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SO FACULTY OF BIOSCIENCES, FISHERIES AND ECONOMICS
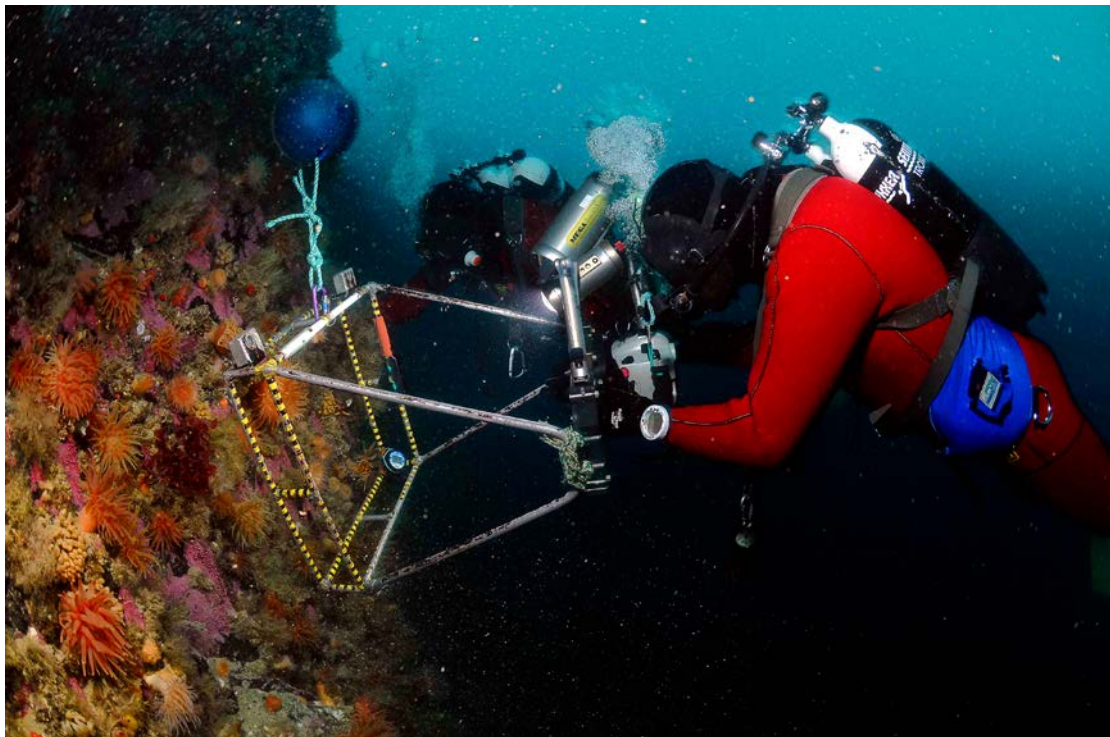DEPARTMENT OF ARCTIC AND MARINE BIOLOGY

Temporal and spatial variation in a high Arctic bedrock macrobenthic community in Hinlopen, Svalbard

- A baseline study related to possible climatic change

Carl Ballantine

BIO-3950 Master`s thesis in Biology

Field of study- Marine Ecology and Resource Biology

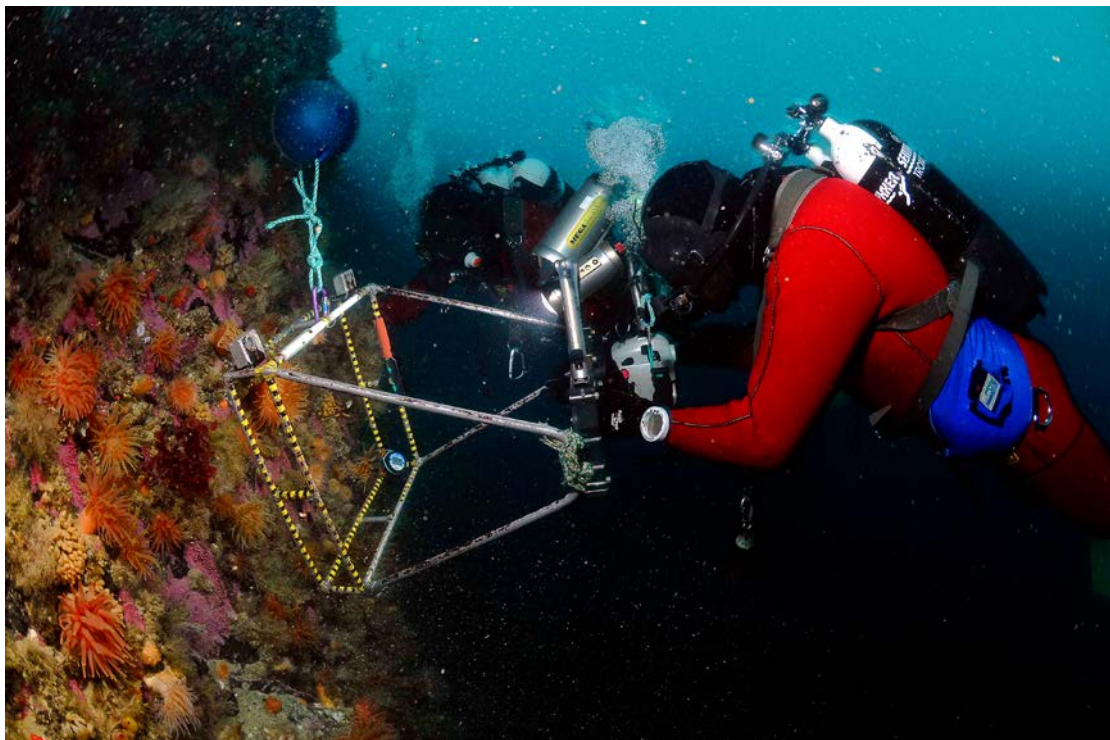Research group- Arctic Marine system ecology

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Abstract

Zonation patterns within a high Arctic, hard bottom community within the Hinlopen Strait, Svalbard were investigated using image analysis of underwater photoquadrates. This long term study consists of depth transects taken over a six year period were on a sublittoral vertical wall permanent monitoring station. Analysis indicated that the depth in which the greatest number of species occurred increased from 15m down to 30-35m throughout the study. Zonation patterns were indeed present within the Arctic sublittoral community in two distinct subzones; infralittoral and circalittoral. The circalittoral subzone can be divided further into an upper and lower zonation pattern due to the presence of depth related organisms such as the mollusc *Chlamys islandica*, the cnidarian *Capnella glomeratum*, and the echinoderms *Gorgonocephalus* spp, Henricia spp and *Pteraster* spp. Depth and total sea ice cover were tested as predictors for the variation in community structure between years. All together the two environmental parameters accounted for 26% of the variation. Depth explained the greatest proportion of variation within the community structure between years.

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Introduction

Marine macrobenthic organisms (organisms > 1mm) are often long lived leading a sessile or reduced motility life style when adults, making them ideal indicators of long term change and therefore perfect for long term studies (Beuchel et al. 2006, Kortsch 2010).

Petersen and his co-workers, over 100 years ago (Benson 2002), established that boreal macrobenthic community structure (species composition, abundance) varies with depth, giving a zonation in the vertical distribution of species. This zonation is primarily attributed to differences within the physical environment (variation in factors such as water temperature, salinity, desiccation, water currents, sediment composition, angle of substrate, wave action, light attenuation, and in the arctic- ice scour) that are related with depth. Determining the importance of a single physical factor is however difficult due to the interlinking of the factors. For example the angle of inclination of the bottom and current velocity influence the sediment accumulation and composition, with courser sediments usually found in localities with high water velocity and greater angle compared to horizontal bottom with no currents. Biological factors such as predation, competition, and grazing may also play a major role in determining the community composition.

Any attempt to solve the problem with interlinking physical factors and to quantify the effect of a single factor, i.e. temperature, therefore needs to reduce, or make constant as many as possible of the other variable factors. Therefore sublittoral Vertical walls are perfect natural features in order to reduce the problem of interlinking factors associated with substrate. This is due to their reduced variation in the angle, composition and structure of the substrate.

Benthic communities associated with vertical walls have been less studied compared to, for example, horizontal soft bottom due to their angle, shallow occurrence and inaccessibility to larger research vessels equipped with traditional sampling equipment (trawls, dredges and cores) (Bohnsack 1979, Voronkov et al. 2013). Prior to the SCUBA (Self Contained Underwater Breathing Apparatus) era, when SCUBA equipment became more accessible and affordable, few studies had been undertaken (Sebens 1985, Voronkov et al. 2013). Therefore most studies of vertical walls, overhangs, gulleys and submarine caves have only been undertaken within the last 40 years or so

Investigations of vertical walls show that a clear stratification in species composition and density of organisms with depth is present (Evans et al. 1980). These assemblages are typically dense (have high biomass) diverse communities of suspension feeding sessile invertebrates (Miller & Etter 2008), yet most of these studies have been undertaken within temperate and tropical regions (Miller & Etter 2011). The marine hard bottom benthic assemblages of fauna and flora within the sublittoral Arctic are relatively young and although organisms may occur in high abundances, such as that recorded in Beuchel & Gulliksen (2008), they are not as diverse as at lower latitudes (Grey 2001). This is due to the few endemic species and lack of species, which can tolerate the physical conditions within this region (Dunton 1992).

Algal zonation is evident along rocky bottom coastlines worldwide due to the reduction of sunlight with increasing depth. In the Arctic, algal zonation is often very pronounced and can be found in a band ranging from the surface (or below the area of seaice scour) down to about 30m at exposed areas (Gulliksen & Svensen 2004), especially in areas not influenced by sea urchin grazing. It is however hypothesised that zonation of sessile epibenthic organisms is not as pronounced within high arctic rocky bottom communities (Gulliksen pers.com.). This is thought to be due to reduced solar warming, shorter period of freshwater runoff and increased/deeper mixing when compared to temporal and tropical regions. These factors when combined act to prevent the formation of physical clines (thermocline, halocline, and pycnocline). Yet, with climate change/global warming it has also been hypothesised that an increase in zonation of biological assemblages within the arctic will occur due to increased development of physical clines. This has already been seen within the littoral zones of Spitsbergen and Greenland with an increase in kelp biomass and extension landward due to reduced sea ice scour (Weslawski et al. 2010, Krause-Jensen et al. 2012).

A number of earlier ecological studies have concluded that SCUBA is the best-suited sampling method for vertical rocky walls, especially when combined with underwater photography (Gulliksen 1978, Bohnsack 1979). Underwater photography has been used within the science community since around the middle of the last century. Yet due to the drawbacks of image based sampling, photographs were, until recently, used as a precursor to the traditional sampling methods. With advances in technology, especially digitalisation of photographs and image analysis, this method

is starting to have a more regular occurrence within community analysis on its own accord (Beuchel et al. 2010, Kortsch 2010, Selin 2011, Kortsch et al. 2012).

Sampling using underwater photography has many advantages: The collected data can be stored in areas with finite storage space for an unlimited time period and can be re-examined at a later date. A large proportion of data can be collected within a limited time frame i.e. during one dive. This is also very beneficial considering the high cost and limited time available while undertaking marine field activities in relatively remote areas with expensive research vessels. The most important feature however, is that it allows the communities being sampled to remain intact i.e. it is a non-destructive approach. This is a prerequisite that allows scientists to monitor the same sampling locations/communities non-intrusively over time and eliminates confounding effects that can be caused by other sampling methods (Beuchel et al. 2010).

Benthic time- series studies using underwater photography may focus on community composition and abundance (Jørgensen & Gulliksen 2001, Selin 2011, Laudien & Orchard 2012, Voronkov et al. 2013), organism distribution and zonation (Gulliksen 1978, Logan et al. 1984, Tkachenko & Zhirmunsky 2002), recruitment and succession (Beuchel et al. 2008, Kortsch 2010, Schulz et al. 2010) climatic variations (Beuchel et al. 2006, Kortsch et al. 2012) seasonal variation (Rice et al. 1986) and how changes in the benthos may affect higher trophic levels (Renaud et al. 2008) .

To my knowledge there are few studies that look at sublittoral high Arctic (following the definition described by the Circumpolar Arctic Vegetation Maps Figure 1) hard bottom communities (Gulliksen 1979, Rozycki 1987, Dale et al. 1989, Jørgensen & Gulliksen 2000, Sahade et al. 2004, Konar & Iken 2005, Beuchel et al. 2006, Beuchel & Gulliksen 2008, Kortsch 2010, Kortsch et al. 2012, Laudien & Orchard 2012, Voronkov et al. 2013) and even fewer concerning Sublittoral high Arctic vertical walls (Kortsch 2010, Kortsch et al. 2012) compared to more boreal areas.

The main purpose of this study is to determine if the community structure of a sublittoral high Arctic vertical wall has a clear-cut zonation in the distribution of organisms and if the pattern of distribution of organisms has changed over the investigated six years (2007-2012). A secondary purpose of this study is to compare "sample-based incidence data" described by Gotelli & Cowell (2001) to the more traditional approach as used in Kortsch et al. 2012.
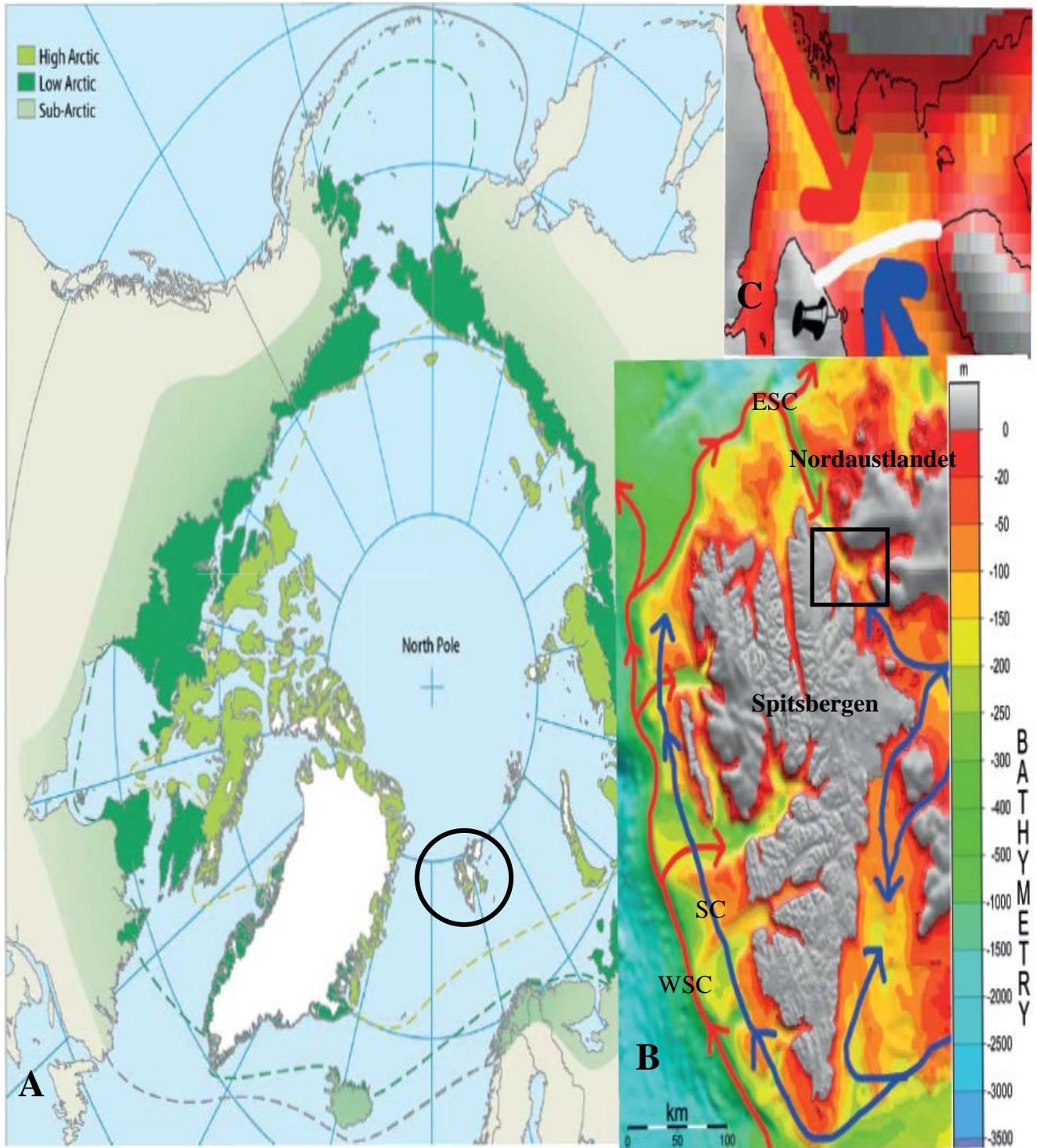
Figure 1: A) Circumpolar map of the Arctic Ocean and surrounding landmasses with the high, low and sub- Arctic zones portrayed according CAVM Team 2003. The separation of the high and low Arctic zones follow the division between sub-zones C & D (CAVM Team 2003). The lines indicating the marine zones are based upon rough boundaries between the fluctuating water masses (Meltofte 2013). The archipelago of Svalbard is shown with the black circle B) Bathymetric map of Svalbard with the approximate major flow patterns of the two main waters masses to be found around the Archipelago (red arrows = Atlantic water, Blue Arrows = Arctic water). WSC = west Spitsbergen current, SC = Sørkapp current, ESC = East Spitsbergen current and the Hinlopen strait is indicated by the black box. C) Bathymetric map of the Hinlopen strait showing the approximate position where the two main water masses converge to generate the Polar Front (white line), The study locality is indicated by the drawing pin point.

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Materials and methods

Study site

The main island of Spitsbergen as well as a number of other islands and islets situated between 74° - 81°N, 10° - 35°E, make up the arctic archipelago of Svalbard, which is the most northerly extension of the European continental shelf. Svalbard is centrally located between four separate geographical water bodies; the Greenland Sea, Norwegian Sea, Barents Sea and the Arctic Ocean. In oceanographic terms however the areas around Svalbard are mainly influenced by two dominant water masses Atlantic water (AW) and Arctic water (ArW) (Walkusz et al. 2003, Nilsen et al. 2008). Mixing of these two water masses with each other, freshwater (melt water runoff and sea ice melt) and brine (produced during sea ice creation) generate the slightly different water masses that are found within the fjords of Svalbard (Cottier et al. 2005).

AW with salinity >34.9 PSU and a temperature >3.0^{o}C is transported from the Atlantic Ocean via the West Spitsbergen Current (WSC), which is the northerly extension of the warm Gulf Stream. The WSC flows along the entire west coast of Spitsbergen, dividing into two separate branches just northwest of the island. The eastern branch flows northwards around Spitsbergen following the continental shelf and the western branch flows north-westwards away from Spitsbergen (Walkusz et al. 2003) (Figure 1b). ArW with a salinity of 34.3-34.8 PSU and temperatures below 0°C flows southwards from the Arctic Ocean in the East, yet due to a mixture of bathymetric and Coriolis steering part of it is diverted so as it flows northwards along the west coast of Spitsbergen (Figure 1b). It is referred to as the Sørkapp Current (SC) (Figure 1b).

The northeast flowing branch of the WSC is a topographically steered current following the continental shelf boundary as it moves around the north of Spitsbergen. As it reaches the northern part of the Hinlopen strait, the body of water that separates the islands of Spitsbergen and Nordaustlandet (Figure 1b), it is steered southwards down the 400m deep trench (Hinlopenrenna) becoming part of the East Spitsbergen Current (ESC) (Figure 1b)(Pfirman & Milliman 1987). The cold water from the Arctic Ocean is steered via Coriolis into the southern part of the Hinlopen strait. Where the two water bodies converge within the Hinlopen Strait a "polar front" is generated, which oscillates northwards and southwards depending upon the amount of AW and

ArW (Gulliksen pers. com.). Although no published oceanographic data is available for the Hinlopen strait it is an area that is constantly sampled biologically, geologically and oceanographically by the University Centre in Svalbard (UNIS) during their teaching cruises, therefore a lot of unpublished data and knowledge has been accumulated about the conditions within the Hinlopen strait.

It is known that "polar fronts" are areas where primary production is elevated due to this mixing of water masses. The diving location for this study is thought to be located within this oscillating "polar front", at an area just north of Tommelpynten (Figure 1C). The dive site is located on the eastern side of Spitsbergen, the largest island in the archipelago, on one of the highly productive vertical walls that the Hinlopen straight shoreline is so characteristically known for (Beuchel et al. 2011). The locality became safe to dive during 2007 when the glacial overhang retreated landwards revealing a vertical wall with an eastern orientation that consists of hard bedrock descending from about 80-100m above sea level to sublittoral depths below 60m (Gulliksen pers. com.).

Photoquadrate collection

This study spans a six-year period from 2007-2012. The collection method is based upon the non-destructive photographic technique developed by Lundälv (1971). In August 2007 a permanent monitoring station was established north of Tommelpynten, Spitsbergen (Figure 1c). Over the study period annual depth transects of photographs have been taken between late August and late September using a digital Nikon D100 6mpx camera with a Nikkor 14mm lens, F/2.8 AF-D, and two external mounted strobe flashes. The diver-operated camera set-up was attached to a 50 x 50cm metal frame, which ensured accurate positioning of the camera over the enclosed area of the seabed giving a fixed focal distance and a known sampling area ($0.25m^2$), thus allowing quantitative analysis to be undertaken on the images (Lundälv 1971, Garrabou et al. 1998, Beuchel et al. 2006, Beuchel & Gulliksen 2008, Kortsch 2010). Due to the metal frame being used to allow for quantitative analysis the photographs will from here be known as photoquadrates.

The diver took photographs roughly every meter whilst descending and ascending the vertical wall, with the deepest photograph being taken at ~45m. In total, for all years, 591 photographs were taken covering an overall area of $148m^2$. Due to

pragmatic reasons (time restrictions, image quality and duplicates) this study was limited to the analysis of a selection of photographs (appendix 1).

Image analysis and processing

'*Adobe Photoshop® CS6 (64 bit) extended*' was used for digital image analysis for it includes a scientific measuring function allowing for area and count data as well as separate count data to be taken. This potentially allows for a faster approach to photographic analysis without having to spend time marking the area of each organism, which should be an improvement on the methods described by Beuchel et al. (2010) and those used by Kortsch (2010). The measurement tool enables calibration of the pixels in the photograph to the original frame size (0.5m x 0.5m) in meters. The area measurement tool allows for organisms within the same species/family/group to be collectively measured with the total area covered being measured in cm^2, with count data being based upon the number of areas encircled. The "separate" count tool allows for many species groups to be counted simultaneously giving a running total of individuals as well as a running total of overall organism count per photo.

All the images were firstly processed using a script, as described in Beuchel et al. (2010), that was pre-made and could be loaded into '*Adobe Photoshop® CS6 (64 bit) extended*'. The script automatically converted the image from JPEG to Photoshop format, followed by manual actions for cropping, calibrating, and adjustment of the colour and contrast gradients. Unequal lighting from the camera strobes and a non-uniform substratum resulted in areas that were over/under exposed which required a greater amount of processing before analysis could be undertaken (Figure 2).

Organisms were identified manually down to the lowest taxon possible and presence absence as well as count data was recorded. The presence/absence and count data was manually typed into Excel for there was no automatic function within '*Adobe Photoshop® CS6 (64 bit) extended*' for exporting this data automatically.
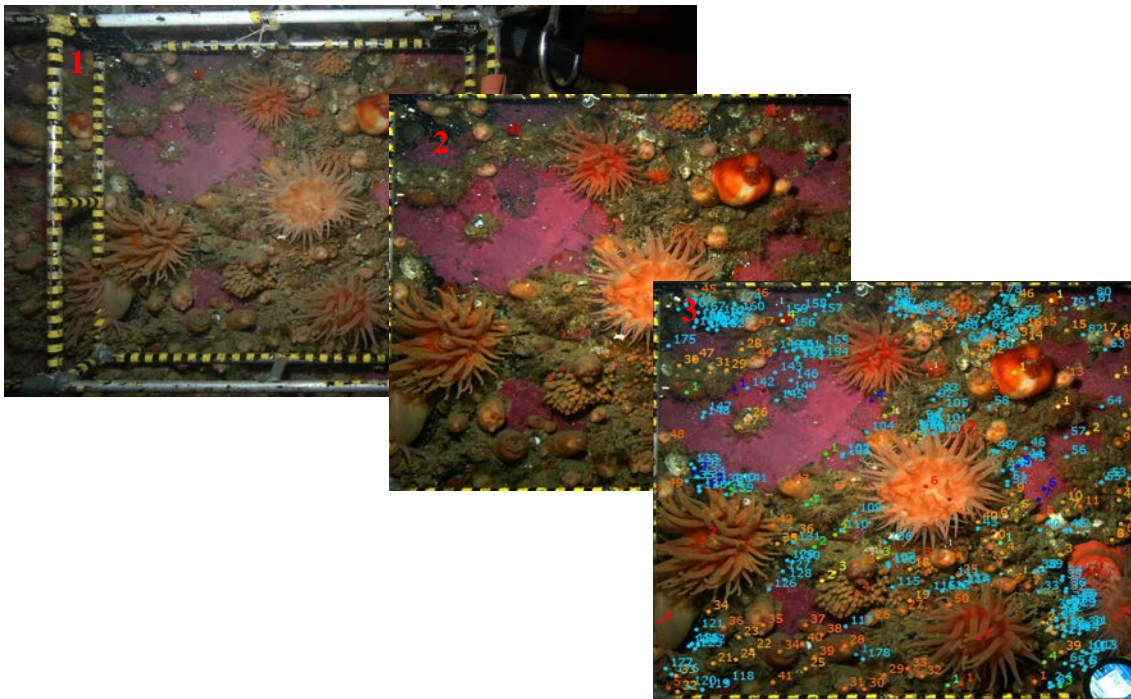
Figure 2 : The steps undertaken during image analysis. 1) Original image 2) Image after cropping, calibrating, and colour adjustment 3) Final analysed photo. Photo 3 is using the new method of the count tool. Photos 1,2,3 are taken from 2010 at a depth of 34m.

Unlike with previous studies organisms were not classified into solitary or colonial groups. Where an obvious single colony could be identified it was counted the same way as a single individual, based upon the presumption that one individual will have started the colony (Marshall et al. 2006). This method however was under the discretion of the analyst using personal judgement to determine distinct colonies located within a single photograph. *Phycodrys rubens* (red algae) were not counted as individuals for they often were so close together that they could not be distinguished as individuals therefore count data is representative of presence. Due to the known survival abilities of *Lithothamnium sp* (calcareous red algae) when overgrown and the inability to determine one individual it was only counted as a presence/absence data. Bryozoans and hydrozoans due to the difficulty in species identification along with their tendency to intertwine with one another were also only counted as presence absence.

The images when downloaded, as a camera preset, follow the cameras internal memory corresponding to the time they were taken, instead of depth where they were taken. Therefore since photoquadrates were taken whilst descending and ascending

the photoquadrate depths do not run in a consistent order from shallowest to deepest. The tabulated data from the analysis firstly had to be ordered to follow a depth transect from the surface to the maximum depth for each year of the study.

There was an inconsistency with the depth at which the photoquadrates were taken between years, which in part is due to the monitoring station being the entire vertical wall, the large number of photoquadrates taken each year as well as the time of the tidal cycle (which can range between 1m for neap and 2m for spring tides). Therefore to correct for this the depths were transformed into 5m depth bins. The individual organism count for each photoquadrate within each depth bin was summed together to give an average abundance for that particular depth. In order to quantify the information individuals per m^2 had to be calculated. The following equation was used to get individuals per m^2:

(sum of all organisms in the depth bin) / (number of photos in each depth bin/4) = Individuals per m^2

Equation 1: The equation used in order to go from individuals per depth bin to individuals per m².

Environmental data

The Sea Ice index data for the Hinlopen Strait covering the same time period as the photographic time series was obtained from the Norwegian Meteorological institute (Nick Hughes pers. com.). The CTD data was taken from R/V Helmer Hanssen`s onboard server and collected during student teaching cruises primarily for use in student projects and assessments.

Statistical analysis

Due to the nature of the study site being a full sublittoral vertical wall, one cannot expect to count all the species present. Rather the total species richness was estimated as well as the sampling effort needed to obtain reliable estimates of this richness. Gotelli & Colwell (2001) suggest that it is preferable to use sample based species accumulation curves when dealing with patchy distributions, otherwise individual-based rarefaction curves may inevitably overestimate the number of

species found with less effort. Sample based species accumulation curves are plotted from samples taken randomly within a given area, for this study the area is the wall and the photographs are all taken randomly within a vertical transect upon the wall. Using the presence/absence data for every photograph analysed sample based species accumulation curves were created. They were created using the statistical program 'R i386 3.0.1' (R core team 2013) using 1000 random permutations over the entire photographic data set for each year.

The overall species list was broken down so as only species that appeared in at least one of the depth bins for that particular year was present. The number of species recorded within each depth bin covered by a single year was then counted and recorded. This gave a total number of recorded species per depth bin. The count data per m^2 for each of the most conspicuous sessile species observed over the range of years were taken in order to determine if abundance varies between years and depths. Motile organisms, although conspicuous (*Strongylocentrotus droebachiensis* and *Lebbeus polaris*), are able to migrate between the depth bins in order to feed resulting in accumulations or feeding aggregations (appendix 2), therefore they were not selected to look at variations in abundance between depths and years.

Non-parametric multidimensional-scaling (MDS) was carried out based on Bray-Curtis similarity measures to reveal community structure. MDS is an exploratory technique enabling visualisation of patterns in the data by emphasising structural variation in a low dimensional space. Analysis was performed using the statistical package 'R i386 3.0.1' (R Core Team 2013).

Canonical Correspondence Analysis (CCA) was used to assess the strength of the relationship between the species abundances and physical characteristics of depth, year, and sea ice cover. The positions of the species within the CCA triplot are determined by their correlation to the ordination axis and to the environmental gradients. The arrows representing the environmental gradients were orientated in the direction of maximum change for that given gradient. The arrow length is proportional to the maximum rate of change. Monte Carlo permutation tests (199 permutations) were performed to see whether significant statistical differences were present among depths. All CCA estimations were performed in the statistical program 'R i386 3.0.1' using the package 'vegan' (Oksanen et al 2013). The three species of zooplankton as well as the two fish species were not included within the analysis.

Results

In total 424 photoquadrates were analysed, yet due to unknown depth for some of the photoquadrates 387 were used within this study. Thus the total area covered in the study was 96.75m². In total 77,992 individual organisms were counted covering 56 taxonomic groups of which 29 were identified down to species and 11 down to genus level. The remaining 16 taxa were identified to higher taxonomic levels (e.g. phylum, class, order). Of all the 56 taxa recorded 53 were true benthic organisms with the remaining 3 being identified as zooplankton. All taxa recorded have been previously observed in the coastal waters of the Svalbard archipelago (Gulliksen et al. 1999, Hop et al. 2002, Gulliksen & Svensen 2004, Palerud et al. 2004)
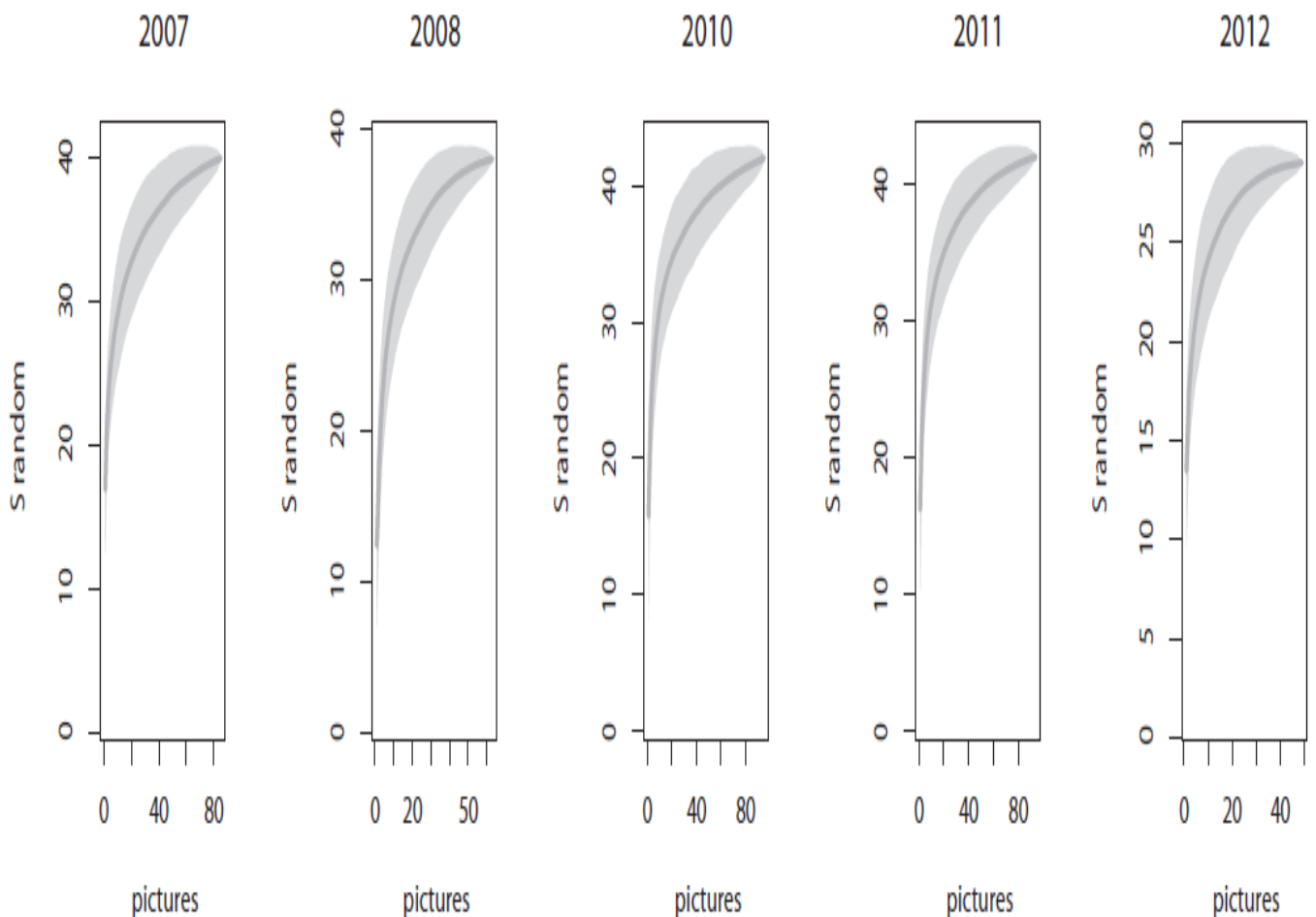

Figure 3: Sample based species accumulation curves for all years. The dark grey line is the curve plotted based on the actual data and the light grey area is the deviation away from this. Note the difference in horizontal scale on each plot, this is due to the difference in sampling effort for each year.

Sample based species accumulation curves (Figure 3) based upon 1000 random permutations were run in order to determine if the amount of samples (photoquadrates) taken for each year were adequate to estimate the total species richness of the submarine vertical wall. They show that, initially as the amount of samples increase the amount of species increased rapidly at first then more slowly as the increasingly rare species are added. It seems that for most years, apart from 2012, the species accumulation curves do not reach an asymptote. Since all photoquadrates were analysed for all years, with exceptions due to the pragmatic reasons stated, this indicates that increased sampling effort is required in order to capture all organisms of the community.

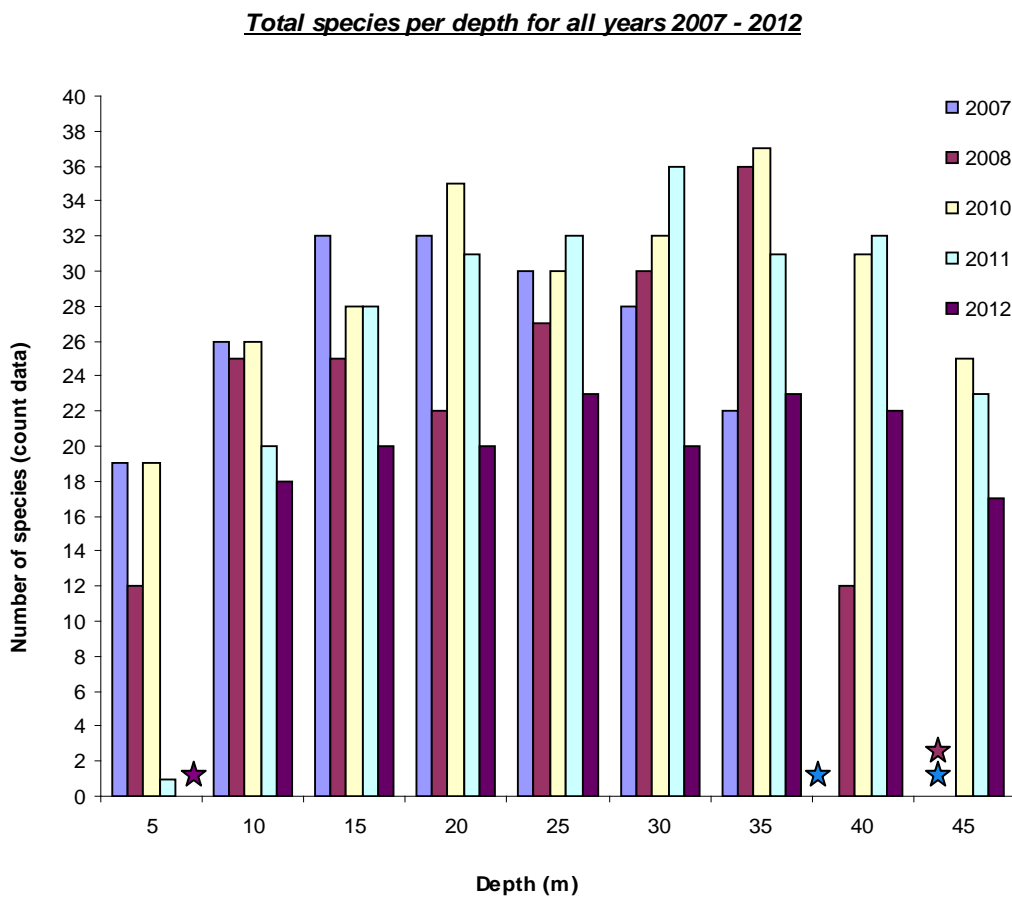**Total species per depth for all years 2007 - 2012**

Figure 4: The total number of species found within each depth bin for every year in the study. Star indicates that no images were taken at that depth for that particular year.

Taxa abundance was greatest between 10 and 40m for all years with the greatest number of identified taxa within a single depth bin being 37 taxa per m^2, within the 35m depth bin during 2010 (Figure 4). Depths at which zero species were recorded indicate that no photographs were taken at that depth bin for that year (Figure 4). The lowest abundance of taxa, from years where photographs were taken, was 1 taxa per m^2 within the 5m depth bin during 2011 (Figure 4). Taxa abundance increased markedly from 5 to 10m for all years, with the greatest increase being for 2011. Abundance did fluctuate with depths for all years yet abundances did not drop below 18 taxa per m^2 between 10 and 35m with all abundance peaks being found within this depth frame. Years 2008, 2010, and 2011 have a single abundance peak located within the 35, 35, and 30 m depth bins respectively, whereas 2007 and 2012 have split maximums of 15 and 20m (2007) and 25 and 35m (2012). The shallowest abundance peak was found during 2007 with deeper abundance peaks found in following years.

All the conspicuous sessile organisms show that there is variation between the numbers of individuals per m^2 with depth (Figure 5). No data is available for 2007 below 35m, for 2008 the deepest depth bin has no data points and for 2012 no information was available for the top 5 m (Figure 5, and appendix 3). Each species has its greatest abundance located within different depth bins for each year. The number of individuals found per m^2 also changes with year for all organisms.
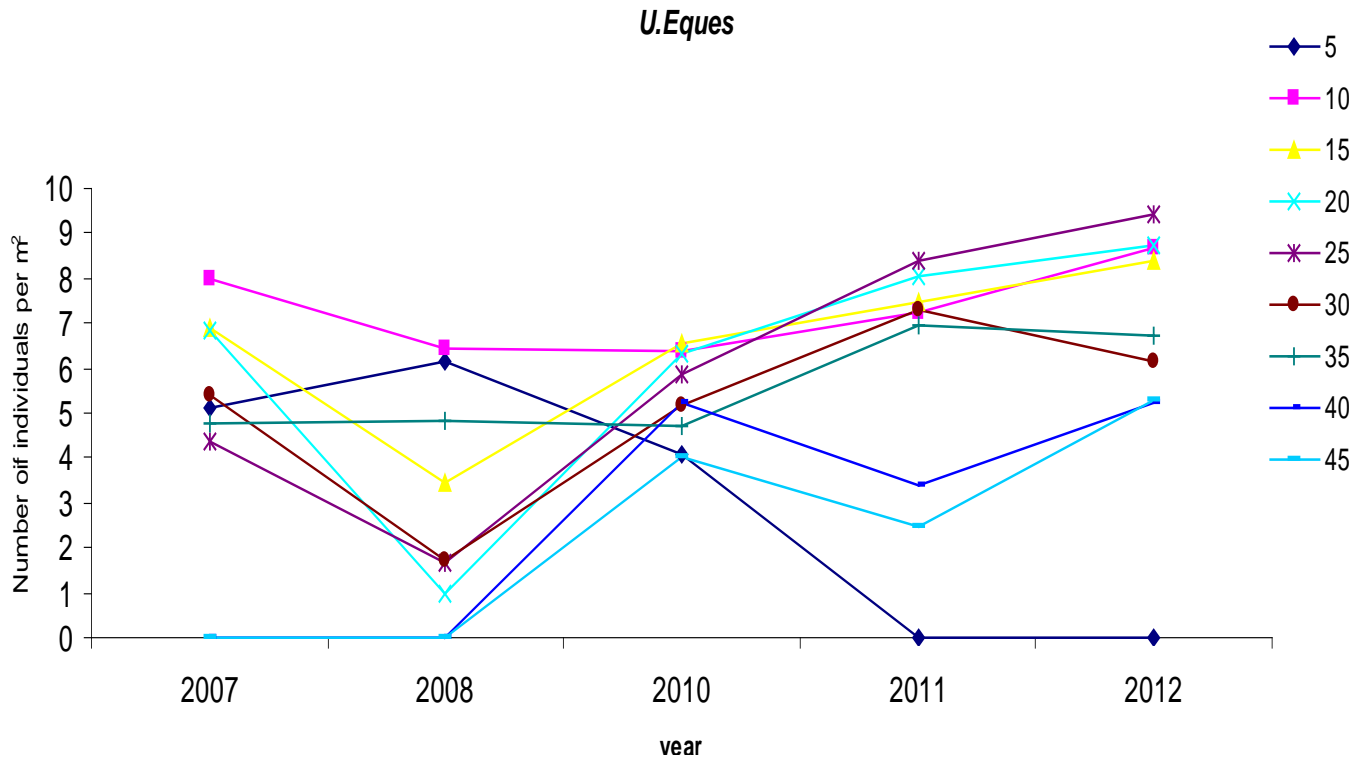
Figure 5: Number of individuals per m² of *Urticina Eques* for each depth bin across all years. Each line represents a different depth bin and the key is in meters. The individual abundance per m² for the remaining conspicuous sessile organisms can be found in the appendix 3.

The CCA triplot visualizes the association and correlation between species and years related to environmental variables (Figure 6). The CCA shows that total sea ice cover (tot_sic) and depth are at 90 degree angles to one another, suggesting that they are not correlated. Depth and total sea ice cover explains 26% of the variation within the organisms, with depth alone accounting for 18%. This indicates that the benthic community north of Tommelpynten thus seems to be oriented in the direction of depth and to a lesser extent total sea ice cover. The organisms mostly associated with the shallower depths were *Chlorophyta* spp (gre_al), *Laminaria* spp (lam_sp) and *Desmerestia* sp (Desm_sp) all of which are algal species and associated with the infralittoral subzone. The organisms associated with the deepest depths were the mollusc *Chlamys islandica* (Chl_is), the cnidarian *Capnella glomeratum* (Cap_glo) and the echinederms *Gorgonocephalus* spp (Gor_sp), Henricia spp (Hen_sp) and *Pteraster* spp (Pte_sp) indicating a lower circalittoral subzone. The remaining species seem to be clustered about mid depths indicating the upper circalittoral zubzone.
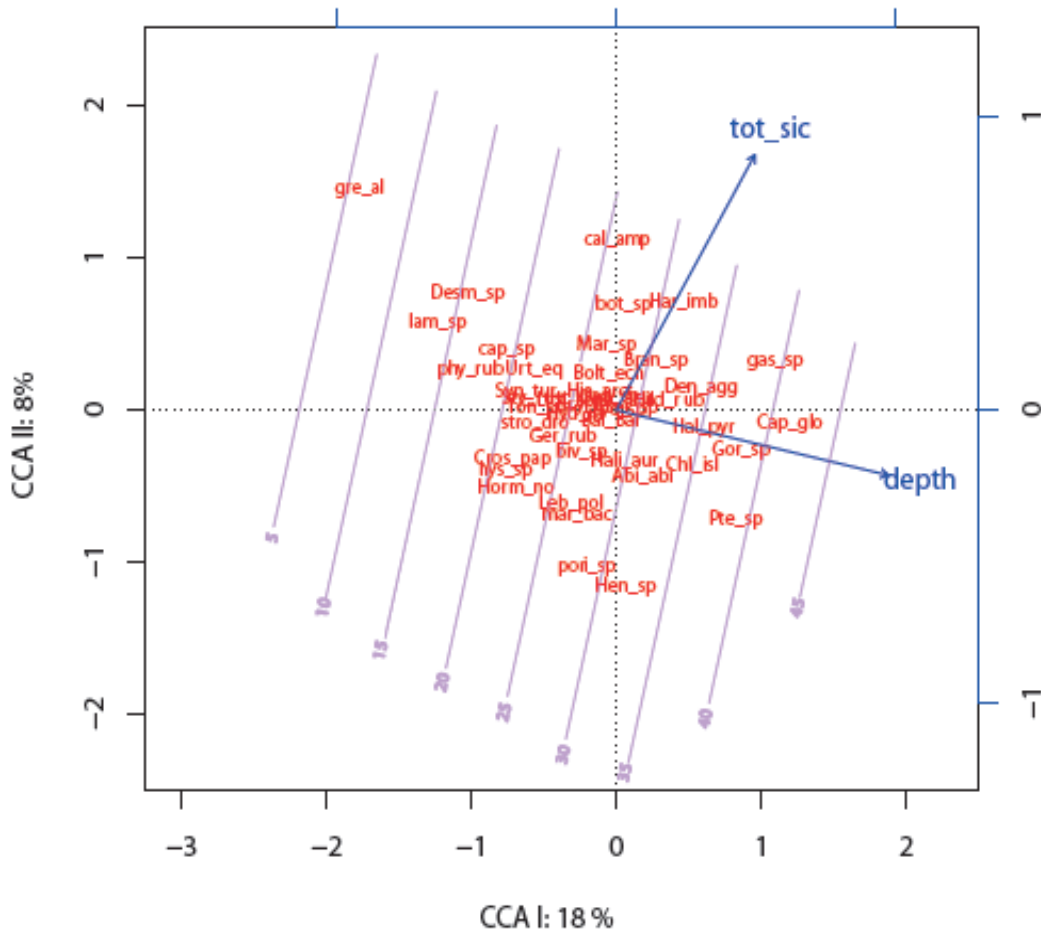
Figure 6: Canonical correspondence analysis (CCA) showing photographs (samples) related to the year and environmental variables of depth and total yearly sea ice cover going from October to September (tot_sic). Depth bin lines have been plotted (grey lines). The variation accounted for by axis 1 (horizontal) and axis 2 (vertical) are 18% and 8% respectively.
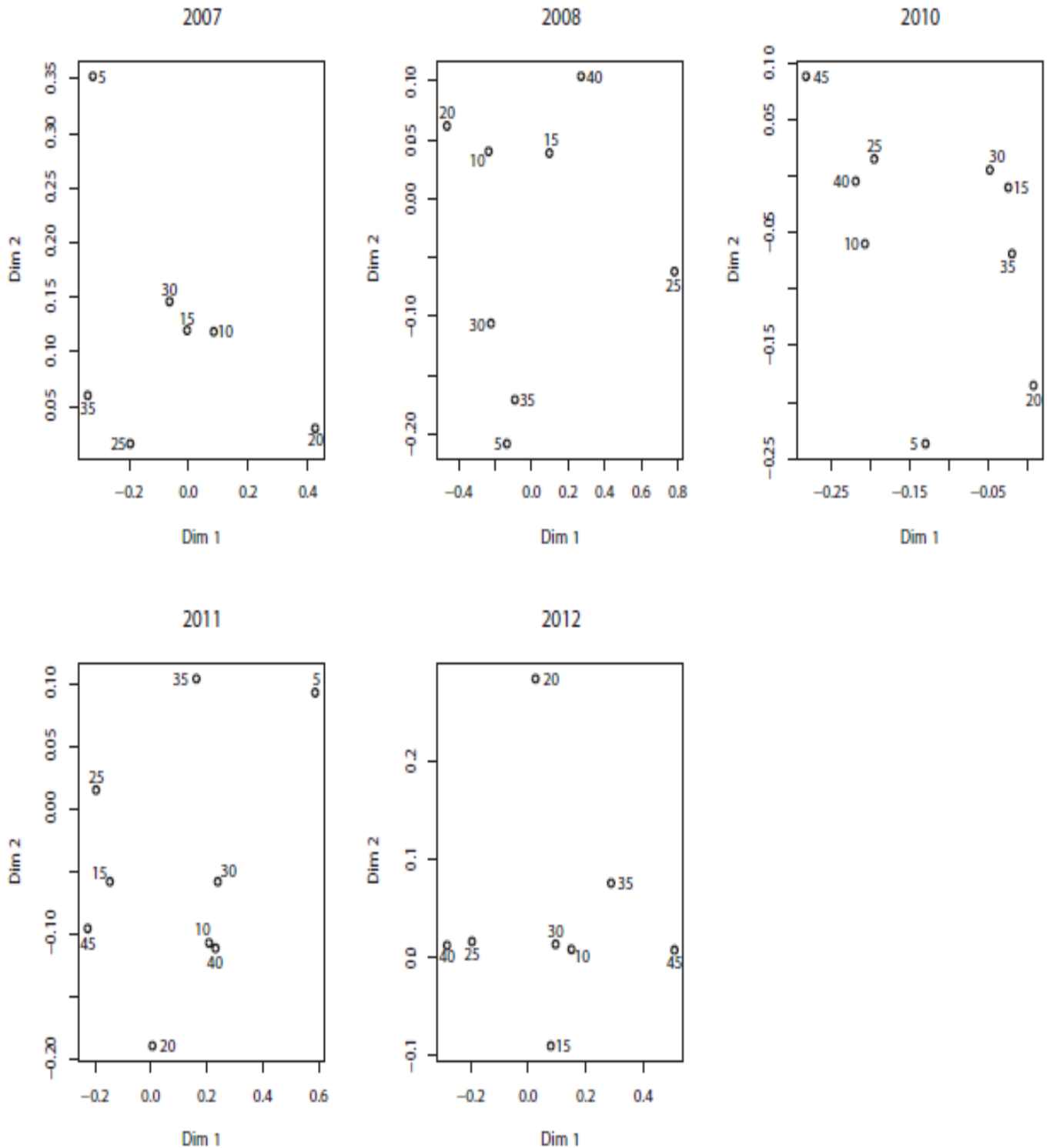
Figure 7: Non-parametric multidimensional scaling (MDS) plots showing the benthic community similarity between the depth bins within years based on Bray-Curtis. The data was transformed into individuals per m2. Depths located within close proximity are more similar in community structure than years far apart. Note the difference in scales on the x and y axis for all years.

MDS plots based on organism abundance per m^2 were created for all years, showing the similarity of the depth bins within each year. The tighter the cluster of depths bins the greater the community similarity is between them. Only in 2007 does it show that consecutive depth bins are more similar to one another (Figure 7). In 2008, 2011 and 2012 groups containing both consecutive and inconsecutive depth bins are formed (Figure 7). 2011 contains groupings of only inconsecutive depths. 2008 is split into 3 groups, 2007 and 2012 are split into 4 groups and 2010 and 2011 are split into 5 groups, all of which contain different depth bins (Figure 7). It seems that for all years that a large change occurs between the 5m and the 10m depth bins.

The general trend is that the depth bins for 5 and 45m are the most dissimilar to the other depths as well as each other, where both bins occur within the same year, by being located on their own and as far apart from each other as possible (Figure 7). This separation of the 5m and 45m bins suggest that zonation is occurring. This pattern however does not apply for the 5m depth bin in 2008, which is similar to the 35m depth bin, and for the 45m depth bin in 2011, which is similar to the 15m depth bin (Figure 7). Therefore due to this grouping and seperation the 5m depth bin can be labelled as the infralittoral, and the 45m depth bin can be labelled as the lower circalittoral with depths in between being the upper circalittoral.

Discussion

Zonation

This study has indicated that zonation does occur within the hard bottom communities of subtidal vertical walls. Although the rocky sublittoral zone has yet to be divided into a widely accepted zonation scheme applicable for all coastlines, many attempts have been undertaken. Peres and Molinier (1957) who divided the sublittoral zone into two subzones, the infralittoral and circalittoral, with the infralittoral subzone extending from the extreme low water spring tide mark to the lower limit of the foliose macro-algae and the circalittoral extending from this lower infralittoral boundary to the lower limit of growth for sciaphilous (shade loving) algae is the most used zonation pattern for the sublittoral zone (Logan et al. 1984). Hiscock and Mitchell (1980) however re-evaluated these subzones fractionating them into upper and lower units depending upon certain algal species presence. The upper infralittoral is identified by dense kelp forests, lower infralittoral sparsely populated kelps dominated by foliose red algae (unless high grazing has occurred), upper circalittoral dominated by animals with red foliose algae sparsely present (unless high grazing has occurred), and the lower circalittoral dominated by animals without the presence of foliose algae but with crustose corraline algae (Connor et al. 2003). This study has indicated that the ifralittoral subzone occurs within the 5m depth bin, and the circalittoral subzone. Based on Hiscock and Mitchell (1980) the circalittoral zubzone can be further divided into the upper circalittoral subzone (10-40m bins) and the lower circalittoral zubzone (45m).

The lower limit of kelp growth is based upon a compensation depth representing an area where photosynthesis equals the natural loss of carbon on an annual basis, which varies between species. Roughly this is where 1% of the surface irradiance reaches the sea floor (Logan et al. 1984). It has been estimated for Young Sound, NE Greenland (74°N) that 0.7-1.6% of the annual surface irradiance was available at the lowest kelp boundary located at a depth of 15-20m on horizontal bedrock (Borum et al. 2002). Gulliksen (1978) studied a submarine gulley, rocky bottom vertical walls, in Northern Norway and indicated that the non- calcareous red algae along with brown algae were found down to 10m with their highest abundance just below the surface ~3m. Krause-Jensen et al. (2012) found that the distribution of kelp forests around the coast of Greenland were narrower and shallower in the north

and that the coverage was highest towards the shoreline declining with depth, with 1% coverage occurring at this compensation depth. For this present study it would seem that the zonation of infralittoral is present which is clearly seen with the 5m depth bin, yet this subzone can not divided further. This could in part be due to the photographic technique used, which may over estimate the abundance of kelp due to the fronds covering the entire photoquadrate. The infralittoral subzone identified in this study is much thinner than those found further south on similar substrates (Gulliksen 1978) as well as being much shallower than those found at similar latitude (Krause-Jensen et al. 2012). The sublittoral wall extends vertically above the sea surface for ~ 100m and has an eastern orientation both of which may reduce the amount of light reaching the wall leading to a shading effect (Gulliksen pers. com.). This combined with the high latitude of the study site may lead to extreme environmental gradients. These extreme gradients have been shown to cause marked zonation patterns of organisms with examples being shown from around the world (Blaber et al. 1974). In Svalbard the perennial macroalgae, such as kelp, were found to occur from depths no shallower than 5m (Gulliksen & Svensen 2004). Yet due to the presence of Atlantic water and the reduction in ice scour, reduced sea ice formation, may also lead to its increased shoreward expansion noted here and in other studies (Weslawski et al. 2010).

The infralittoral during 2008 seems to be very similar to the 30 and 35m depth bins of the upper circalittoral. This may be a factor of the large increase in algal detritus observed in the photographs often attached to organisms such as anemones and sea urchins. It has been observed that mechanical stimulation of anemone tentacles causes them to clasp the particle and bend towards the mouth inducing a feeding motion (Pantin & Pantin 1942). This will occur even with inanimate objects such as filter paper therefore it may also occur with falling detritus (Reimer 1972). It has long been known that sea urchins not only feed on detritus but also use it to clothe themselves in order to avoid predators, reduce temperature changes, or to reduce light levels (Millott 1955).

The communities found associated with sublittoral vertical walls, within diving depths, worldwide have been described as being typically dominated by sessile invertebrates especially ascidians, sponges, bryozoans, and cnidarians (Miller & Etter 2008), a pattern which is also depicted within this study. Therefore due to organisms dominating these walls below the 5m depth bin it is safe to say, based on the description of Peres and Molinier (1957) circalittoral zonation is present. However the

45m depth bins seem to be dissimilar to the rest of the depth bins meaning that unlike the infralittoral subzone, the circalittoral subzone can be divided into the upper and lower fractions as suggested by Hiscock & Mitchel et al. (1980). It has been accepted that algal zonation is apparent within the High Arctic due to reducing light intensity with depth (Borum et al. 2002. Wulff et al. 2009, Krause-Jensen et al. 2012), yet the hypothesis that the sublittoral High Arctic sessile epibenthic animal communities display, if any, a reduced vertical zonation pattern (Gulliksen pers. com.), is indicated in the results of this study.

This reduced zonation is thought to be due to a reduction in solar warming, shorter period of freshwater runoff and increased/deeper mixing when compared to temporal and tropical regions. These factors when combined act to prevent the formation of physical clines (thermocline, halocline, and pycnocline). Yet, with climate change it has also been hypothesised that an increase in zonation of biological assemblages within the arctic will occur due to increased development of physical clines.

Species abundance

It is well known that in Polar Regions ice scour has a major effect upon the benthos. The effect of ice disturbance alters with a number of factors such as depth, latitude and substratum profile. In the Arctic the summer period is highly disturbed by vast amounts of freshwater input, ice scour, wave action and biological activity (Barnes 1999). These disturbances may produce marked zonation patterns of species accumulation in deeper waters.

Ice scour is due to the impact of floating ice as it comes into contact with the substratum and within the Arctic it has a major yet predictable influence on depths shallower than 5-8m (Gulliksen & Svensen 2004). The majority of the affect is during the summer months (July- September) when sea ice breakup and glacial calving is at its peak (Barnes 1999). Even if scour is not observed directly its presence can be shown via the removal of organisms from localized areas. Ice scour may be used to explain the lack of organisms within the shallowest depth bins.

Kortsch et al (2012) noted that in two High Arctic fjords on the west coast of Spitsbergen, Kongsfjord and Smeerenburgfjord, the benthic community restructured over a period of 30 years. Although the studied time series is not as long as those

studied by Kortsch et al (2012), it is shown that community changes can occur over a very short time period (long term with no change followed by an abrupt change) which has been labeled a tipping point. In Kongsfjord over 80% of anemones were lost and replaced by filamentous brown algae, while in Smeerenburgfjord the community went from barnicle/ascidian/hydrozoan dominated community towards a sponge-ascidian complex. The study by Kortsch et al (2012) was undertaken using permanent monitoring areas with no vertical differentiation. Therefore although the communities at these depths are reorganizing, the species may be moving to a deeper position on the bedrock in order to avoid the surface environmental changes i.e. increased freshening of the surface layer from runoff, temperature increase from increased solar radiation, and increased light levels earlier in the season. This may explain the depth movement in species abundance observed within this study, yet even though a depth displacement has been observed more years need to be added to the time series before anything can be concluded.

Increased light levels to the benthos, especially in the study area, may also be due to reduced shading caused from the melting of the retreating glacier that originally opened the study site to diving. Miller & Etter (2008) have shown that in the gulf of Main shaded surfaces over horizontal surfaces can shift communities from algal dominated towards invertebrate dominated. Allowing them to conclude that shading is the major cause behind invertebrate dominance. It is proposed, from these results, that the opposite may have occurred due to the increased light from the retreating glacier. Although the light levels are not strong enough to facilitate algal growth on the vertical wall at depths greater than 5m, it is enough to cause a shift in the benthic abundance to deeper water leading to the zonation within the species accumulation at deeper depths and for algal species to dominate the upper 5m depth bin.

Methodological review

Photographic analysis is a suitable, advantageous and unique tool for long term monitoring projects, due to the non-invasive and non- destructive nature of this technique. The simplicity of the data collection along with the fast acquisition of data makes it a cost effective procedure when compared to other traditional sampling methods. Although just like traditional sampling methods the amount of time required

to extract the data after collection is time consuming and elaborate. Beuchel et al. (2010) used a semiautomated approach to reduce the amount of time required for image analysis from ~1h down to 15- 30 minutes per photograph yet there are two major downsides of this method. Firstly there are two parts to this method the first is to count the organisms by placing a dot on each of them secondly area data is gathered. If the organisms overlap with each other the areas merge becoming a single area, which can be corrected for using a specific tool in photoshop. Secondly each individual species group is assigned an RGB colour code meaning that the group has to be measured at the same time over the entire photograph. The required sorting time for the exported data by matching species name to RGB codes is time-consuming and necessary extra work after the analysis of the photograph.

The main method undertaken in the present study used the separate count tool in "Photoshop CS6 extended" to count all the individuals within the photograph. This approach allows groups of organisms to be counted at the same time by switching the assigned count group in the menu. It reduced the time of photographic analysis from 30minutes (based upon quickest analysis after getting used to the procedure and program) to ~15 minutes maximum. This allows for more photographs to be analysed within a shorter time period. Although a major downside to this method, is the fact that the count data cannot be automatically exported out of the program (although requests for this have been sent to Adobe regarding this). Yet despite of this the time needed to manually export the data is equivalent to the sorting of exported date from the previous method.

This comparison within the techniques and methods used while undertaking photographic analysis indicate that although using the separate count tool may be less time consuming that acquiring the area data, many of the encrusting and colonial organisms need to have area data. This is due to not being able to distinguish between individuals and their count data will be over or under estimated.

Methodological constraints

Like the majority of sampling techniques, photographic analysis can be both advantageous and disadvantageous when used for scientific purposes. The non-invasive and non- destructive method allows long-term monitoring studies of the benthos, such as Kortsch et al. (2012), to be undertaken. It offers the opportunity to

monitor benthic assemblages over time in order to study invasive species, succession and recolonisation, abundance fluctuations, or community variations in relation to climate variability (Beuchel & Gulliksen 2008). Due to many benthic species being long lived and sessile it also offers the study of life history traits and auto-ecology of selected species. Finally the photographs can be archived and re-examined whenever necessary, thus being used in different projects in the future. The simplicity of the data collection along with the fast acquisition makes for a cost effective sampling procedure.

Long-term monitoring stations, if placed in appropriate localities, are a vital way of analysing change and recording appearances of new species within shallow water, especially when backed up by personal observations. At areas where regular diving is taking place for either recreational or scientific purposes the divers that dive the locality regularly often have acute knowledge of the flora and fauna. This means that the divers get a "feel" for their location and if any changes occur they are easily and quickly picked up on. Yet personal observation alone is not always accounted for in the scientific community, and thus needs some back up by hard data. A good example of this is from the islet of Sagaskjæret located in Isfjorden, Spitsbergen where regular scientific diving has occurred due to its accessibility, location and variety of organisms available for collection. Berge et al. (2005), while conducting a collection dive for a course held at UNIS, noted that the blue mussel *Mytilus edulis* was abundant in the shallow waters (4–7m). This species had not been recorded in the archipelago for over 1000 years (Berge et al. 2005). Yet Norton & Feder (2006) suggested that the population may have been a patchy relict population from the Holocene. One of the response arguments given by Berge et al. (2006) was that Svalbard has been highly studied and the locality of appearance has been extensively dived by the same divers since 1993. If long term image monitoring had been undertaken here from the beginning of diving research then this appearance would not have been contested. A long-term monitoring station has been located in the area as of 2006 (Pers. obs.)

The greatest constraint to photographic analysis is the quantitive inaccuracy due to the varying image quality (induced by: strong currents, wave action, and low visibility due to variations in the particulate matter within the water column). Although photographs can be seen on the cameras display screen whilst in *situ* poor image quality can still be problematic especially in the Arctic. However the advances

of the processing ability of software such as "Photoshop" may allow for image quality problems to be overcome.

The difficulty in identification of taxa to species level (i.e. bryozoans, hydrozoans, algae) along with the inability to identify cryptic and small (<1mm) organisms may result in an underestimation of species, and thus an underestimation of diversity. A study undertaken by Jøgensen & Gulliksen (2001) concluded that large epibenthic organisms (i.e. *Tonicella spp* and *B. balanus*) were in similar abundance when comparing the two sampling methods of photographic analysis and suction sampling. This indicates that photographic analysis can be considered reliable when defining macro- benthic (organisms >1mm) assemblages (Jørgensen & Gulliksen 2001). However if digital photographic equipment continues to advance at the current rate meio-benthic (<1mm >0.1mm) organisms may be identified.

Future work

With the phenomenon of climate change affecting marine communities especially those in the Arctic, where climate warming is happening most rapidly, it is a common plea by the scientific community that long term studies should be undertaken (Butler & Connolly 1999). Due to this study spanning a six year period it has the potential to build into a much longer photographic time series with strong acuity. It will also add an extra habitat to the long-term time series data already accumulated around Svalbard (Beuchel et al. 2006, Renaud et al. 2007, Berge et al. 2009, Kortsch 2010, Kortsch et al. 2012). Yet with long-term photographic time series I must stress that it is not enough to collect only the photographic data. It is of vital importance that environmental data is also collected whilst undertaking the dive. If at all possible a series of mini loggers (temperature, salinity, current and light) can be placed along a depth transect down the vertical wall at 5m spacing to correspond with the depth bin boundaries. In failing this, a small CTD device can be mounted to the cameras underwater housing that will at least give temperature and salinity during the dive. Light measurements should be taken either before or after the dive via a Secchi disc, or a slowly lowered light measuring mini logger. It is not advisable to conduct light readings during the dive due to interference from the camera strobes.

Conclusion

In this masters thesis it has been attempted to answer or at least provide pioneering work towards

      1.   Determining if clear cut zonation is predominant within the organisms of sublittoral vertical walls in the Arctic

      2.   Determine if the distribution of organisms has changed over the investigated period

      3.   Compare the methods used by Kortsch et al. (2012) to those suggested by Gotelli & Cowell (2001)

Clear-cut zonation is observable especially between the ifralittoral and circalittoral subzones. The circalittoral can be further divided into upper and lower zones indicated by the presence of species only associated with the deeper depths such as the mollusc *Chlamys islandica*, the cnidarian *Capnella glomeratum*, and the echinoderms *Gorgonocephalus* spp, Henricia spp and *Pteraster* spp. The peaks in species accumulation have gradually become deeper over the study period leading to zonation patterns associated with abundance. The parameters of total sea ice cover and depth were used as predictors to the community variation. It was found the most significant environmental parameter was depth, which accounted for 18% of the variation across years. Yet the environmental factors of depth and sea ice cover explain, in total, only 26% of the variance indicating other environmental variables are contributing to the zonation pattern observed. This indicates data for more parameters, as well as more photoquadrates, need to be collected in order to explain the phenomenon of zonation within this community as well as the change in depth accumulation.

The methodology comparisons indicate that three parameters are needed for the image analysis due to the complexity of the community. For species that cannot be divided into individuals such as hydroids, bryozoans, *Phycodrys rubens* (red algae), and *Lithothamnium sp* (calcareous red algae) area is required in order to determine there true impact within the community. For solitary organisms presence/absence data while coupled with count is more than enough information to determine the community composition.

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Appendix

Appendix 1: Table of photoquadrates available for each year, the amount of photosquadrates that were analysed (variation is due to pragmatic reasons), the photosquadrates used for analysis (variation due to unreadable depth therefore could not be used in the analysis). All areas are in m^2

Year	Photoquadrates available	Area covered by all photoquadrates available	Photoquadrates analysed	Area covered of selected photoquadrates	Photosquarates used for analysis	Area of photoquadrates used in analysis
2007	89	22.25	85	21.25	85	21.25
2008	71	17.75	70	17.5	63	15.75
2009	59	14.75	13	3.25	0	0
2010	111	27.75	108	27	95	23.75
2011	148	37	97	24.25	95	23.75
2012	114	28.5	51	12.75	49	12.25
Total	592	148	424	106	387	96.75

Appendix 2: A photoquadrate from 2007 at a depth of 21.5m showing a feeding aggregation of *Strongylocentrotus droebachiensis* (14 individuals) and *Lebbeus polaris* (92 individuals). This is the greatest number of individuals from both species found on a single photoquadrate over the entire study period.
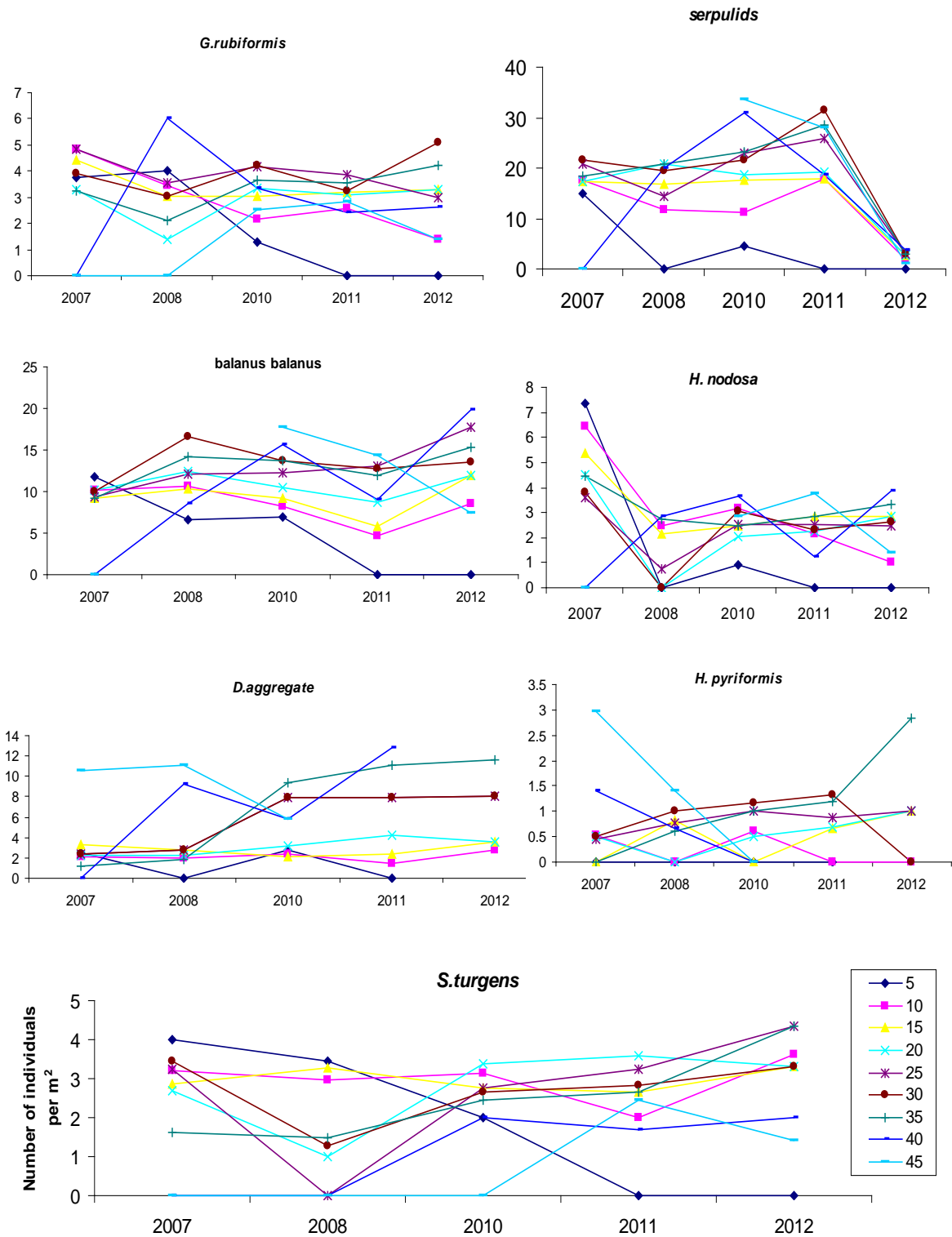
Appendix 3: Number of individuals per m^2 of the remaining conspicuous sessile organisms for each depth bin across all years. Each line represents a different depth bin. The colour key is the same for all plots as is the axis labels. Note the difference in the Y axis scale.