platforms depending on the depth and area cover wanted. Optical sensors may be mounted on ROVs for depths where divers and satellites can't reach (Ludvigsen et al., 2007, 2013). The sensors can also be mounted on airplanes and satellites and then be used for large scale surface optical information, often directed toward phytoplankton blooms and ocean colour properties (Volent et al., 2011, Johnsen et al., 2009). Optical information may even be attained through standstill and towed frames (for depth out of reach for divers and satellites) and divers often used to map transect or smaller areas as well as organism and community behaviour (Colton and Swearer, 2010).

Material and methods

Research platforms

The Research Vessel Gunnerus

The NTNU research vessel (RV) Gunnerus was used to map the survey site at the Tautra sill. Of equipment relevant to the study, the vessel was equipped with a geographical positioning system (GPS), Furuno Navigator GP-90, to geolocalise its position during the cruise. This GPS is also used together with a dynamic positioning (DP) system of the type Kongsberg SDP-11/cPOS to keep in position or to move along a transect line. The acoustic positioning system on the vessel, Kongsberg HiPAP 500, was used to geolocalise the Remotely Operated Vehicle ROV while it was in the water, as normal GPS localization is not possible below the water surface due to attenuation of radio waves. The acoustic positioning system was an ultra-short base-line (USBL) localization system, where a transponder mounted on the vessel sends out acoustic signals that were received by the ROV and then sent back to a transceiver also mounted on the vessel. The time and angle in which the transceiver receives the signal will determine where in the watercolumn the ROV is located in relation to the research vessel (Hansen, 2013).

Multi-beam echo sounder (MBES)

For bathymetrical data of survey sites, the RV Gunnerus was equipped with a multibeam echosounder (MBES) of the type Kongsberg EM 3002s. The MBES is well suited for seafloor mapping down to 200 m depth and has a single sonar head swath width of 130 degrees (Kongsberg, 2006). Depending on how fast and in which angle the acoustic signal is received after hitting the seabed, it will give data depicting the topography of the seabed and in some cases even give a reading on the hardness of the seabed based on signal strength. The MBES was used at the Beitstadfjorden site, but not at Tautra. The bathymetrical data used for Tautra was the same as the data collected and mentioned in Ingrid Myrnes Hansen's MSc thesis, Optical mapping of cold-water corals in Trondheimsfjorden and Svalbard (Hansen, 2013).

Remotely operated vehicle

A ROV is an instrument-carrying platform designed to perform tasks under water. A ROV is able to carry heavy instruments and reach depths divers are not able to reach over longer distances and larger areas. To be able to control a ROV a control container was used to communicate with the vehicle through an umbilical. The length of the umbilical and the depth range of the mounted equipment on the vehicle will limit its depth range. The depth rating of the ROV would also be determined by the mechanical properties of the components such as buoyancy block, electronics housing, camera housings, lights, etc. The umbilical provides a power source for the ROV and optical fibres in the umbilical was used to be able to transmit video and footage from optical sensors from the vehicle. To be able to manoeuvre the ROV, the pilot needs to be able to see live video of the surroundings and the seascape around. A joystick connected with a control system in the control container communicated with the ROV to be able to manoeuvre through the water. By using the dynamic positioning (DP) system, a pre-programmed route with heading, speed and altitude may be used to ease the steering of the ROV and to get a more accurate transect than with manual steering only.

The ocean space is a 3-dimensional area in which the ROV can move. Meaning the ROV will be moving along an x-, y- and z- axis. Movement along these axes respectively are referred to as surge, heave and sway (Hansen, 2013, Ludvigsen, 2010).

The ROV used for both Tautra and Beitstadfjorden was a Sperre SUB-fighter 30K ROV. The ROV has a depth rating of 1500 m, but the operations was limited by the length of the umbilical (650m) connecting the control container on board R/V Gunnerus to the ROV. During the surveys done at Beitstadfjorden and at the Tautra sill, the maximum depth was 80 – 100 m depth.

The ROV was mounted with halogen lights, HMI gaslights and a high definition video camera with laser-ruler to give a scale to the images (Ludvigsen et al., 2013). The distance between the lasers were 10 cm. The DP-system of RV Gunnerus and the ROV allowed for a pre-programmed transect line with a decided altitude ranging from 1 to 2 m above the seafloor.

Video Camera

The camera used for both survey sites was a HD video camera of the type Sony FCB-SE600. The FCB-SE600 has 3.27megapixels and films in Full HD (1080i/60) image quality. The camera was equipped with a measuring laser that gives a 10cm scale to the picture frame. The camera was time-synchronised with the ROV control system, enabling an overlay text in the picture frame giving information about heading, depth, time and coordinates. Because of its compact size, the camera is practical to equip on the ROV without implementing a heavy payload to the vehicle.

Transects

The Beitstadfjord transect

The County Governor of Nord-Trøndelag, Trondhjem Biological Station with Jon-Arne Sneli, and the Geological Survey of Norway, performed a cruise on the R/V Seisma in the outer Beitstadfjorden in September 2014 and found the shallowest registered cold-water coral in the world at the site. The stone coral *Lophelia pertusa* was found at a depth of 36 to 37 meters depth (Sneli, 2014).

Based on the transect lines from the 2014 cruise, the Beitstadfjord cruise was set out to re-visit the site on May 25th 2015. 3 transect lines were re-visited: V1410012, V1410014, and V1410014 shown in the *Figure 5* below. These transects covered what is called the Hoøygrunnen in the outer Beitstadfjorden. After video transects were performed, a MBES-survey over the same area was done to retrieve bathymetrical data of the area for further processing in NaviModel (*Figure 6*).

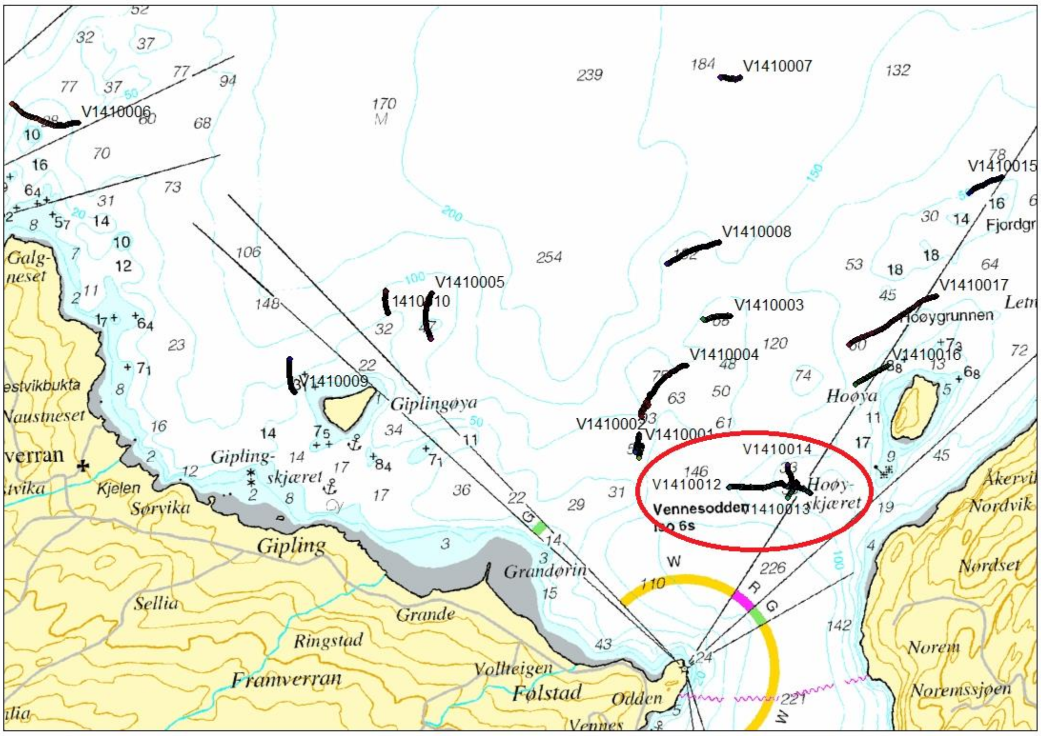

Figure 5: Transects from the cruise on R/V Seisma in 2014 showing the outer Beitstadfjorden and the entrance to Skarnsundet and the middle fjord basin of the Trondheimsfjord. The red circle indicates the 3 transects that were re-visited during the cruise on the 25th of may 2015. The transects were performed with a towed camera unit instead of a ROV. Image taken and altered from (Sneli, 2014).

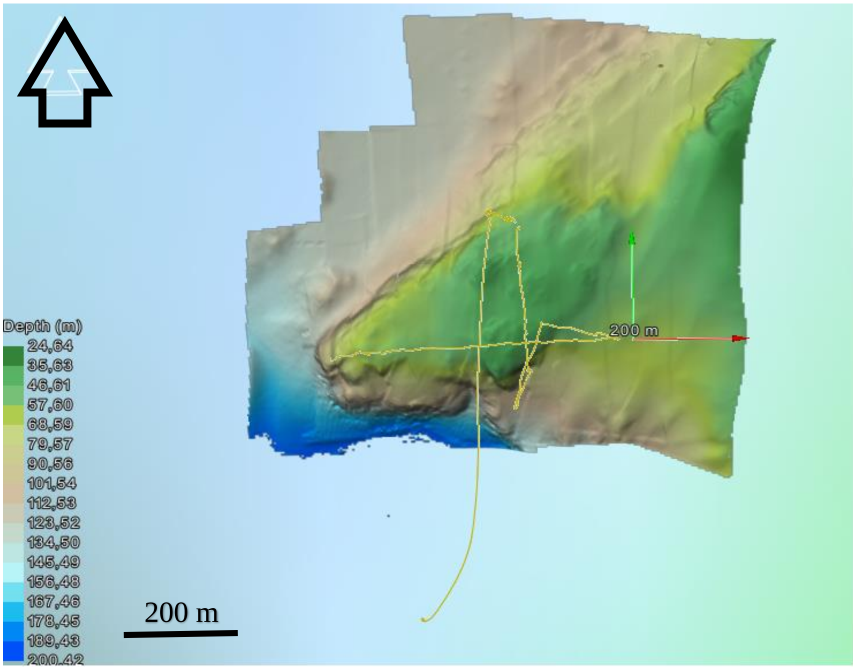

Figure 6: Digital terrain model of the survey area and transect lines from the Beitstadfjord survey. The arrow in the upper left corner indicates north direction. Black line in the lower left corner has a scale of 200 m. Dark green indicates depth of approximately 25 m, dark blue indicates 200 m depth or more. The area is within the red circle in Figure 5.

The Tautra sill transect

The transect on the Tautra sill was based on transects done in relation to Ingrid Myrnes Hansen's Masters thesis in 2012 (Hansen, 2013). A box transect of 10 x 20m was planned on June 25th 2015 and a linear transect of 500m was planned along the sill on June 26th 2015. Transects were planned in accordance to the Norwegian standard, NS9435 – "Water quality: Visual seabed surveys using remotely operated and/or towed observation gear for collection of environmental data" (superseded by a newer version: NS-EN 16260:2012) (Standard Norge, 2009). Survey area is shown in *Figure 7*, *8* and *9*.

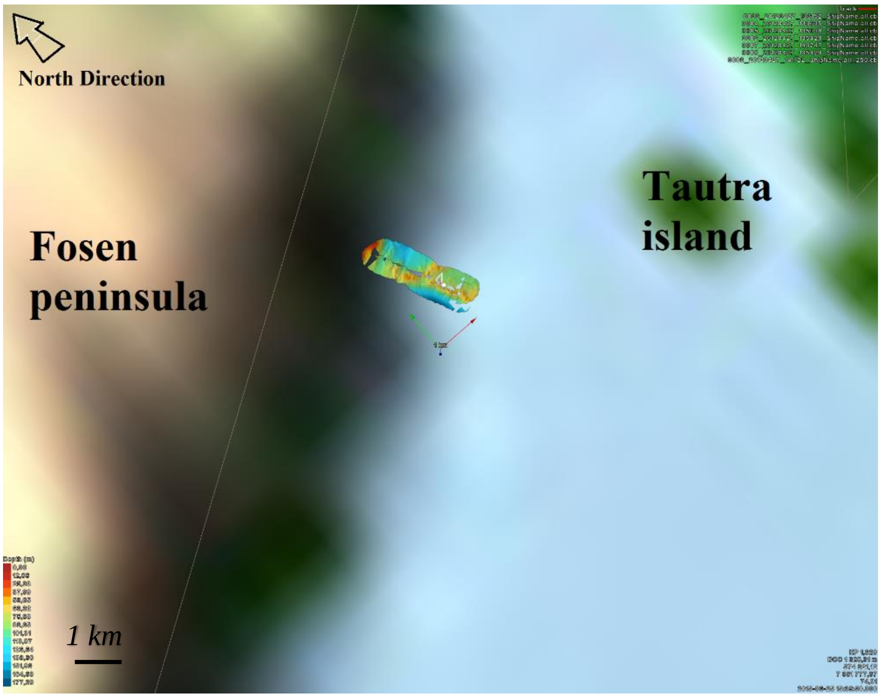

Figure 7: Area covered by MBES data from FFI cruise in 2012, processed in NaviModel 4. Black line in lower left corner of the figure indicates 1 km scale. Lower left corner indicates colour scheme for depth in the digital terrain model (DTM), where yellow-orange indicates around 65 - 70m depth. Upper left corner shows northward direction.

June 25th, 2015:

Due to strong currents leading to failure to complete the full transect, the box transect was discarded. The ROV had too much trouble completing the transect in full and only a couple of lines in the box were completed, This was considered to be not enough to make a good visual mapping of the chosen area. In order to solve this for the next survey, a better timing with the tidal currents were planned. An earlier departure from dock and an earlier launch of the ROV would make it possible to avoid the tidal currents when they were at their strongest.

June 26th 2015:

The planned transect was according to Standard Norway NS9435. Altitude was set to 2 m above seafloor and speed to 0.2 m^{-s}. Camera was tilted at a 40^{o} angle, measuring laser was turned on at 13:37 as it was forgotten in the beginning of the transect. The ROV left the water surface at 12:34, and reached the seabed at 12:40. Transect started at 12:58, 0 m. The transect ended at 14:54, and with a total travel distance between start and end of transect of 1578m for the ROV. The ROV was retrieved at approximately 15:04.

Because of efficient time management and favourable current conditions at the site, the original transect of 500m was extended to cover 1 km overhead line along the sill. This transect included video-visually uncharted territory in the last 500m, but it was already covered by the available bathymetry data collected from the 2012 bathymetry (Hansen, 2013). The transect was mainly run in DP-mode (pre-programmed survey line) for the ROV to easier keep the heading of the transect, but manual steering was also needed as some current and topographical challenges were faced when the survey was performed.

Data processing and analysis for the Hoøyskjæret in Beitstadfjorden

A three-dimensional digital terrain model (DTM) were made from the MBES-data obtained from the Hoøyskjæret survey. On further details on how a DTM was made, see section below and referenced manual for NaviModel 4 (JEK, 2015). Track-line was laid over the DTM and run through with linked video to identify areas with coral occurrence. Other organisms were not registered. Afterwards a DTM with plotted in points for coral occurrence was made and areas for further investigation was suggested based on were the corals were located.

Data processing for the Tautra sill

After the cruises were finished, data was stored on an external hard-drive. Data included a trackfile in *.NPD file format for the ROV where heading, pitch, time and corresponding position throughout the trackline, bathymetrical data from MBES in a *.navi EIVA file format, in addition to video footage with embedded timestamp in the picture frame.

A 3-dimensional bathymetrical model also called a digital terrain model (DTM), was made of the seascape based on MBES data processed in EIVA NaviModel4 (NM4) for both survey sites. MBES data was collected in parallel linear runs, which was afterwards was put together in NaviModel 4 (NM4) to cover the survey site area. In NM4 the MBES tracklines were "sewn" together to make a coherent model with as few gaps between data points (cells) as possible (for more information on how to do this see page 42 – 82 in NM4 manual, referenced (JEK, 2015)).

For each data point from MBES a spatial resolution of 2 m between each data point (species analysis and numbers) was chosen in NM4 to give a better visual presentation of the area and to interpolate data points. This is also referred to as cell size for the DTM. Once the DTM was finished, the trackline for the ROV was added on top of the model with linked video from the survey. The result is shown in *Figure 9*. An official starting point was chosen for the transect line for the Tautra sill transect and the belonging kilometre point (KP) in the transect was noted. The KP of the runline in NM4 indicates travel distance in meters or kilometres enabling the user to decide to go to a specific point in the current run line chosen in NM4. E.g. the starting point KP and beginning for video-analysis for the Tautra sill was decided to start at KP =1788 to find a point 2m away from this KP = 1790 would be the next point. For practicality, this was converted to meters in the transect and in figures in the Results e.g. KP1788 is 0 meter or start and KP1790 is then 2 m from previous point.

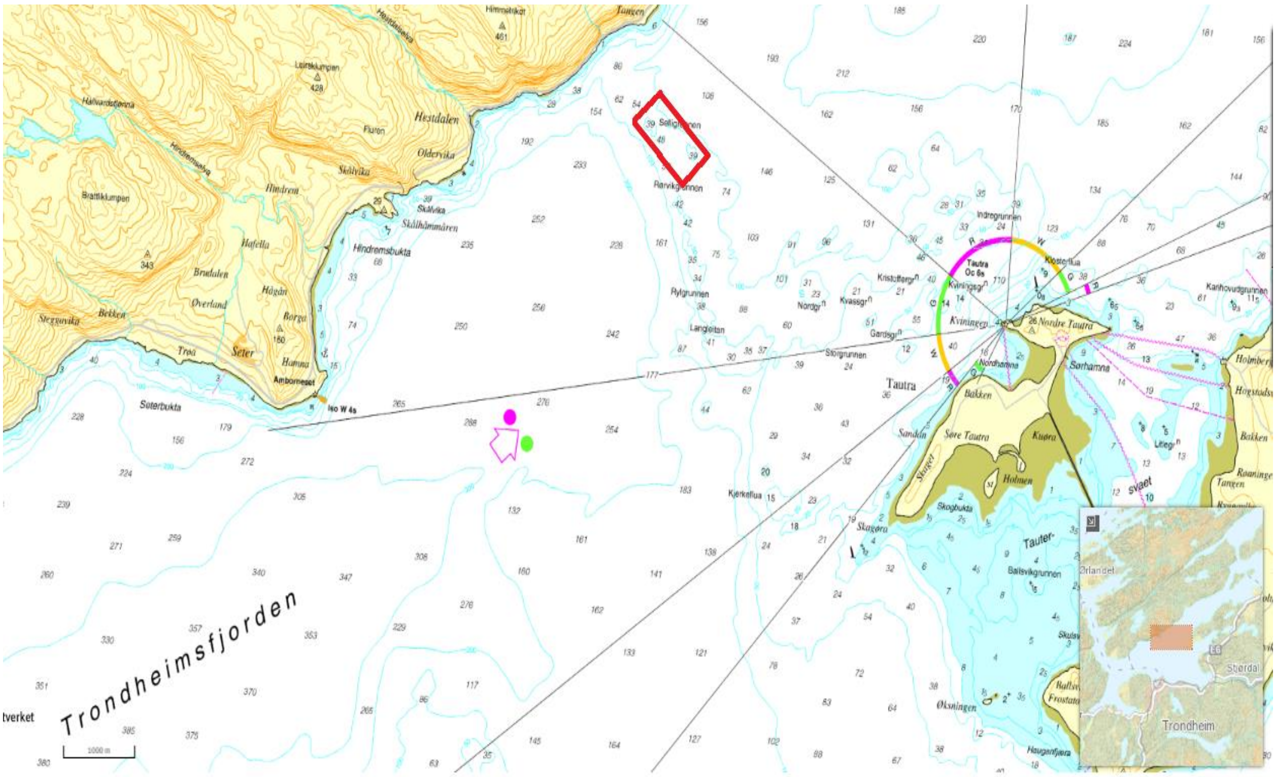

Figure 8: Map from the Trondheimsfjord depicting the Tautra reef survey area marked with a red box. Lower left corner a black scale indicates a distance of 1 km. Lower right corner shows where in the Trondheimsfjord the area is located.

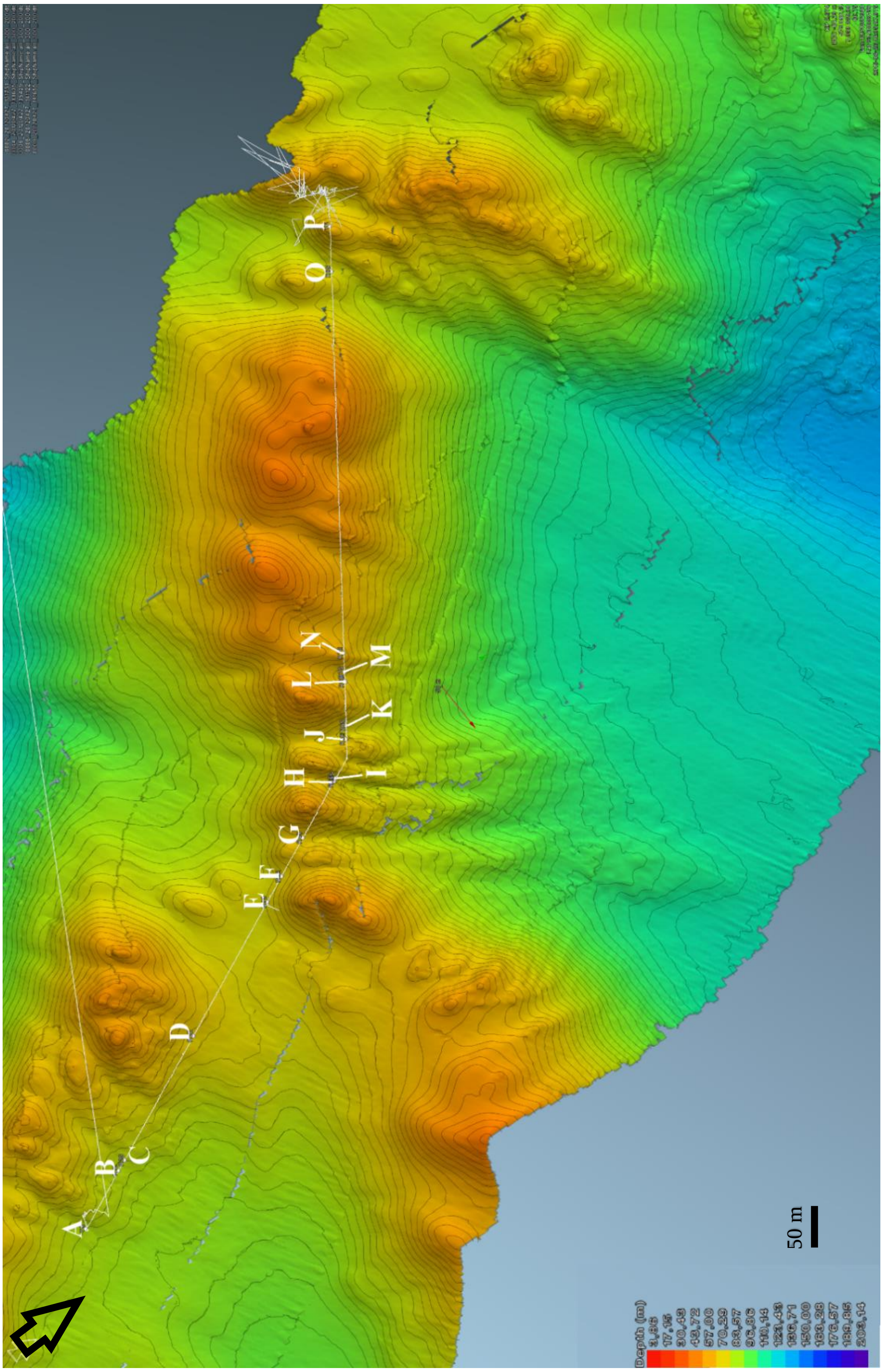

Figure 9: A seabed bathymetry map of the Tautra reef from MBES made in NM4 showing the survey transect with a white line. Lower left corner has a small arrow indicating north. Contour lines indicates a depth change interval of 2m. Dark blue indicates 200 m depth or more. Between green and orange, the depth goes from approximately 90 m depth to 40 and 30 m depth. Black line on the lower left side indicates a scale of 50 m length. **A**: Transect start and start of Reef 1, **B**: End of Reef 1. **C**: Start of Reef 2, **D**: End of Reef 2. **E**: Start of Reef 3, **F**: End of Reef 3. **G**: Start of Reef 4, **H**: End of Reef 4. **I**: Start of Reef 5, **J**: End of Reef 5. **K**: Start of Reef 6, **L**: End of Reef 6. **M**: Start of Reef 7, **N**: End of Reef 7. **O**: Start of Reef 8, **P**: End of transect.

Data analysis for the Tautra sill

It was decided to investigate every second meter (every second KP point) in travel distance along the runline. A total of 790 points were originally set up for analysis. Points were excluded if they were too close in time (less than 3 seconds) or if the picture were too blurred or dark for analysis. This would occur if the ROV were too high above the seabed.

Video timestamp was noted for each 2m interval KP point along the runline in NM4. Pictures for further analysis was retrieved from video by using Adobe Premiere Elements 12™ for Windows 10. The resolution of the pictures retrieved form video was 1920 x 1080 pixels.

Lophelia pertusa was not counted as individuals, but rather calculated percent live coral coverage in picture by using ImageJ plugin. The number of pixels covered by cold-water corals was calculated relative to the total number of pixels in the picture and from this the percent coverage was found. Percent live coral coverage and organism registration was done independent of area coverage in the picture, which changes as altitude changes.

Percent live coral coverage were categorised as follows:

No cover = 0 – 2%

Low cover = 2 – 25%

Medium cover = 25 – 40 %

High cover = 40 – 80%

Full cover = 80 – 100%

Organisms other than the *Lophelia pertusa* were counted and identified down to the most accurate taxa level as possible (species, genus, class or phylum). Colony forming organisms, such as hydroids, was counted as one individual per colony spotted in footage. For identification the book "*Marine fish & invertebrates of Northern Europe*" by F.E. Moen and E. Svensen (2004) was used.

Fish, echinoderms (sea stars and sea urchins), crustaceans (crabs), sponges (Porifera - *Mycale lingua*, *Geodia baretti*), cnidarians (hydriod colonies, other corals than *Lophelia pertusa* and

Sea anemones) were focused on when registering organisms. No pelagic species other than fish were registered. Objects too blurry to identify as a living organism were discarded. In short, there was a main focus on the megafauna of the reef, as organisms smaller than 5 – 10 cm were too small to identify, and as the ROV would not allow for identification of infauna within corals and in the sediment.

After registering abundance of organisms, the Shannon diversity index (H’) was used to set a number to the picture analysis to systematize the biodiversity of the transect line on the Tautra sill.

Shannon’s diversity index, H’, is here defined as (Shannon and Weaver, 1963):

$$H' = -\sum_{i=1}^{S} pi \ln pi \qquad \text{(Equation 1)}$$

Where pi is the proportion of specimens within total number of specimens registered in sample. S is the total number of groups/species found in the sample. The index usually ranges from 0 - no diversity, to about 5 – very high diversity when calculated in this matter, above 5 values are possible and can indicate perfect diversity. The index was chosen because of practicality and because it takes into consideration both species abundance and evenness and taking rare species into consideration. To further validate how the achieved values of H’ is in relation to a thought maximum H’ value based on the groups registered, the equitability or the evenness of the H’ value was calculated as follows:

$$E = H'/H'_{max} \qquad \text{(Equation 2)}$$

H'_{max} was calculated to be 2.89 for the whole transect. The use of one H_{max} for the whole transect enables comparison between points along the transects. The equitability value will range between 0 and 1, being that a 1 value will indicate that the sample has the maximum diversity based on the number of taxon groups registered. E was used to say something about the diversity in the Tautra transect and was categorized as follows:

E = 0, Not present

E = 0.1 – 0.3, low diversity

E = 0.3 – 0.5, medium diversity

E = 0.5 – 0.9, high diversity

E = 1, perfect diversity/evenness

Depth was recorded from ROV track file information and related to percent live coral coverage, and E. Percent coverage of *Lophelia pertusa* was also compared to E, and to numbers of apparent individuals of sponges (Porifera).

When E = 0 there is data registered which equals to no diversity. No diversity can be found if only one species is present or if no species are present. Points where data was not registered because of blurry or dark pictures are marked with black bars in graphs given in [*Results*].

Results

The Beitstadfjord – Hoøyskjæret

Results from the Beitstadfjord included a transect overview from the ROV with marked video coverage and a digital terrain model with marked occurrences of corals. No other groups of megafauna was noted down at the Hoøyskjæret. The survey was mainly done to try to relocate the *L. pertusa* found from the survey done in 2014 with the County Governor of Nord-Trøndelag and to suggest further areas of interest based on video and MBES data visualised in a digital terrain model made in NM4. Few occurrences of *L. pertusa* was found, but high abundances of *Paramuricea placomus* and *Primnoa resedaeformis* were registered.

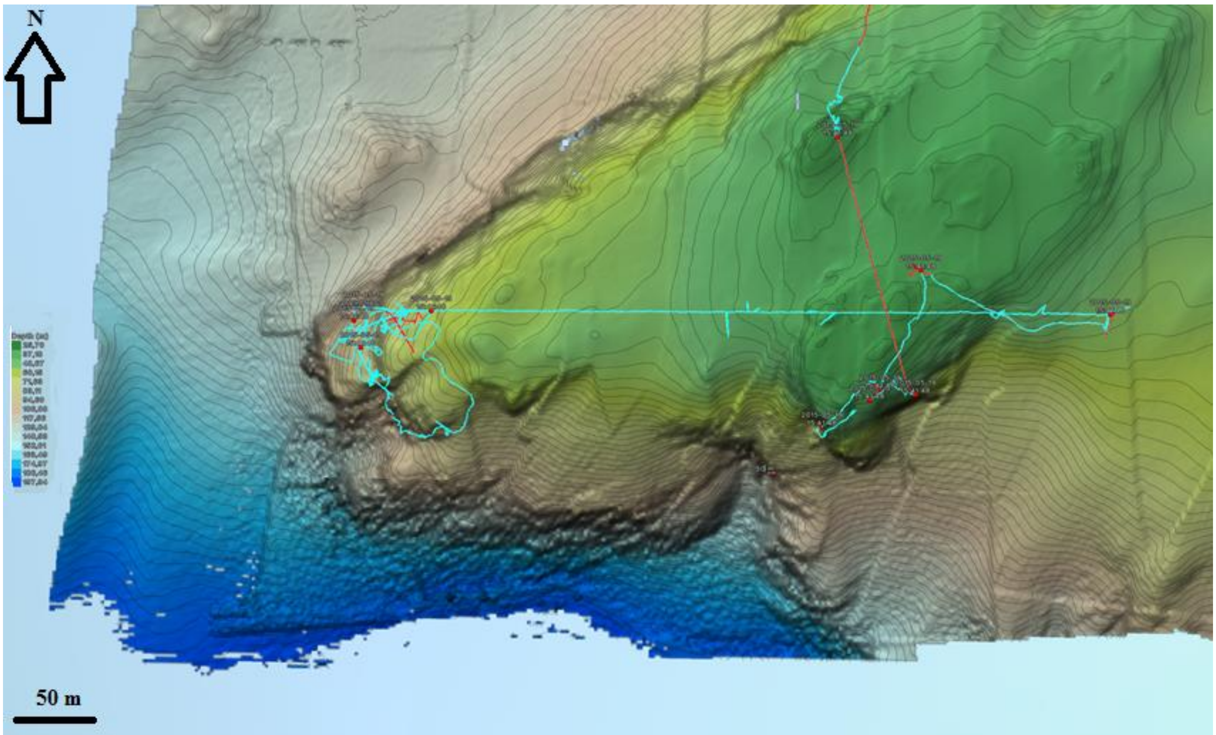

Figure 10: Digital terrain model from survey done at Hoøyskjæret in Beitstadfjord 19th of May 2015. Red and blue line indicates transect of the ROV. Red colour = no video coverage, blue = video coverage. Line in lower left corner indicates 50 m distance. Dark green is approximately 35 m depth, dark blue and light blue is 200 m depth or more. Contour lines indicates 2 m interval change in depth. Upper left arrow indicates northwards direction.

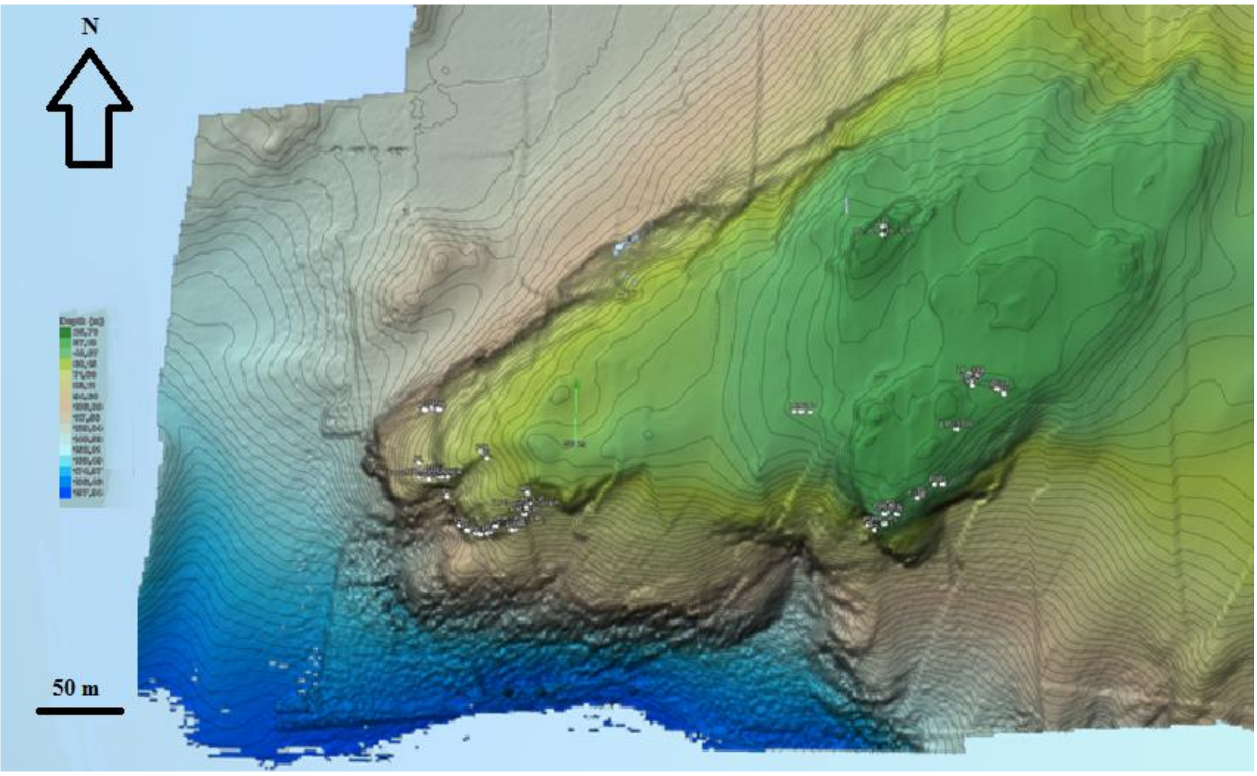

Figure 11: Digital terrain model from Hoøyskjæret. White dots in figure indicates location of corals registered from video survey. Line in lower left corner indicates 50 m length. Dark green indicates approximately 35 m depth, dark blue indicates 200 m depth or more. Contour lines indicates 2 m change in depth. Upper left arrow indicates northward direction.

Mainly corals was found at steep elevations and around the contours of the Hoøyskjæret. On top of the elevation in Figures 10 and 11, indicated with darker green, a relatively flat seafloor with indication of sedimentation accumulation was registered. *L. pertusa* was found as well as areas with hints of coral rubble and sand. On the western side, a large white-looking structure in the visual periphery was registered.

Tautra sill: Total abundance of benthic organisms

The total amount of taxa groups registered along the transect was 21, excluding *Lophelia pertusa* which was the most dominating species by far. In *Figure 12*, it was found that unidentified sponges made up the largest portion of organisms. It was observed that mostly the sponges were to be found on and around live coral, but they were also found in regions where no corals or dead coral rubble were present. No species or detailed organism registration in the video transect was made for organisms smaller than 5 cm length and 2 cm width.

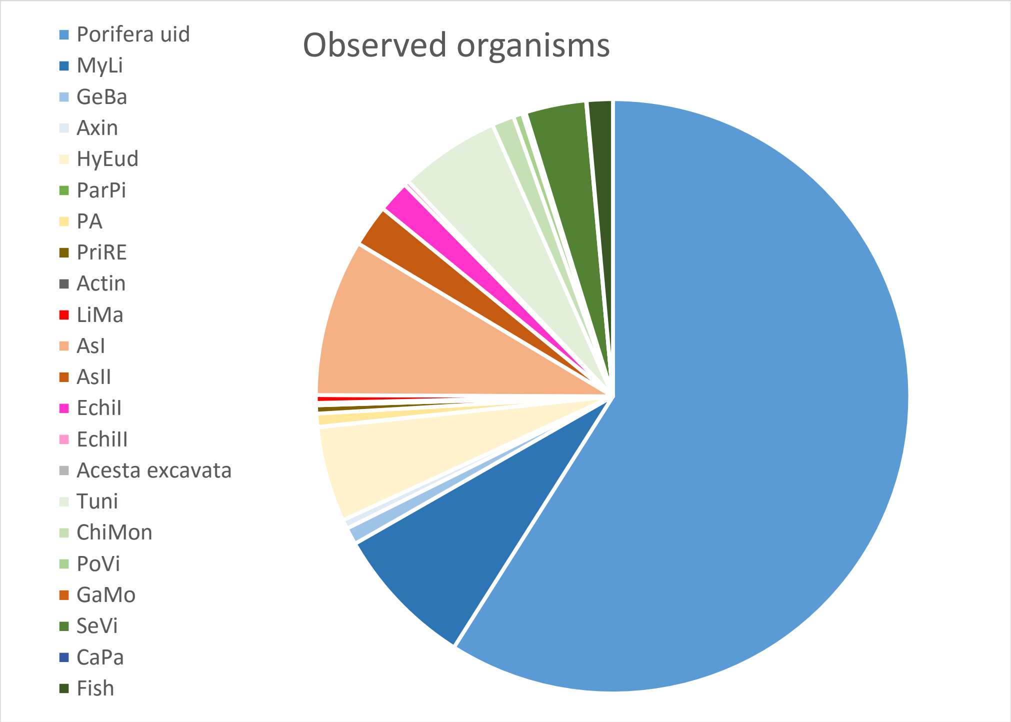

Figure 12: Total megafaunal taxa biodiversity of the Tautra reef. Based on 1580 m long transect line with 2 m spatial resolution (26.06.2015). Porifera indet = unidentified sponges, MyLi = *Mycale lingua*, GeBA = *Geodia baretti*, Axin = *Axinella* spp., HyEud = Hydroid, ParPi = *Paramuricea placomus*, PA =*Paragorgia arborea*, PriRE = *Primnoa resedaeformis*, Actin = Actiniarida, LiMa = *Lithodes maja*, AsI = Asteroidean (resembles Henricia sp), AsII = Unidentified asteroidean, EchiI = *Echinus* spp, EchiII = unidentified echinoidean, *Acesta excavata*, Tuni = Tunicate, ChiMon = *Chimaera monstrosa*, PoVi =*Pollachius virens*, GaMo = *Gadus morhua*, SeVi = *Sebastes viviparus*, CaPa = *Cancer pagurus*, Fish = unidentified fish.

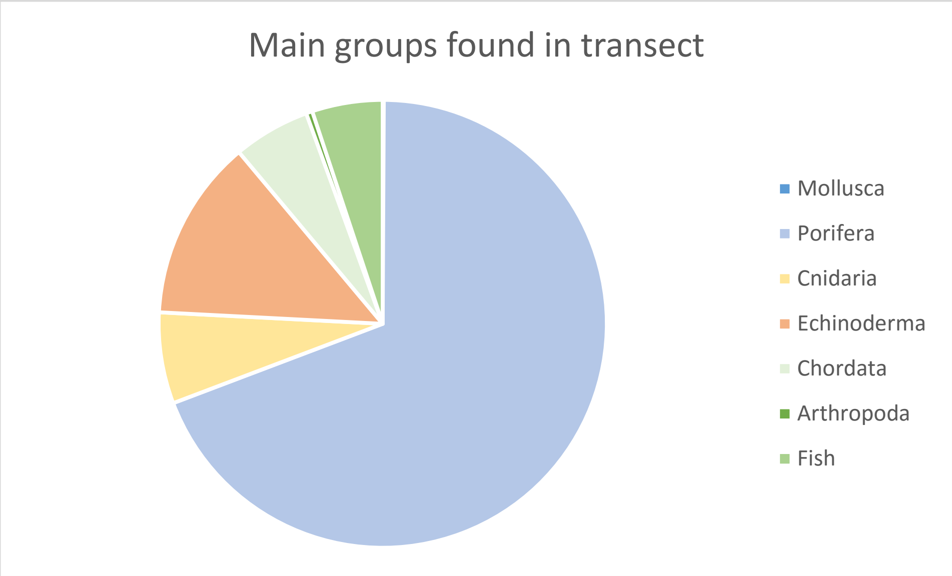

Figure 13: Major taxa from total Tautra transect June 26th 2015. Molluscs =0.08%, sponges (Porifera) = 69.15%, Cnidarians = 6.58%, Echinodermata = 13.09%, Chordata = 5.55%, Arthropoda = 0.45%, Fish = 5.09%

In *Figure 13*, the taxon groups identified are reduced down to 7 main groups based on phylum for overview. Sponges makes up 69.2% of the specimens, molluscs 0.08%, cnidarians 6.6%, echinoderms 13.1%, chordates equals 5.6%, arthropods 0.5%, and fish altogether 5.1% of the species. In total 3751 specimens were registered in the total transect.

***Table 1**: Overview of taxon groups and number of species found (including colonies of corals and hydroids, not including* Lophelia pertusa *reefs) at the Tautra transect, using nomenclature from the Norwegian registry of species (Artsdatabanken, 2015).*

Phylum: Porifera	
Class: Demospongiae	2245
Family: Mycalidae	
Species: *Mycale lingua*	295
Family: Axinellidae	
Genus: *Axinella*	19
Family: Geodidae	
Species: *Geodia baretti*	35
Phylum: Cnidaria	
Class: Hydrozoa	197
Class: Anthozoa	
Order: Actinaria	5
Order: Alcyonacea	
Species: *Paragorgia arborea*	27
Species: *Primnoa resedaeformis*	17
Species: *Paramuricea placomus*	1
Phylum: Echinodermata	
Class: Asteroidea	87
Genus: *Henricia*	325
Class: Echinoidea	10
Genus: *Echinus*	66
Phylum: Mollusca	
Class: Bivalvia	
Species: *Acesta excavata*	3
Phylum: Arthropoda	
Class: Malacostraca	
Species: *Lithodes maja*	16
Species: *Cancer pagurus*	1
Phylum: Chordata	
Class: Ascidiacea	
Family: Cionidae	202
Species: *Ciona intestinalis*	6
Class: Holocephali	
Family: Chimaeridae	
Species: *Chimaera monstrosa*	46
Class: Actinopteri	54
Family: Gadidae	
Species: *Gadus morhua*	7
Species: *Pollachius virens*	19
Family: Sebastidae	
Species: *Sebastes viviparus*	126

Equitability and Shannon's diversity index

To illustrate how the equitability can have the same peaks as the H' values, H' and E was plotted into graphs below to show their relationship. E seemed to vary with H' and had the same peaks as H' as illustrated in *Figure 14, 15, 16 and 17.*

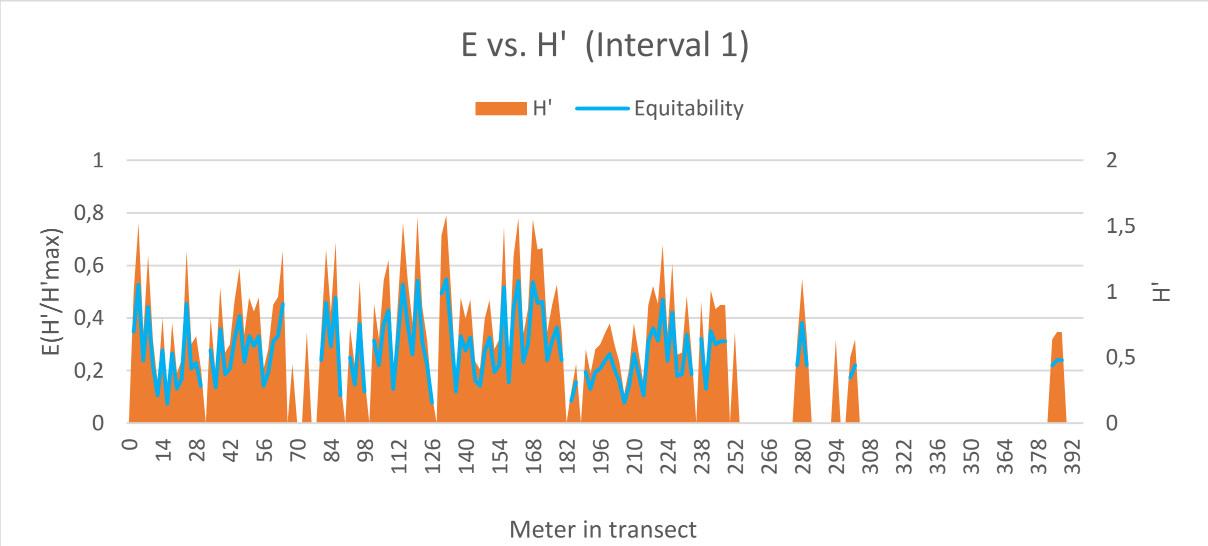

Figure 14: Interval 1 of total 4 intervals from the Tautra transect from the 26th of June 2015. Comparison of how Shannon's diversity index, H' indicated by the secondary y-axis, and the equitability of H', E (indicated by the primary y-axis) varies with transect line.

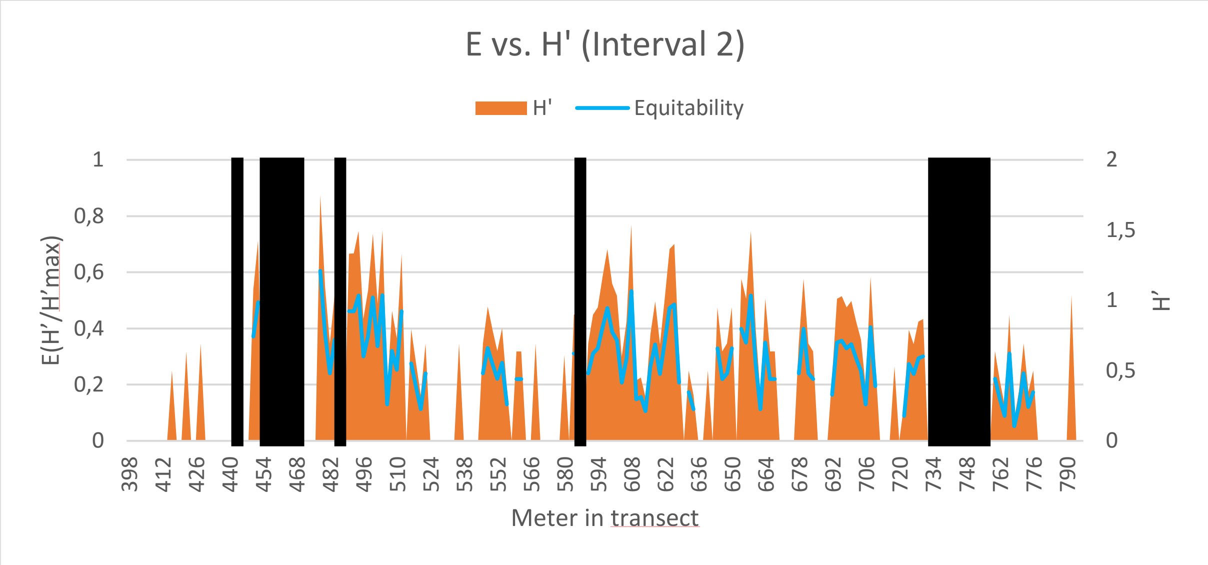

Figure 15: Interval 2 of total 4 intervals from the Tautra transect from the 26th of June 2015. Comparison of how Shannon's diversity index, H' indicated by the secondary y-axis, equitability of H’, E is indicated by the primary y-axis varies with transect line. Black bars represent points with no data.

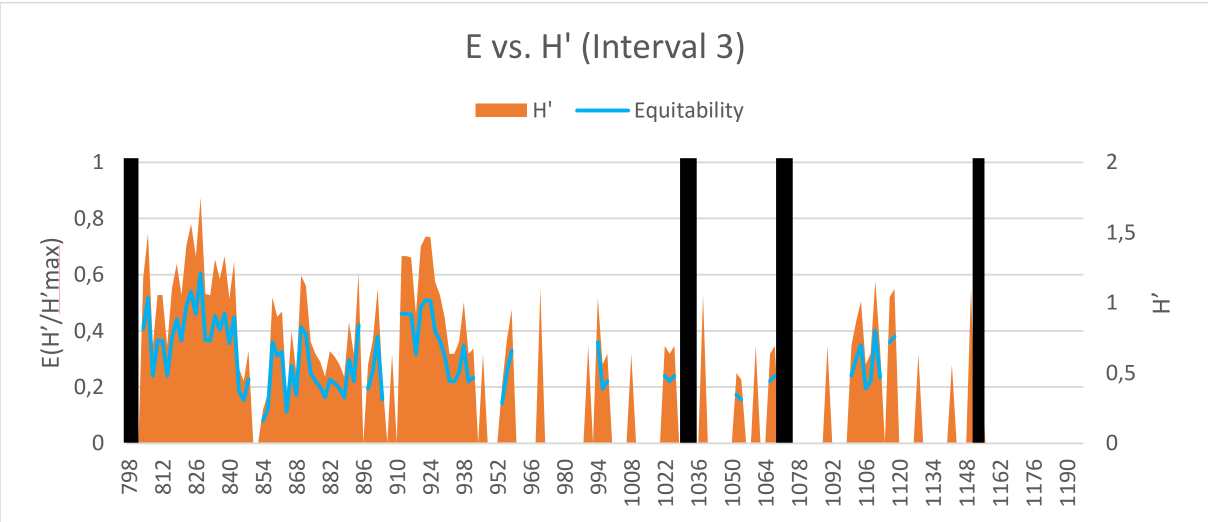

Figure 16: Interval 3 of total 4 intervals from the Tautra transect from the 26th of June 2015. Comparison of how Shannon's diversity index, H' indicated with secondary y-axis, equitability of H’, E is indicated with primary y-axis varies with transect line. Black bars represent points with no data

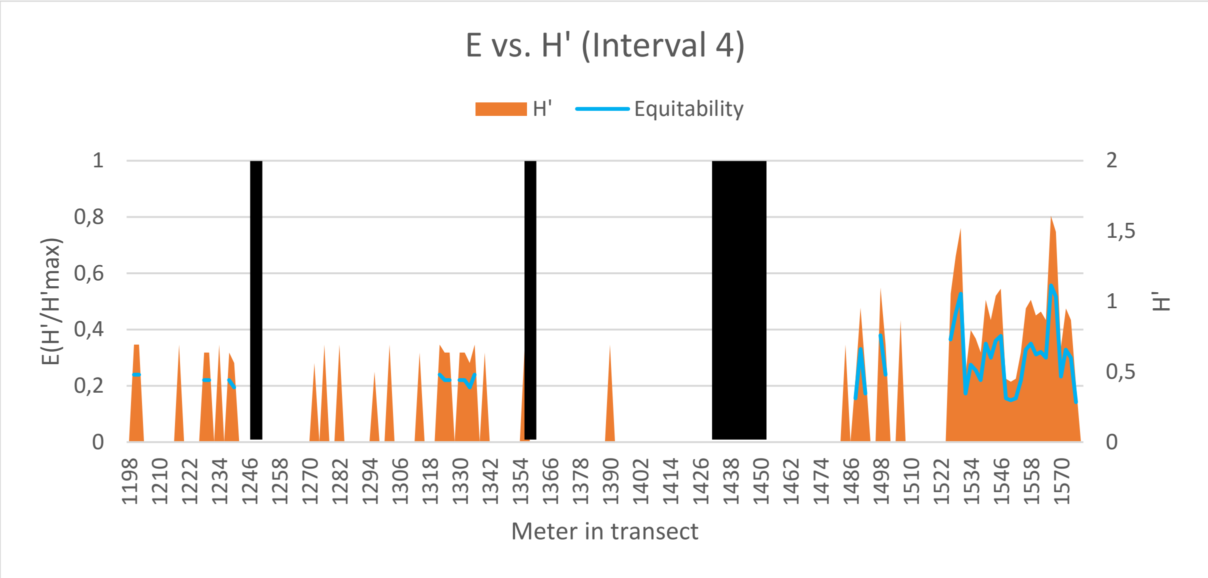

Figure 17: Interval 4 of total 4 intervals from the Tautra transect from the 26th of June 2015. Comparison of how Shannon's diversity index, H' indicated with secondary y-axis, the equitability of H', E is indicated with primary y-axis varies with transect line. Black bars represent points with no data.

Tautra sill: The equitability (E) of Shannon diversity index, H’, and depth

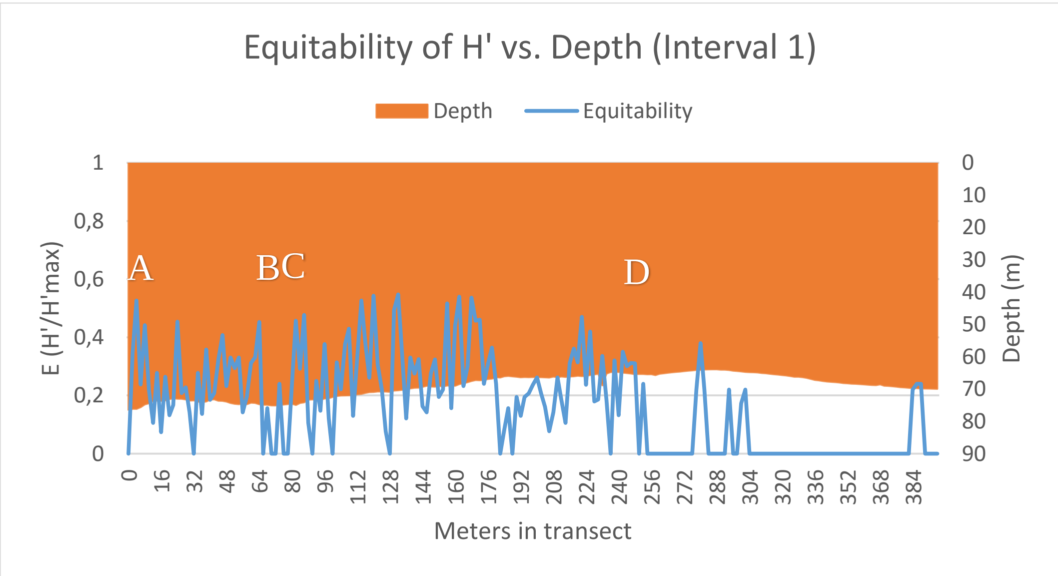

Figure 18: First interval of total 4 intervals from the Tautra transect from the 26th of June 2015. The interval covers points A, B, C and D in Figure 9. Direction from left to right is equal to an east to west direction on the map. Orange indicates depth below surface shown in meters on the secondary y-axis. On the primary y-axis E is shown ranging from 0 - No diversity, to 1 – perfect evenness/diversity (H’ value for the data point is equal to the thought H’max for the transect).

In *Figure 18*, the first interval of the Tautra transect is shown. The transect includes points A, B, C and D from figure 5. It shows a medium-high E associated with a topographical slope, a hill upwards from east to west. At the decline from approximately 62 m down to 70 m depth and from 278 m to 390 m, the E value decreases and E = 0, indicated no or low biodiversity of megafauna at most of the slope.

In *Figure 19*, the second interval is shown. It is not as a protruding trend, but it can be seen that the diversity was higher in slopes and around topographical varying seascape and around highpoints. The black bars indicates where no data are available.

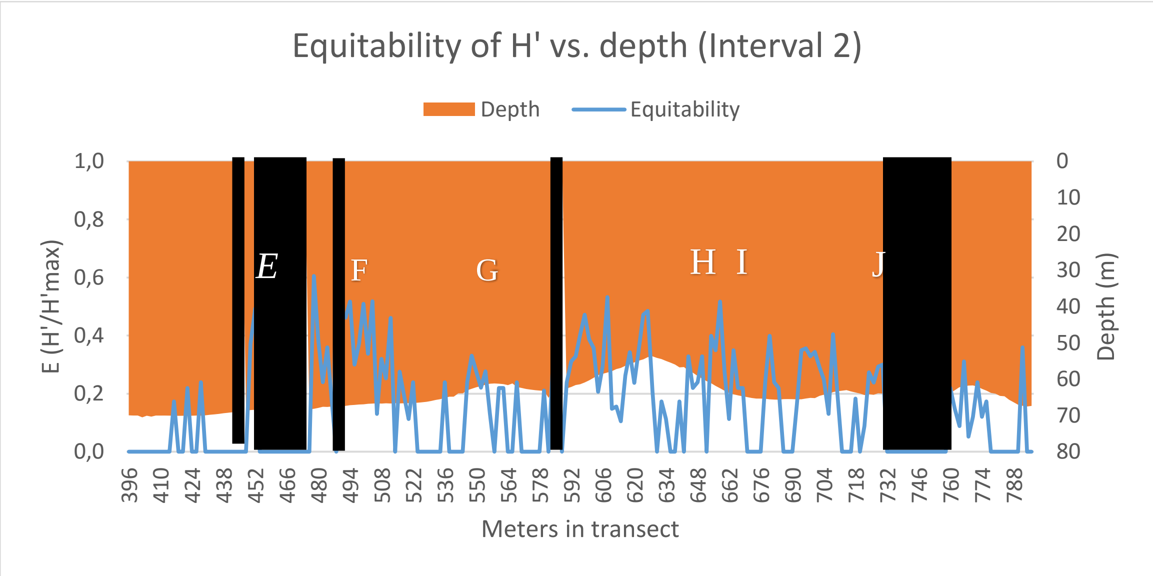

Figure 19: The second interval of total 4 intervals from the Tautra transect from the 26th of June 2015. Transect covers points E, F, G, H, I, and J in Figure 9. Direction from left to right is equal to an east to west direction on the map. Orange indicates depth and is shown in meters on the secondary y-axis. On the primary y-axis E is indicated ranging from 0 - No diversity, to 1 – perfect diversity/evenness (H' value for the data point is equal to the thought H'max for the transect). Black bars represent points with no data.

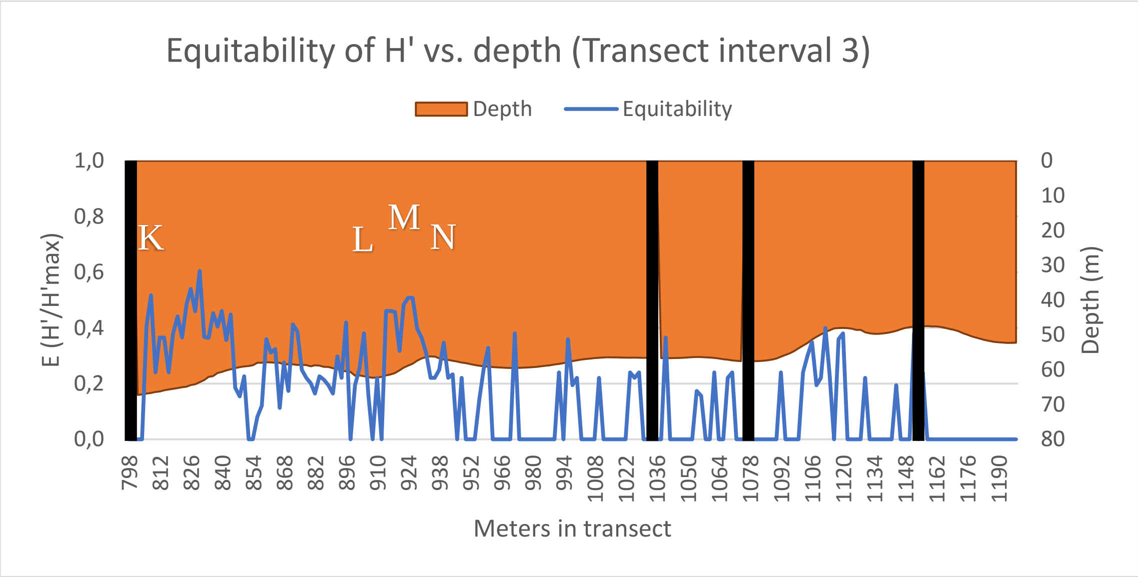

Figure 20: Third interval of the Tautra sill transect from 26th of June 2015. Interval covers points K, L, M, and N in Figure 9. Direction from left to right is equal to an east to west direction on the map. Orange indicates depth and is shown in meters on the secondary y-axis. On the primary y-axis the equitability of Shannon’s diversity index is shown ranging from 0 - No diversity, to 1 – perfect diversity/evenness (H’ value for the data point is equal to the thought H’max for the transect). Black bars represent points with no data.

In *Figure 20* the topography between 796 m to 950 m had an uneven terrain before it goes into a relatively flat area between 950 m to 1090 m. Where the terrain has the highest topographical variations in this figure, there is also shown a higher presence of diversity with E peaking on approximately 0.6 and 0.52. E lightly increased at the slope between 1090 m and 1118 m, but then it seemed to decrease again from1118 m to end of the interval.

Figure 21 shows an even slope without many sudden peaks or changes in angle from 1198 m to 1426 m. The E value around this slope shows a low to not present indication of diversity. Whereas when the topography shows a tendency to be more uneven and sharp the E value increases to a medium – high indication of diversity from 1486 m – to 1572 m.

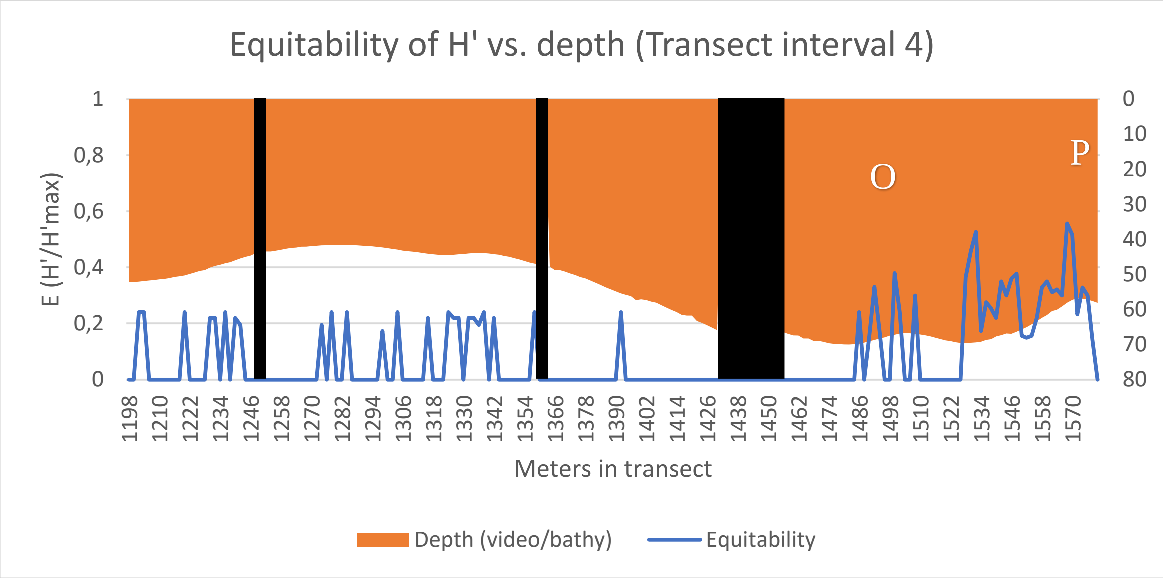

Figure 21: Last transect interval of Tautra sill transect from 26th of June 2015. Transect includes points O and P from Figure 9. Direction from left to right is equal to an east to west direction on the map. Orange indicates depth and is shown in meters on the secondary y-axis. On the primary y-axis, E is indicated ranging from 0 - No diversity, to 1 – perfect diversity/evenness (H' value for the data point is equal to the thought H'max for the transect). Black bars represent points with no data.

Tautra sill: Live *Lophelia pertusa* coverage in relation to depth

The percent live coral coverage was based on visible live coral coverage in the pictures retrieved form the video transect. In total, eight reefs was found, shown in *Figure 9*. A reef can be defined as a framework that alters sedimentation pattern and as a structure which provides a complex three dimensional habitat. It is also subject to bio-erosion and growth (Davies et al., 2008). *Reef 1* (point A to B, *Figure 9*) was 64 m long, *Reef* 2 (point C to D, *Figure 9*) was 132 m long and was the longest reef in the survey. *Reef 3* (point E to F, *Figure 5*) was the second shortest reef with a measured 27 m. *Reef 4* (point G to H, *Figure 9*) measured 64 m, *Reef 5* (point I to J, *Figure 9*) was 42 m, *Reef 6* – 44 m (point K to L, *Figure 9*). *Reef 7* (point M to N, *Figure 9*) was the shortest, measuring 19.31 m in a straight line and *Reef 8* (point O to P, *Figure 9*) was 46 m long. The reefs are numerated in following figures to indicate where they are located in the graphs.

In the first interval, shown in *Figure 22*, the first two reefs were found. *Reef 1* reached from 0 m (start) to 65 m. There is a sudden drop in live coral coverage at this point representing the space between *Reef 1* and *Reef 2*. It also represents the bottom of a possible small valley in between *Reef 1* and *Reef 2*.

Figure 23 shows *Reef 3, 4 and 5*. *Reef 3* was a small reef with a peak live coral coverage of 20%. *Reef 4* covered a small hilltop, the highest live coral coverage was a little above 60%. *Reef 5* had three peaks of 60% live coral coverage, and an overall medium-high, high coverage. *Reef 5* were situated on a plane field where there is little change in topography.

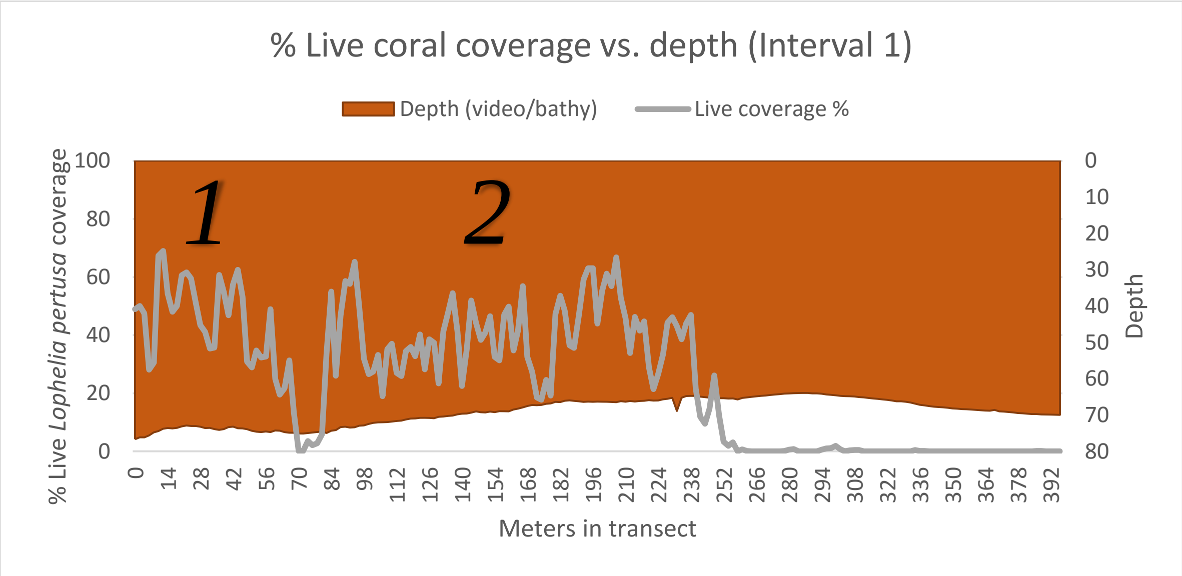

Figure 22 : First interval out of a total four intervals. Per cent live coral coverage of Lophelia pertusa at the Tautra sill survey line, 26th of June 2015. The primary y-axis indicate percent live coverage of L. pertusa ranging from 0 to 100 %. Depth is shown in orange and indicated on the secondary y-axis. X-axis indicates travel distance done by the ROV in transect. Numbers in the figure indicates Reef 1 and 2. Reef 1, corresponds with points A to B in Figure 9, Reef 2 corresponds to points C to D in the same figure.

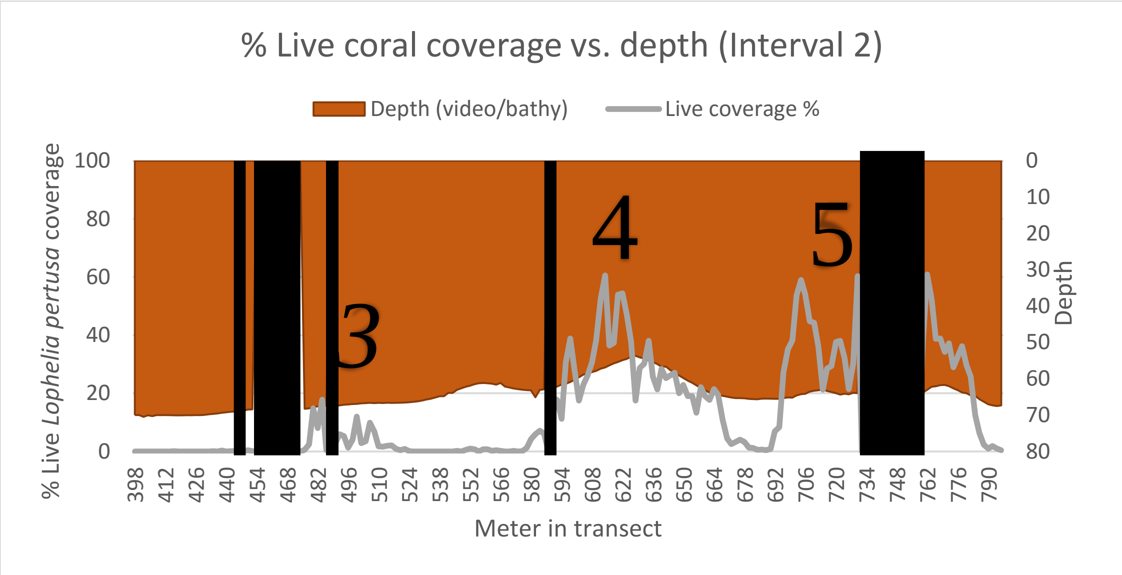

Figure 23: Second interval out of a total four intervals. Per cent live coral coverage of Lophelia pertusa at Tautra sill survey line, 26th of June 2015. The primary y-axis shows per cent live coverage of the stone coral L. pertusa ranging from 0 to 100 %. Depth is shown in orange, indicated with the secondary y-axis. X-axis indicates travel distance done by the ROV in transect. Black bars represent points with no data. Numbers in figure indicates Reef 3, 4 and 5. Reef 3 corresponds to points E to F in Figure 9, Reef 4 corresponds to points G to H and Reef 5 corresponds to points I to J.

Figure 24 shows *Reef 6* and *Reef 7*. *Reef 6* reaches from approximately 798 m to 900 m and has one of the highest peaks in live coral coverage in the transect, reaching up to around 85% coverage. It was placed on a small upwards slope and round hilltop with medium-high coverage. *Reef 7* was small with medium live coral coverage. Reef 7 was placed in a slope and stopped at a hilltop.

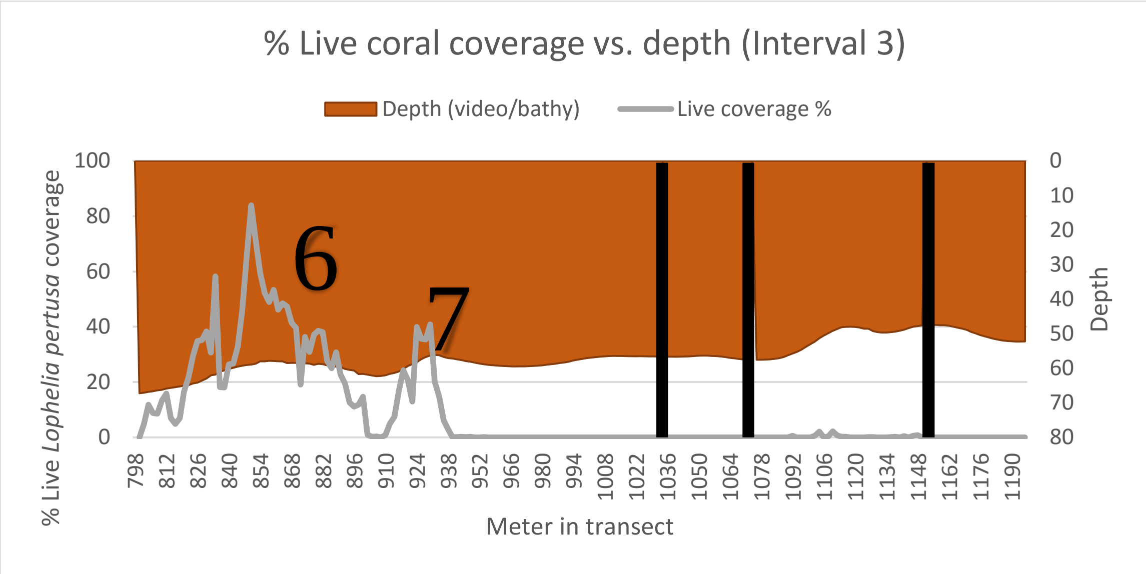

Figure 24: Third interval out of a total four intervals. Per cent live coral coverage of Lophelia pertusa at the Tautra sill survey line, 26th of June 2015. The primary y-axis shows per cent live coverage of the stone coral L. pertusa ranging from 0 to 100 %. Depth is shown in orange, indicated with the secondary y-axis. X-axis indicates travel distance done by the ROV in transect. Black bars represent points with no data. Numbers in the figure indicates Reefs 6 and 7. Reef 6 corresponds to point K to L in Figure 9, Reef 7 corresponds to points M to N in the same figure.

Figure 25 shows the last interval of the Tautra sill transect and the last observed reef in the transect line. *Reef 8* reached from 1520 m to the end of the transect line. Video indicates that there is continuous live coral cover beyond this point. The reef has a medium-to-medium-high live coral coverage with the highest peaks at just above 40% coverage. *Reef 8* was placed in a small valley and in a steep upwards slope.

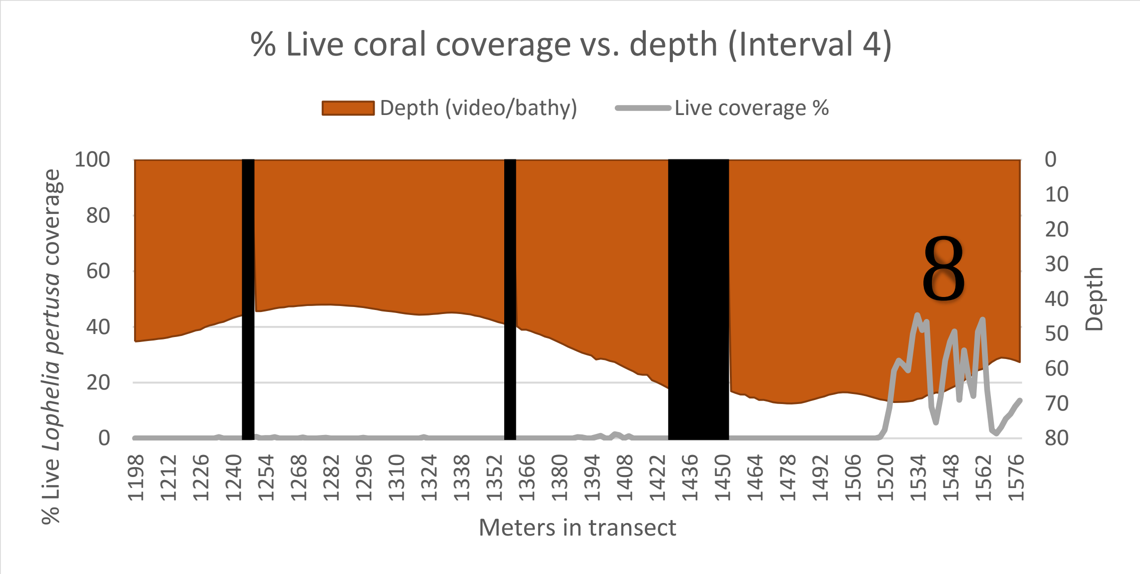

Figure 25: Fourth interval out of a total four interval. Per cent live coral coverage of Lophelia pertusa at Tautra sill survey line, 26th of June 2015. The primary y-axis shows percent live coverage of the stone coral L. pertusa ranging from 0 to 100 %. Depth is shown in orange, indicated with the secondary y-axis. X-axis indicates travel distance done by the ROV in transect. Black bars represent points with no data. The number 8 refers to Reef 8 which reaches from points O to P in Figure 9.

Tautra sill: Live coral coverage and E

A general tendency towards a higher biodiversity around the coral reefs were found throughout the transect line. Highest biodiversity were located at the beginning and the end of each coral reef where there was a medium live coral coverage, while there was lower biodiversity at the highest live coral cover peaks.

Figure 26 shows that both *Reef 1* and *Reef 2* had higher peaks in biodiversity with areas of medium live coral coverage. *Figure 27* shows the second interval of the Tautra sill transect. *Reef 3* with the lowest live coral coverage has the highest diversity overall in the whole transect. There was medium-to-medium-high E values where there was no live coral coverage and at the beginning and ends of *Reef 4 and 5*.

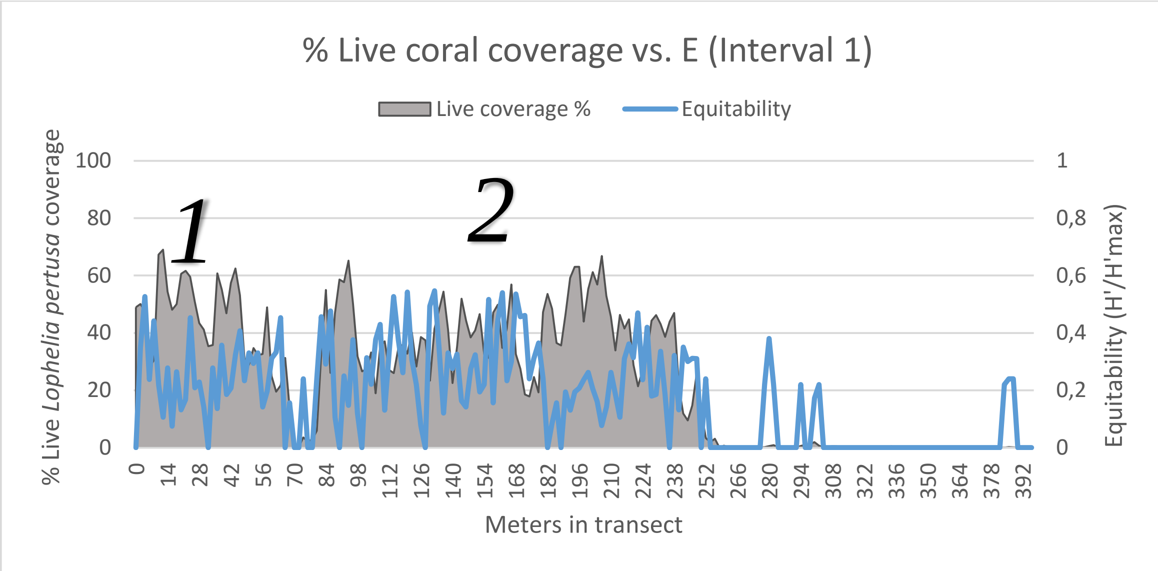

Figure 26: Tautra sill, transect meters 0 – 396 m. Per cent live L. pertusa coverage at the primary y-axis, E is indicated by the secondary y-axis. Travel distance done by the ROV shown at x-axis. Reef 1 and Reef 2 is indicated by numbers 1, and 2 in the figure.

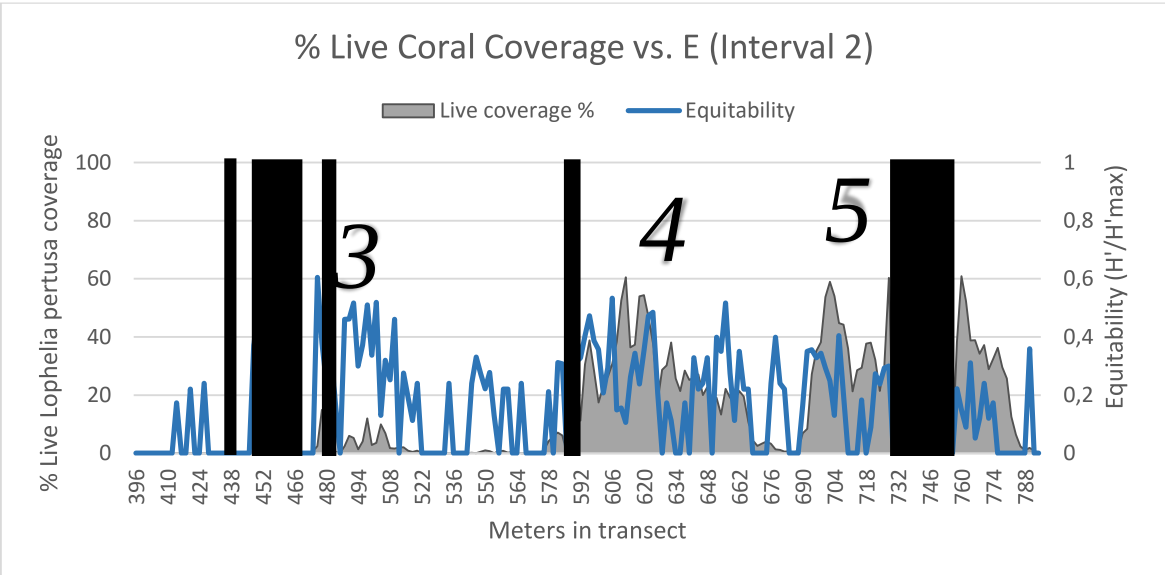

Figure 27: Tautra sill, transect meters 396 - 796m. Shows Reef 3, 4 and 5 indicated by the numbers 3, 4 and 5 in the figure. Per cent live L. pertusa coverage shown with primary y-axis, secondary y-axis indicates equitability of Shannon's diversity index. Travel distance done by ROV is shown with x-axis. Black bars indicate points with no data.

Figure 28 shows *Reef 6* and *Reef 7*. *Reef 6* had a high E value where the live coral coverage was at a level of medium-to-medium-low. There was a sudden drop in E where the live coral coverage peaked. *Reef 7* had a medium live coral coverage, but had a high diversity. Peaks of medium-high diversity continues where there is no live coral coverage. Around the 1106 m site, there was a cluster of peaks of high E values corresponding to live coral coverage of < 5%.

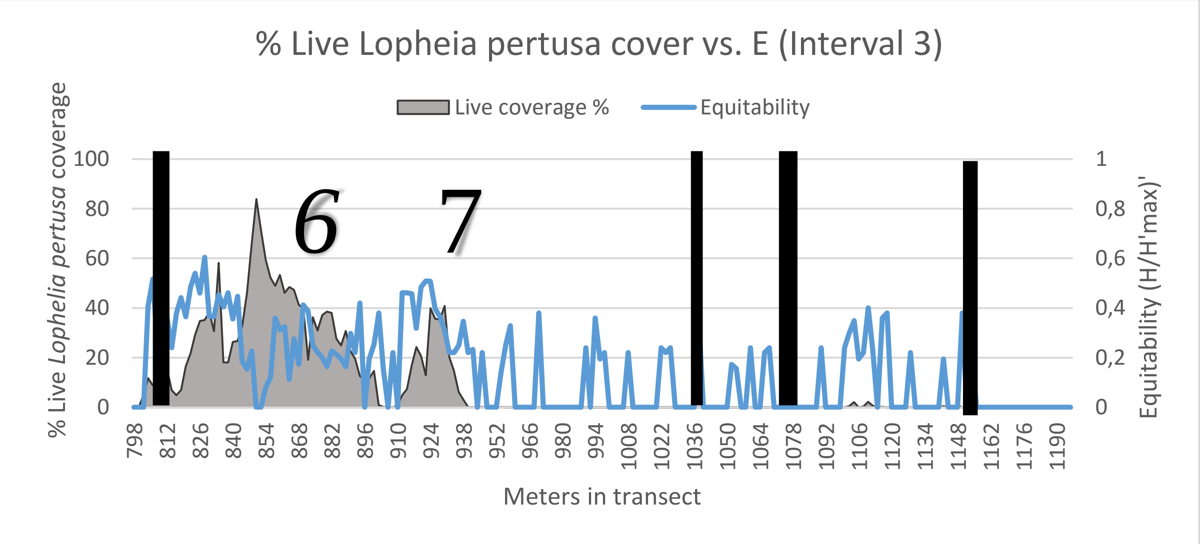

Figure 28: Tautra sill. Third interval (798 - 1196m) of a total of four intervals. Showing Reef 6 and 7. Percent live L. pertusa coverage is indicated with the primary y-axis on the left. The secondary y-axis indicates E. Meter in transect is shown with the x-axis. Black bars represent points with no data.

In *Figure 29*, the last interval of the Tautra sill transect is shown with *Reef 8.* There are peaks of medium E values through almost the whole interval, but there is more gathered diversity around the reef. *Reef 8* has a medium live coral coverage, with medium-high E.

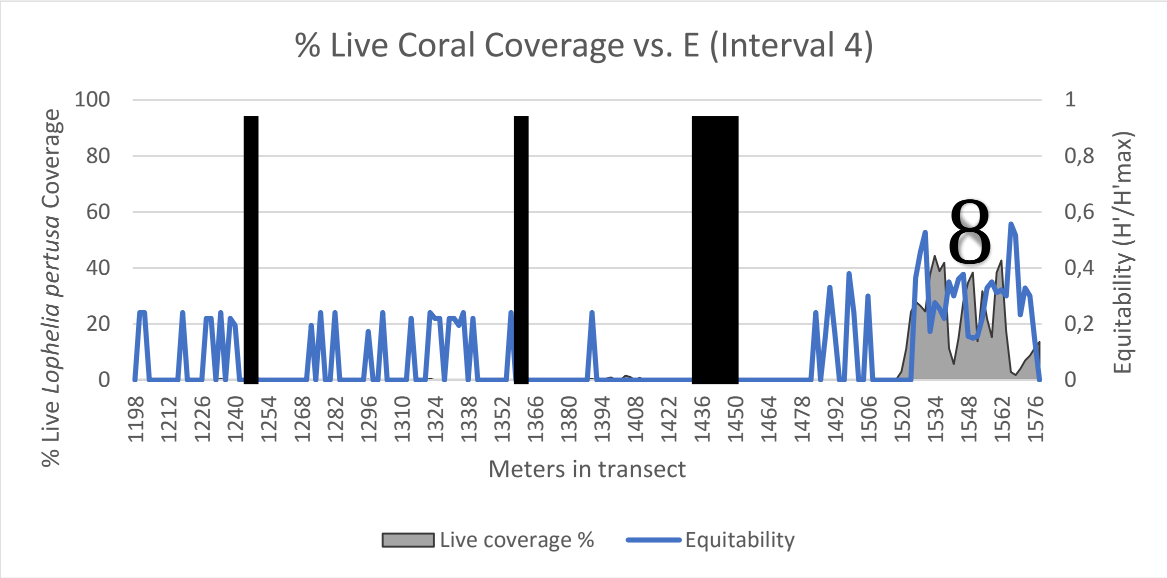

Figure 29: Fourth interval of a total of four intervals on the Tautra sill transect. Percent live L. pertusa coverage is indicated with the left, primary y-axis. The secondary y-axis to the right indicates Shannon's diversity index, H'. Meter travel distance done by the ROV is indicated with the x-axis. Black bars represent points with no data.

Tautra sill: Live *Lophelia pertusa* coverage in relation to numbers of sponges

The occurrence of sponges and live *L. pertusa* are related. Where there was located high coral cover (from 40 – 100 %) there was also found high abundances of sponge specimens (mainly between 10 and 30 individuals). Correspondingly, medium numbers of sponges (between 5 and 15 individuals) was located at sites with no coral coverage.

Figure 30 shows the first interval at the Tautra sill. The interval has a correlation coefficient between number of sponges and live *L. pertusa* cover of 0.8. It shows that there are higher peaks in number of sponges when there is a high live coral coverage.

Figure 31 shows peaks of sponge abundance where there were no or low live coral coverage. The correlation coefficient for the second interval is 0.6. *Reef 5* had the highest peak of sponges reaching between 25 and 30 individuals at live coral coverage of 60 %.

Figure 32 shows a good correlation between sponge abundance and live coral coverage in the third interval with a correlation coefficient of 0.8. The highest peak of percent live *L. pertusa* coverage (approximately 80% live coverage) and number of sponges (20 individuals) are found at the same location. There were occurrences of sponges where there was no or low coral coverage, but few peaks reaches above 15 individuals (this will be discussed later).

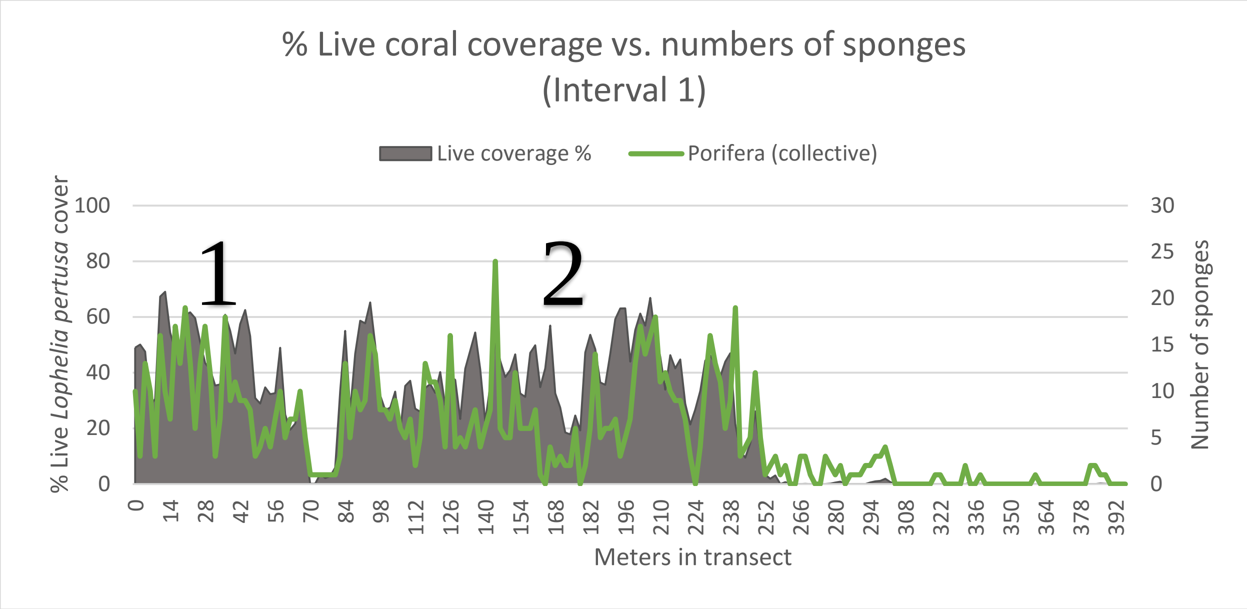

Figure 30: First interval from the Tautra sill transect. Showing Live L. pertusa coverage indicated at the primary y-axis. Numbers of individual sponges are listed on the secondary y-axis. Travel distance by the ROV is shown with the x-axis. Reef 1 and 2 are indicated with numbers in the figure.

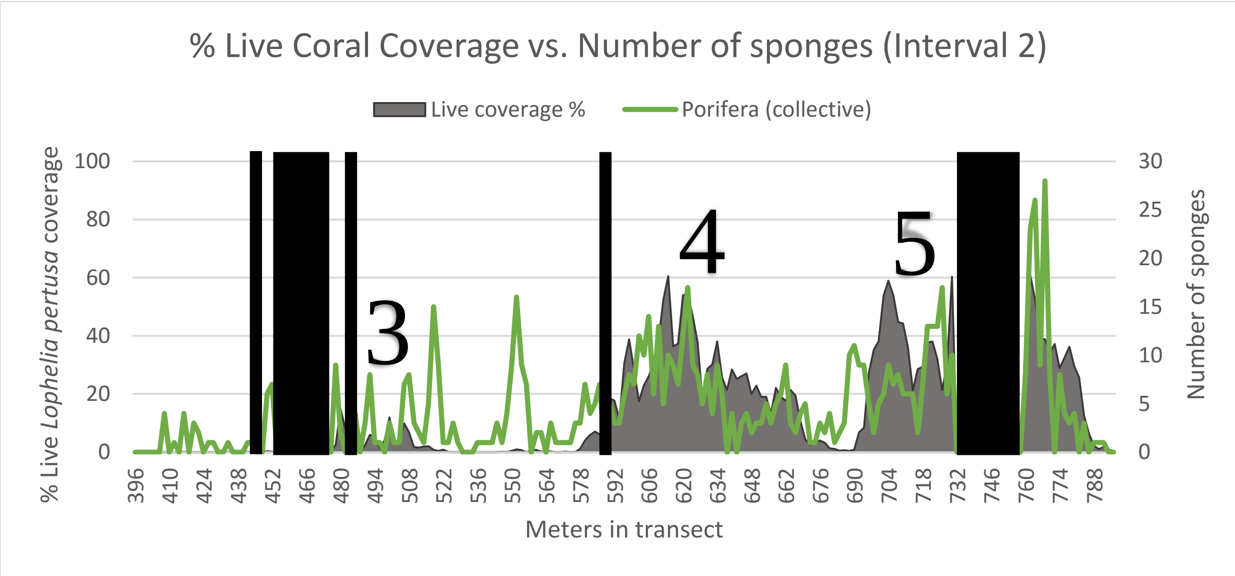

Figure 31: Second interval of the Tautra sill transect. Live L. pertusa coverage is indicated on the primary y-axis. Numbers of individual sponges are listed on the secondary y-axis. Distance by the ROV is indicated with the x-axis. Black bars represent points with no data. Reef 3, 4 and 5 is indicated with numbers in the figure.

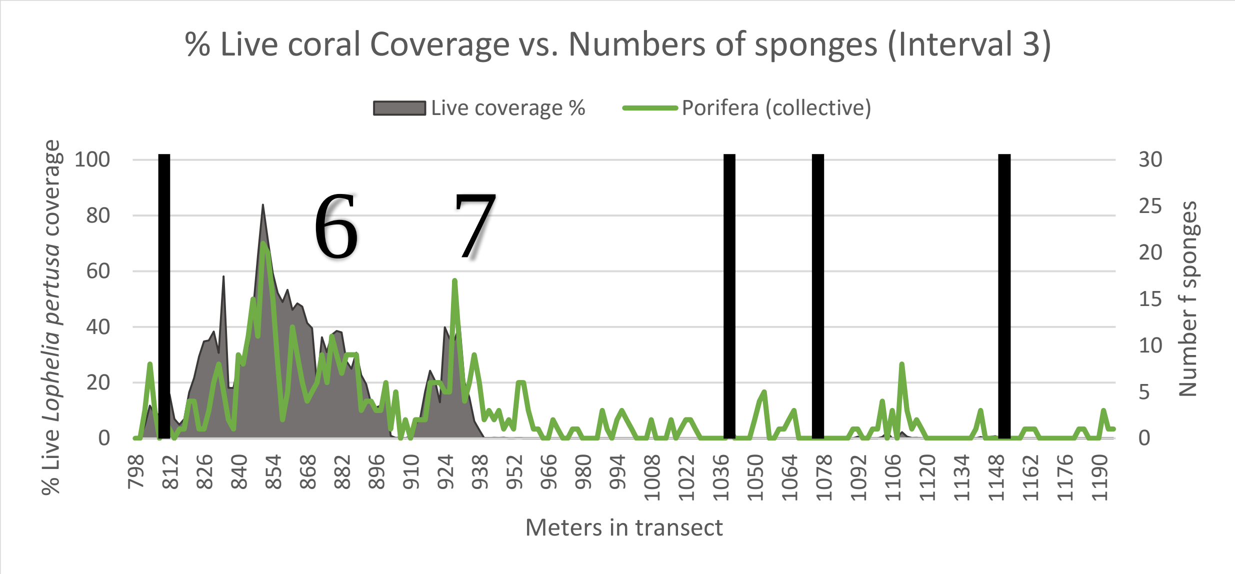

Figure 32: Third interval at the Tautra sill transect. Per cent live L. pertusa coverage is indicated with the primary y-axis. Numbers of individual sponges are listed on the secondary y-axis. Travel distance in meters done by the ROV is shown in the x-axis. Black bars represent points with no data. Reef 6 and 7 are indicated with numbers in the figure.

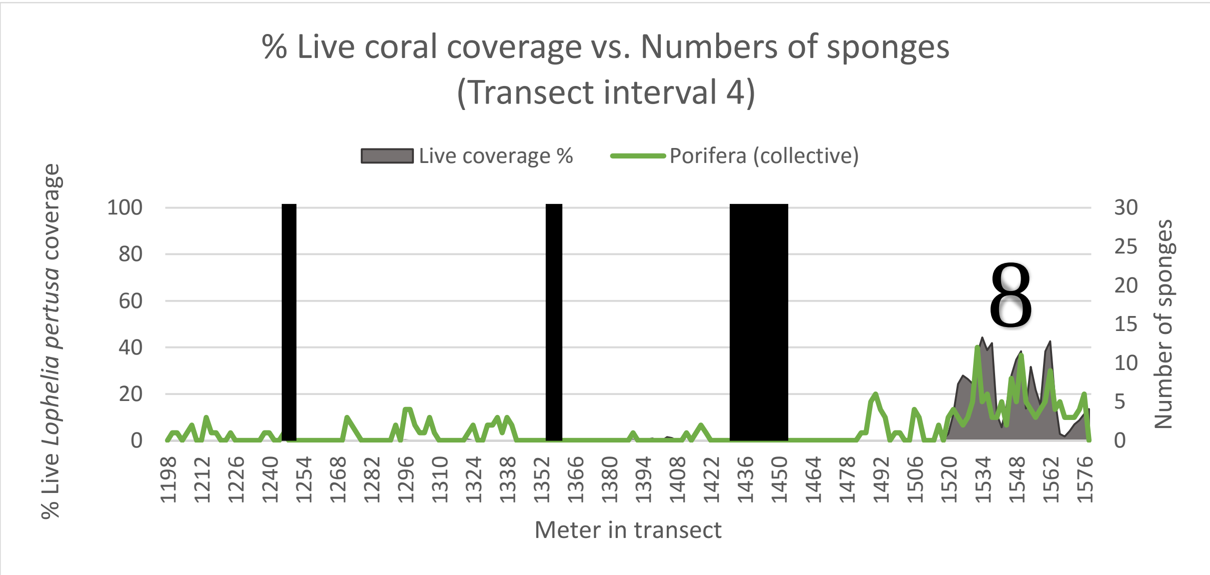

Figure 33: The last interval of the Tautra sill transect. Per cent live L. pertusa coverage is indicated with the primary y-axis. Numbers of individual sponges are indicated with the secondary y-axis. Travel distance in meters done by the ROV is indicated at the x-axis. Black bars represent points with no data. Reef 8 is indicated by number in the figure.

Figure 33 shows the last section of the Tautra sill transect. The correlation coefficient between sponges and live coral cover in this interval is 0.7. Number of sponges peaks are seen at points where there are no live coral coverage. Starting at 1478 m the number of sponges increase and reach an interval high at 1534 m and 1548 m. This is also where there is a medium-high live coral coverage.

Shannon's diversity index, H'.

Average H' for each interval and for the full transect are listed in *Table 2*. Variance (=DVARIANSP) and standard deviation (=DSTDEVP) were calculated in Microsoft Excel 2013. The variance of H' along the transect and for the four intervals are larger than half of the average value of H'. There was no protruding differences between interval H' values and H' values for the whole transect.

Table 2*: H' in interval 1, 2, 3, 4 and total H' for transect. H' max indicating highest recorded H' value in interval.*

Interval/transect length	**Average H'**	**Variance**	**Standard deviation**	**H' max**
Interval 1 (396 m)	0.8	0.58	0.34	1.58
Interval 2 (398 m)	0.82	0.58	0.33	1.75
Interval 3 (400 m)	0.87	0.57	0.32	1.75
Interval 4 (384 m)	0.77	0.51	0.26	1.61
Total transect (1578 m)	0.82	0.57	0.33	1.75

Fish associated with live coral cover

Most fishes found along the Tautra reef transect was found in association with high live *L. pertusa* cover, such as redfish and cod. In contrast ratfish and saithe was found almost exclusively in locations without any live coral cover.

Table 3 shows where the different fish species and unidentified fish were found in relation to percent live *L. pertusa* coverage. The ratfish (*Chimaera monstrosa*) was exclusively found where there were no *L. pertusa* coverage. Cod (*Gadus morhua*) were exclusively found where there was a high percent live *L. pertusa* coverage. Redfish (*Sebastes viviparus*) was found from no cover to high live *L. pertusa* coverage. Mostly at sites with medium-high coverage. Redfish was also the highest occurring fish registered through the transect. Saithe (*Pollachius virens*) was found mostly at sites with little to no live *L. pertusa* coverage. Unidentified fish specimens were mostly found at sites with no live *L. pertusa* coverage. In total were most fish registered at sites with medium to high live *L. pertusa* coverage.

Table 3: *Number of fish associated with different degrees of live* Lophelia pertusa *cover.*

Fish	**No *L. pertusa* cover (0 – 2%)**	**Low *L. pertusa* cover (2 – 25%)**	**Medium *L. pertusa* cover (25 – 40%)**	**High *L. pertusa* cover (40 – 80%)**	**Full *L. pertusa* cover (80 – 100%)**	**Total**
Chimaera mosntrosa	46					**46**
Pollachius virens	18	1				**19**
Gadus morhua				7		**7**
Sebastes viviparus	1	31	55	39		**126**
Unidentified fish	43		5	6		**54**
Total	**108**	**32**	**60**	**52**	**0**	**252**

Live *L. pertusa* gradient

Figures 34 to 38 shows an illustration of varying degrees of live *L. pertusa* coverage ranging from 0 – 80 %. Since 80% was the highest registered live *L. pertusa* coverage there is not depicted any illustration of higher cover.

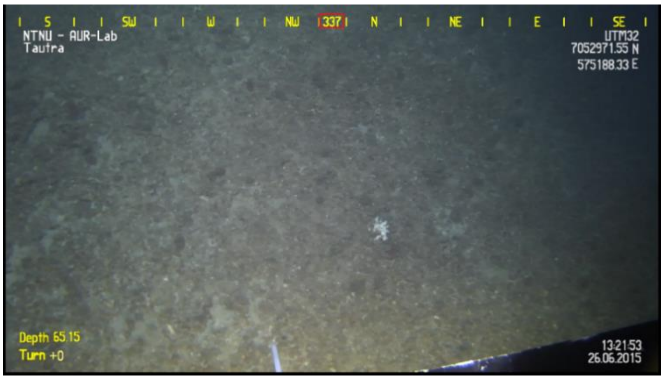

Figure 34: Illustration of No (0%) live Lophelia pertusa cover.

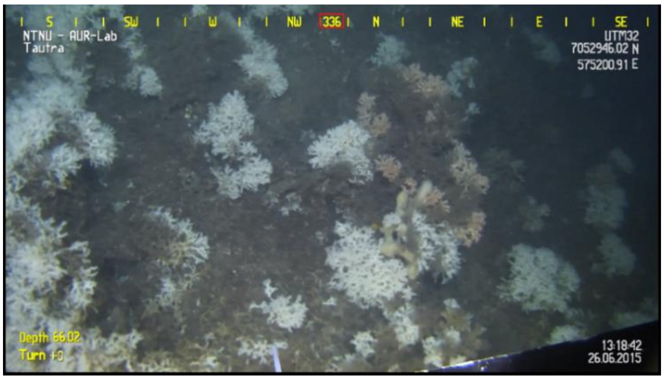

Figure 35: Illustration of Low (20%) live Lophelia pertusa cover.

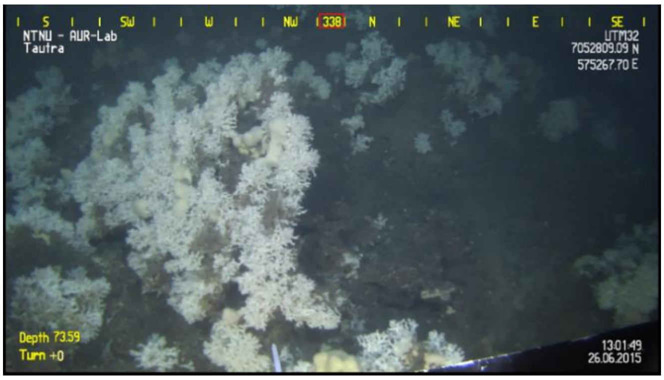

Figure 36: Illustration of medium (40%) live Lophelia pertusa cover.

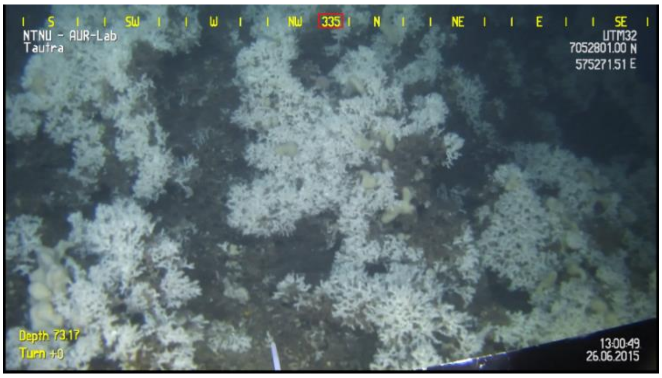

Figure 37: Illustration of high (60%) live Lophelia pertusa cover.

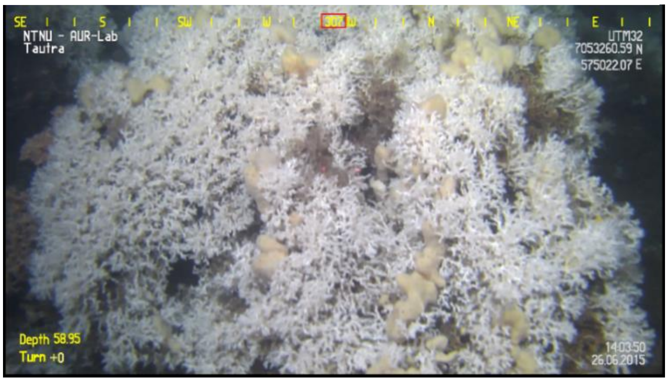

Figure 38: Illustration of full (80%) live Lophelia pertusa cover.

Discussion:

The way the MBES and video were combined provided large amounts of data in a short amount of time. The spatial resolution and level of information taken from the non-invasive techniques, which MBES and video, is of high detail (spatial resolution). As far as I am aware, this may be one of the most detailed surveys of a cold-water coral reef from a transect of this extent provided by the use of non-invasive techniques. The main findings based on data analysed suggests a high correlation between sponges and live *Lophelia pertusa* cover, as well as between megafauna biodiversity and live coral cover. By using digital terrain models, video surveys were placed in relation to the topography of the seafloor. This provided a new level of easily obtainable information from the data of how the corals were located in relation to the seabed. Based on these findings, it is suggested here that MBES data visualized with programmes such as NM4 to create digital terrain models, will better the process of finding areas of interest highly. The way biodiversity was registered mainly applied to megafauna. The spatial resolution was of a high level of detail with 2 m spatial resolution. A steady altitude and speed of the instrument carrying ROV, in addition to a closer altitude than 2 m above the seafloor will further improve specimen registration through video transects. Although providing a high level of detail, a 2m spatial resolution is highly time demanding in regards to data processing and analysis. To improve time efficiency of data processing, an 8 m resolution (or even a 16 m resolution), could be sufficient to further improve the process of seabed mapping and surveying.

Live *Lophelia pertusa* coverage

L. pertusa was found in slopes on the sides of topographic highpoints. The slopes could be interpreted as valley sides that could provide good current flow-through, providing favourable food and living conditions for the coral. I found no studies categorizing the percent coverage as I have done in this survey. Many used comparisons of changes in percent live coral coverage to get an overall view and indication of changes through time. The change in live coral cover can be used as grounds for monitoring and environmental management can be based on the knowledge of and from these changes (Li et al., 2015, Nava et al., 2014, Lescinsky et al., 2012).

As well as live coral cover, at certain locations along the Tautra sill in areas with low or no taxa biodiversity, biofilm on the seabed was in many cases recorded. The recording of biofilm and absence of live coral coverage can suggest that these areas are shielded from heavy current conditions allowing sedimentation in the area, causing sedimentation stress (Li et al., 2015). The same area shows a part of the transect with a generally lower biodiversity at the foot of the wide topographical highpoint mostly known as Selligrunnen, shown between points N and O in *Figure 9*. This could be explained by the fact that many sessile benthic organisms rely on hard substrata to colonize areas (Nava et al., 2014, Kuklinski, 2013, Kutti et al., 2013). When there is a weaker deep-water current allowing for sedimentation, the mortality rate for certain benthic fauna might increase and it could also inhibit new colonization of the area (Kuklinski, 2013). When there in addition is no coral rubble or dead coral blocks, there is no place for sessile fauna dependent on hard substrata to settle.

Bioturbation

There were indications of infaunal activity in the sediment at certain locations, an example is shown with *Figure 39* below. Circles indicates areas where there a signs of possible infaunal activity. Visual surveys have previously recorded fauna and their effect on sediments (Hughes et al., 1993, Robert and Juniper, 2012) swiping the seafloor for food by bioturbation. Fauna feeding through bioturbation can be both infauna and epi-benthic fauna such as echiurians and echinoderms as well as certain types of fish (Robert and Juniper, 2012). This makes identification uncertain in this case as only indications of bioturbation was registered and no specimens. Signs of bioturbation may indicate healthy, non-contaminated sediment as organisms performing bioturbation tend to avoid sites contaminated (Remaili et al., 2016).

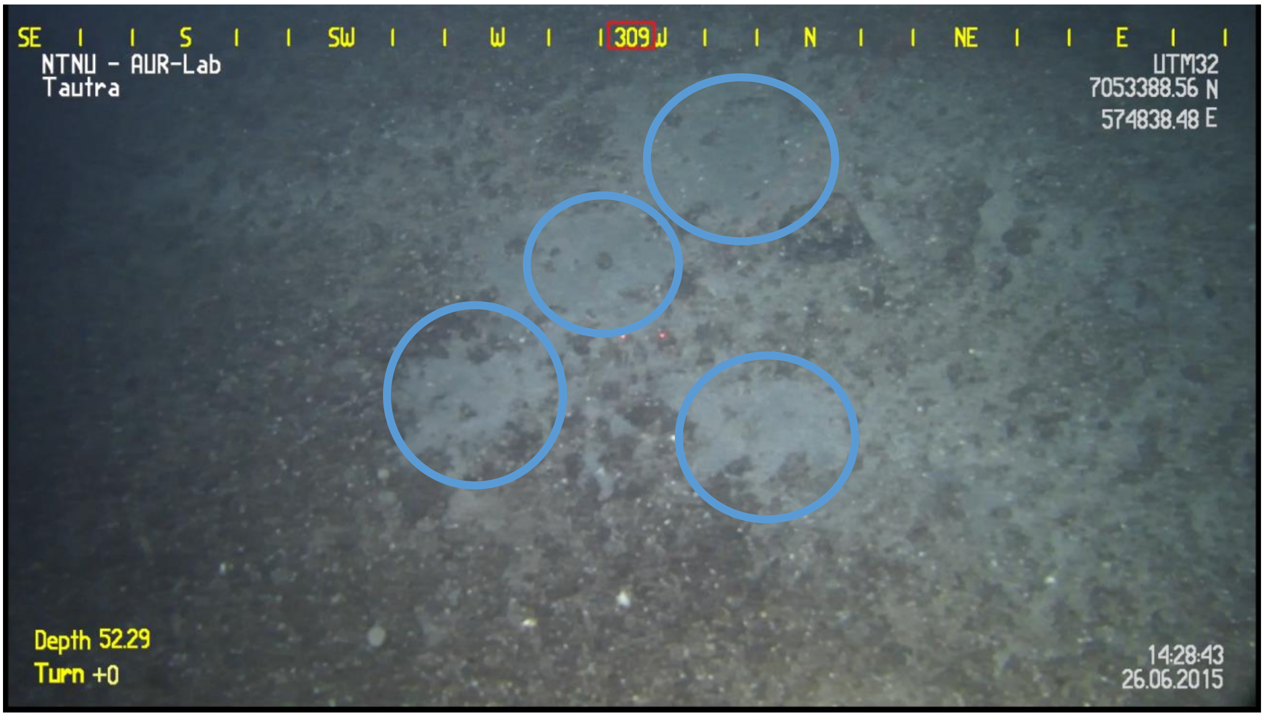

Figure 349: Image from video survey performed at the Tautra sill on the 26th of June, 2015. Blue circles indicates signs of bioturbation showing clean soft bottom areas dominated by marine clay/silt, dark matter on sediment are considered as biofilm.

Biodiversity along the Tautra sill transect.

The survey at the Tautra sill found that there are tendencies toward diversity being higher in the beginning and ends of the reefs, rather than in the "middle" of the reefs where there is a high live *L. pertusa* coverage. This is reasonable as much of the fauna registered in relation to *L. pertusa* reefs are found in relation to dead coral blocks and rubble, located in between the structures, and mostly not in direct relation to live coral coverage.

The biodiversity measured at the Tautra sill are strictly applicable to the megafauna recorded and registered through visual survey with ROV video. At some points, the still image would be too blurry. The only way to identify specimens would then be by use of video to get a prolonged look from different angles and a more 3-dimensonal view. It was discovered that the redfish and certain other species were to a degree conspicuous when put in direct light, they could become quite cryptic and inconspicuous once it was located in the periphery of the visual range, outside the light source. By using video, in addition to still images, movement was discovered and a closer look could be taken to identify cryptic specimen, which would not have been found by using still images only.

Because only megafauna was recorded from video, it can imply that a different result might have been found if macro-, meio- and microfauna was observed and registered as well. Much of the smaller fauna associated with coral reefs may also be found in relation to sponges living inside and on the 3-dimensional structures (Kazanidis et al., 2016). This makes it hard to observe them by video, and physical sampling to gain full knowledge about present species is recommended as an addition to visual ground truthing methods such as video.

The Shannon diversity index and equitability was chosen to illustrate how biodiversity may vary along a transect such as the one from the Tautra sill. The index was chosen on the basis of its common usage in biodiversity research and its practicality (Loiseau and Gaertner, 2015) In *Figures 26, 27, 28 and 29*, it is visible that the main diversity is located around the coral reefs. There are however located biodiversity peaks at locations with no coral coverage. The taxon groups mainly found at these peaks were unidentified sea stars (asteroideans), sea urchins, and fish. What is being made evident from *Results* depicting [E vs. depth] and [E vs. % Live *Lophelia pertusa* cover], is that the biodiversity has a high variation along a transect depending on topography and live coral cover. This also becomes evident when looking at the variation and standard deviation of H’ and E for the whole transect. Average values for the whole transect was calculated to be H’ = 0.82 (standard deviation = 0.33, variance = 0.57, maximum value = 1.75) and E = 0.28 (standard deviation = 0.11, variance = 0.01, maximum value = 0.61). This can be discussed as being a medium - low diversity considering that H’ values usually ranges between 1.5 and 5. By using E as an indicator of how close the biodiversity is to a thought H’ maximum for the transect it supports the notion of the biodiversity of being of medium – low nature. A drawback with the Shannon index is how its unsuited for comparing between transects (Loiseau et al., 2016) as different transect widths and lengths may influence H’ and H’max. How the ROV altitude and visual range may affect this is discussed below.

Sponges

Sponges had high correlation with live coral cover as shown in results and with the given correlation coefficients (Pearson’s correlation coefficient) of the first, second, third and fourth interval with 0.8, 0.6, 0.8 and 0.7 respectively. Other findings have found sponges in association with dead coral rubble, but also in between live corals (Purser et al., 2013, Huvenne et al., 2005, Roberts et al., 2008). *Geodia spp.*, *Mycale lingua* and axinellids was mainly found as the main groups of sponges identifiable on the Tautra sill. Since many sponges remained unidentified to species or genus, the diversity of sponges on the Tautra sill may most likely be larger than suggested here (Buhl-Mortensen and Buhl-Mortensen, 2014). Many sponges may require microscopic identification from physical samples (Moen and Svensen, 2014). Sponges has been found to dominate many benthic fauna communities in Norwegian waters, e.g. in the Barents sea (Jorgensen et al., 2015) or at larger *L. pertusa* reefs along the Norwegian continental shelf such as the Træna reef or Sula reef (Purser et al., 2013). In other Norwegian fjords such as the Hardangerfjord large occurrences of *Geodia* spp. and *Mycale lingua*, which belongs in the class Demospongiae, has been found as characteristic taxa in relation to *L. pertusa* reefs (Buhl-Mortensen and Buhl-Mortensen, 2014).

Because the Tautra sill is located at relatively shallow depths compared to the bottom of the basins in the Trondheimsfjord, sponges located at Tautra sill can be thought to endure certain environmental stress variables which comes with being located closer to the surface. These variables may be increased eutrophication from terrestrial river outflow and agricultural activity, increased sedimentation or temperature fluctuations. Sponges found at Tautra sill identified to genus has previously been found in both shallow and deep waters (Van Soest and De Voogd, 2015) which might explain favourable conditions over the Tautra sill. As previously explained, the current conditions must be able to sustain the coral reefs in order for them to feed. In likeness with *L. pertusa*, sponges are filter feeders feeding on plankton and particles carried with the water current (Moen and Svensen, 2014) over the sill.

Fish

Fish associated with CWC reefs has been found in higher correlation with coral rubble, than with live coral coverage (Soeffker et al., 2011) which is coherent with observations of fish during the surveys performed at Tautra, where most fish were found in between coral blocks or adjacent to reefs. During video analysis, it was observed that while there seemed to be little or no reaction from redfish, the cod and saithe seemed to move in the periphery of the visual range or move directly away from the light emitted. Ratfish was observed to follow the vehicle and keep within the light range before swimming away. Different fish species has been shown to have different responses to an approaching underwater vehicle, some are drawn to the light, while others, such as the cod avoids it (Stoner et al., 2008) which was also found in this survey, although it was not a main focus. Many commercial fish stocks are found in and around CWC reefs using the 3-dimensional structure provided by the corals or sponges as habitat for spawning, feeding or just plain hiding (Costello et al., 2005). Because of this, a knowledge about the importance of CWC as a habitat in a marine benthic environment is a necessary tool to avoid a possible destruction of a key factor in the life cycle of many benthic organisms and commercial fish species (Armstrong et al., 2014). In *Table 3*, most redfish was found in relation to live coral coverage and has previously been spotted eating crustaceans located in dead coral blocks (Costello et al., 2005).

Data acquisition/performing a survey

The importance of timing when performing a video survey with ROV became evident during the cruise both on the 19th of May in the Beitstadfjord and on the 25th of June at the Tautra sill. Due to strong tidal currents, the ROV was forced to travel at a faster speed than optimal and certain parts of the video had as a result a lowered quality. This made it hard to identify specimens. The Tautra sill survey on the 25th of June had to be cancelled.

On the 25th of May it was planned to perform transects in Skarnsundet in addition to the Hoøyskjæret survey. Because MBES data had to be acquired at Hoøygrunnen after the video survey, a change in tide occurred because of time usage. This lead to the currents in Skarnsundet being too strong for the ROV to perform the planned transect lines. It was decided that it was not a priority to survey Skarnsundet and that the Høyskjæret data would be sufficient for the purpose of this thesis. As seen in *Figure 10*, the trackline for the ROV seems to jump, pointing to a possible error in the USBL or DP system locating the ROV geographically. Coral occurrence points in the DTM from Hoøyskjæret (shown in *Figure 11*) were plotted where the ROV trackline were seemingly without disturbances (sudden jumps in trackline) to get as precise geolocalization as possible. Based on this, it is suggested that a priority list of areas of interest may be of value in order to get certain wanted data from a survey within a set time schedule.

The challenge with timing related to tidal currents also occurred at the Tautra sill on the 25th of May. Although the survey route and procedure was pre-planned, technical issues lead to a late deployment of the ROV. Because of the late deployment, the tidal currents over the Tautra sill had become very strong. The current ended up being too strong to complete a planned "lawn-mower" transect box of 20m x 10. The transect lines had to be cancelled. Some of the data may still have been used if it hadn't been for technical issues such as issues leading to the freezing of the time-stamp in the video text overlay. Because of a frozen time-stamp, there was no way of knowing when the video took place in time. Without any knowledge of when the videos was recorded, it became an impossible job to link the video with the time information on the track-file for the ROV well enough to get an accurate result. The data ended up being discarded.

Beitstadfjord – Hoøyskjæret

Based on where the corals were found at the Hoøyskjæret, it is assumed that good current conditions are present along the steep elevations. Based on the coral sand and rubble, it can be speculated that there might be unidentified areas with *L. pertusa* at shallow depths on the location not yet discovered. Large, white structures were found at the western edge of Hoøyskjæret, which looked similar to a *L. pertusa* reef and it could be a possible object of interest for future surveys to re-visit.

General areas of interest suggested for further inspection are circled in yellow in *Figure 42* and are based around the western side of the Hoøyskjæret. A discussion came up whether or not the observed *L. pertusa* at 36 and 37 m depth shown in *Figure 40* and *41*, are actually *L. pertusa* or the serpulid *Filograna impluxa* (Berkley, 1835, (Artsdatabanken)). It could be a mixture of *L. pertusa* and the suggested serpulid, as the *Filograna* are commonly found at such depths as 35 m and below, but this is not evidently clear from the video footage from the survey performed on the 19th of May 2015. Despite this uncertainty, I suggested that the observed specimen found at Hoøyskjæret at 37 m depth most likely are *L. pertusa*, but that a more thorough investigation of this is recommended and thought of as advantageous.

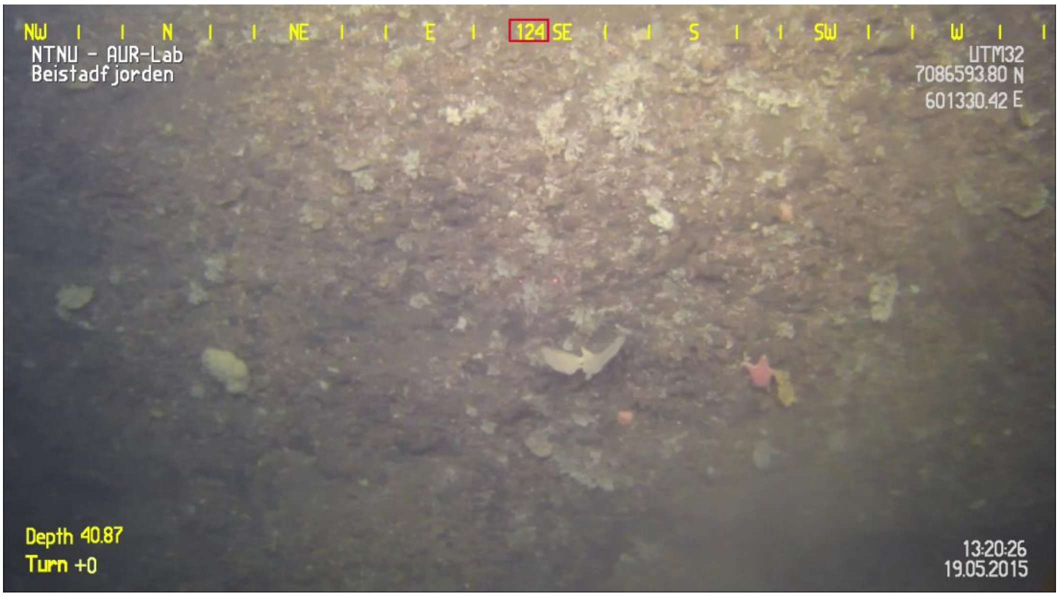

Figure 40: Image from the video transect performed at Hoøyskjæret in Beitstadfjorden. The picture illustrates what was registered as coral rubble, assumed to be from *Lophelia pertusa*, at 41 m depth.

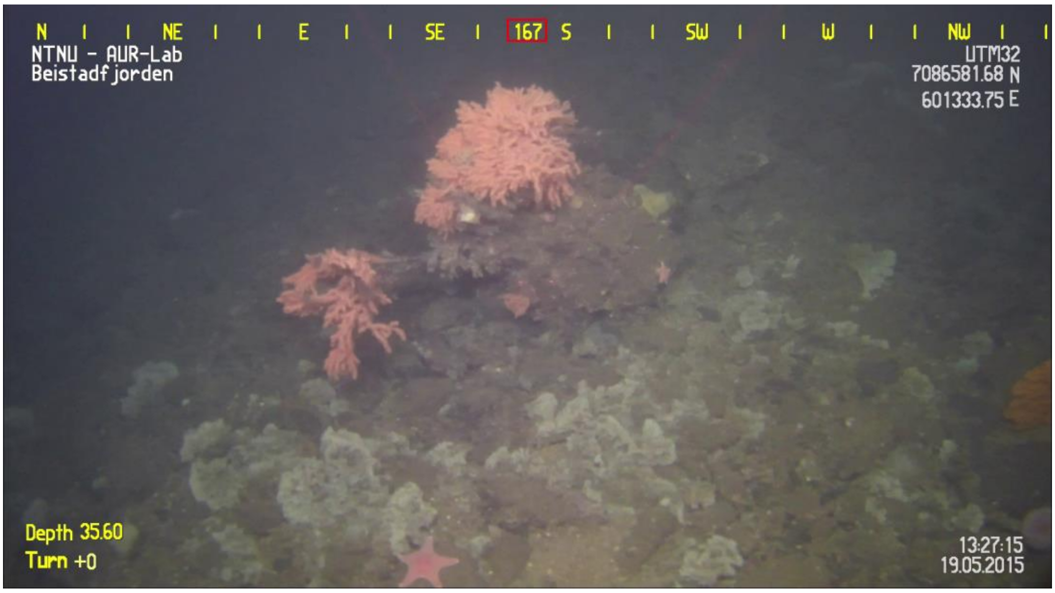

Figure 41: Image from shallowest recorded Lophelia pertusa occurrence at Hoøyskjæret in Beitstadfjorden. *Primnoa resedaeformis* is seen as well resting on a hard substrate block in the middle of the image.

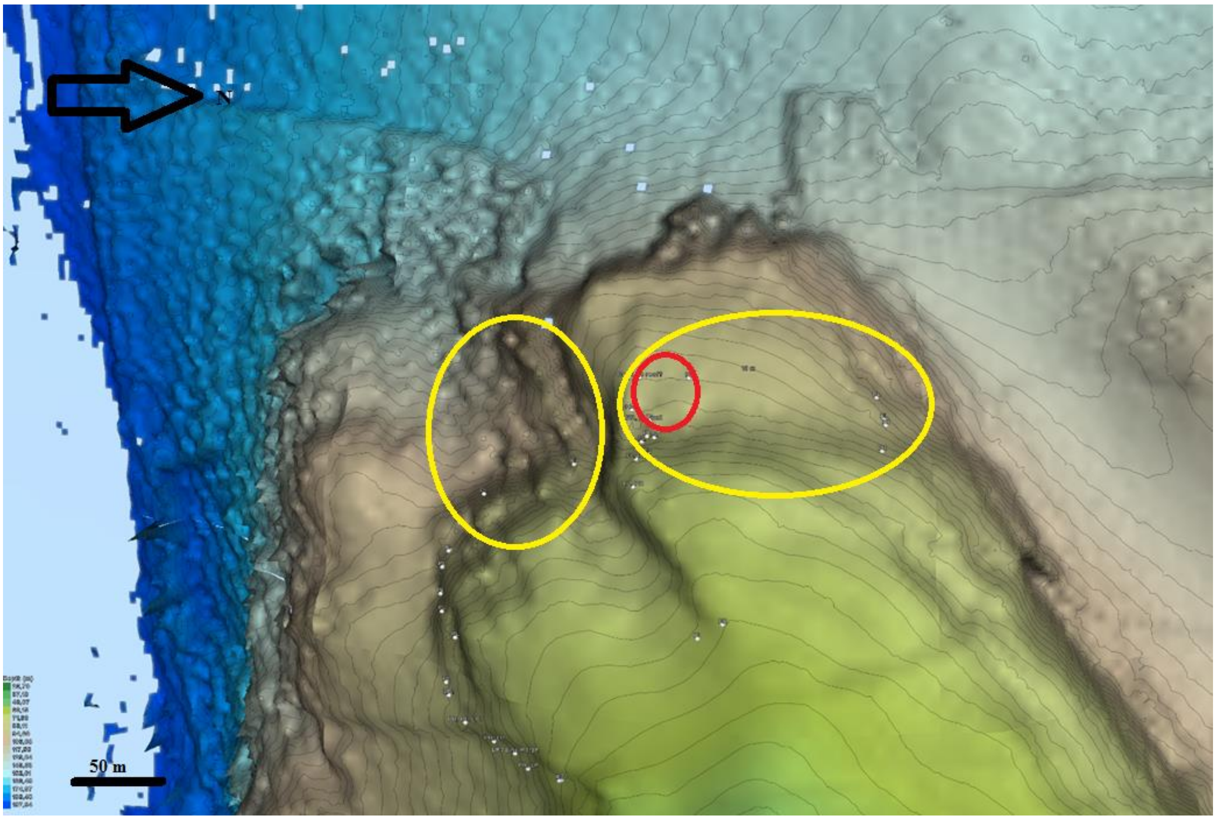

Figure 42: Digital terrain model depicting western end of Hoøyskjæret. Yellow circles indicates areas of interest for further investigation, while the red circle indicates where a thought *Lophelia pertusa* reef may be located based on video survey. Line in lower left corner indicates 50 m length. The arrow in upper left corner indicates northward direction. Green is equal to approximately 35 – 40 m depth, contour lines indicates a depth interval of 2 m.

Analysing data

Time spent processing and analysing data was considerable (approximately 240 working hours). All together producing the data behind the figures shown in [*Results*], have taken about a month's worth of time and a more efficient way of extracting these data should be used when performing a survey with this amount of detail with analysing every second meter in travel distance. *Table 4* shows how changing the spatial resolution may affect E values for the first interval. By having a 2 m spatial resolution it is shown that both variance and standard deviation is lowered as well as a higher average of E values. If the main goal is to gain a general knowledge of an area, having a coarser spatial resolution will be more efficient and give a still adequate image of the diversity of the transect. Based on the numbers in *Table 4*, I recommend either an 8 m or 16 m spatial resolution in order to save time, but a 2 m spatial resolution may portray a much better picture of the biodiversity and have less variance in data.

The data analysis for Hoøygrunnen required a day of work (8 hours) to finish as the only interest was to locate where live corals were to be found, and no other species or live coral coverage registration was done. The information did, even though it was not as a long and complex analysis process, give a good picture of where live coral and what kind of corals were to be found and also locate where areas of interest for future surveys was placed.

Table 4*: E values for the spatial resolutions of 2, 8, 16 and 32 m. The values are calculated based on the first interval of the Tautra sill transect from 0 to 384 m.*

Spatial resolution	**2 m**	**8 m**	**16 m**	**32 m**
Average	0.28	0.17	0.14	0.14
Standard deviation	0.12	0.17	0.15	0.17
Variance	0.34	0.41	0.39	0.42
Max value	0.55	0.54	0.45	0.45

ROV movement and video and image analysis

To be able to identify specimens in both transects, a combination of video and still images was used. As the ROV was caught by the current, the picture would move too quickly in the video. In these situations still images would be the best option to use. The video could be slowed down in these cases, but experience showed that still images worked best for these situations.

Although using ROV is considered a suitable method for investigating hard bottom substrates below depth reachable for scuba-divers (Katsanevakis et al., 2012) it is not without challenges. It was evident from video that strong currents did not only move the ROV forwards but also made speedy elevations of the ROV. This made the altitude above the seafloor more than 2 meters at many points. The altitude of the ROV has an effect on how much area are covered by image. Ideally, the ROV would have a constant altitude above the seafloor throughout the transect, but this did not happen. The changing diversity could be a result of varying visual range in the video image with different altitudes of the ROV. At the same time as altitude increases and visual range becomes larger, details are lost as they become too small to identify properly. The altitude above the seafloor will therefore be a compromise between visual range and level of detail. Because the Shannon index is sensitive to changes in transect length and width (Loiseau et al., 2016) it is all the more important to keep a steady altitude above the seafloor throughout the transect.

Because the ROV moved in a 3-dimensional space, the travel distance sometimes made an overlapping picture, leading to a higher coverage of the transect than an image for every second meter. Some regards were taken to this as data points too close in time or with an obvious overlap were discarded from the dataset. The way an obvious overlap was discovered was through video when the ROV would move slowly and certain reference points in the pictures would not have moved a certain distance in or out of the frame.

Concluding remarks

- The combination of two non-invasive methods such as multibeam echo sounding and video mounted on an instrument-carrying ROV may provide large amounts of biological information of varying themes, which will help to gain a good cornerstone knowledge of an area.
- Based on acoustic and optical surveys new areas of interest can be suggested, and a method for strategical seafloor mapping and management may be provided based on further work with the methods I have used.
- NaviModel4 as a tool of visualization of data provides a dimension to habitat mapping that increases efficiency in gaining a three-dimensional topographic understanding of the seabed in relation to coral occurrence.
- A steady altitude, good lighting covering visual range (400 – 700 nm) at a close range (less than 2 m altitude) is crucial for good video image quality.
- ROV surveys should be timed in accordance to tidal currents as to avoid struggle with manoeuvring.
- A spatial resolution of 2 m intervals for image analysis is highly time consuming, with data processing, extraction and analysis taking about 240 hours. The workload should be divided between several people or the spatial resolution should be made larger, e.g. 8 m or 16 m intervals.
- Sponges are highly correlated with presence of *Lophelia pertusa* in the Trondheimsfjord and almost found exclusively in and around live coral or dead coral blocks.
- *Lophelia pertusa* shows a placement pattern to be located in slopes enabling good current conditions.
- Species diversity in regards to megafauna varies highly along a transect. One index value for the whole transect may give the wrong image of actual conditions on the seafloor.
- Species diversity, in regards to megafauna, was mainly located around live coral coverage on the Tautra sill.

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