Littoral and upper sublittoral macroalgal vegetation from 8 sites around Svalbard

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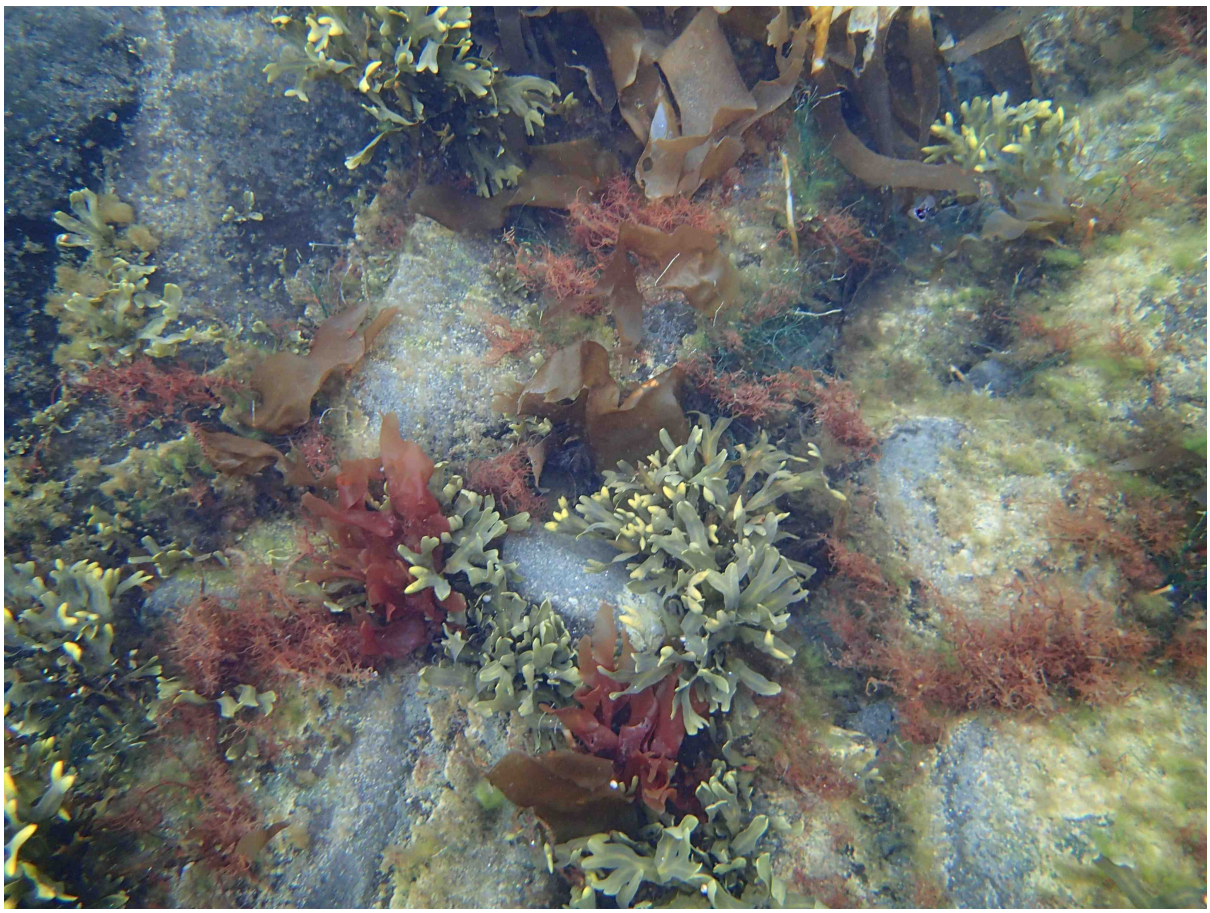

Algal vegetation at Vaigattneset (Sofiaøya) composed of *Fucus distichus, Palmaria palmata, Devaleraea ramentacea, Saccharina groenlandica* and various filamentous green and brown algae.

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Abstract

The macroalgal vegetation is an essential part of the marine community by producing energy rich compounds from inorganic carbon using sunlight as the energy source. The earliest investigations from Svalbard dates back to the 1840's, and several species lists have been drawn up since then. However, macroalgal investigations from large parts of Svalbard are still missing. In this study qualitative analysis of the macroalgal vegetation at eight different sites located around the coast of Svalbard was performed during 1st – 10th of July 2013. The material was collected from the littoral and the upper sublittoral zone and identified to species or genus by use of morphological characters in particular. The use of entirely morphological characters to identify some species of macroalgae can be difficult due to their variability in appearance and similarity to other species. DNA-barcoding of two brown algae and one red alga was therefore included in this study. A total of 53 taxa were identified in the the survey. Norskeøyane, the northernmost site, had the highest number of taxa (34). One new species for Svalbard, *Halothrix lumbricalis* (Phaeophyceae), was recorded. DNA-barcoding identified *Saccharina groenlandica* from six out of seven sites, a species morphologically very similar to *Laminaria digitata*. *Laminaria digitata* was only identified from one site. Barcoding revealed all fucoid algae to be *Fucus distichus* and all the *Ceramium* samples to be *Ceramium virgatum*. Four locations had not been investigated previously, thus this thesis publishes the first records of macroalgal species at these locations. This work may serve as a baseline for future studies with respect to climate changes and distribution of macroalgae from sites around Svalbard.

Acknowledgements

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Siri Røang Moy

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1. Introduction

1.1 Macroalgae

Macroalgae are photosynthetic organisms and thus primary producers that use the energy in sunlight to convert inorganic carbon and water from the environment to organic carbon that serves as energy reserves and cellular building blocks (Graham et al. 2009). The algal vegetation has a key role in the food web by being a source of chemical energy for secondary production (Dunton and Schell 1987; Duggins et al. 1989; Fredriksen 2003). A great proportion of the algal primary production enters the food web through detritus (Dunton and Schell 1987; Fredriksen 2003). Few organisms feed directly on macroalgae, but herbivore gastropods and sea urchins graze directly on the algal vegetation, among others (Fredriksen 2003). The macroalgal vegetation is also an essential part of the marine community by creating a three-dimensional habitat for other algae and animals on rocky shores (Lippert et al. 2001, Carlsen et al. 2007, Wlodarska-Kowalczuk et al. 2009, Hop et al. 2012). Macroalgae do also support life by providing hiding places for other organisms such as crustaceans and fish and by giving the associated fauna protection from stress caused by environmental factors (Lippert et al. 2001 and references therein).

Macroalgae do not have roots like land plants or seagrasses. Instead they have a holdfast that can be a disk, rhizoids or a root-like structure called a hapter. The lack of roots means that they are poorly adapted to grow in soft bottom areas and are dependent on a solid and stable substrate (Kaiser et al. 2011). Their distribution in the ocean is thus restricted to the rocky shores (Wulff et al. 2009), including stones and other hard substrata on shallow soft bottoms. Except for the substrate demands, the most important factor for the geographical distribution of algal species is temperature. Algal species have an upper and lower limit of which they can reproduce, grow and survive and there are different temperature borders for the different life stages (Lüning 1990). Many algal species have their north-south boundaries along the Norwegian coast (Lüning 1990) and the number of species diminishes northwards (Hop et al. 2012).

The euphotic zone, where there is enough light for algal growth, is divided into three zones. The upper zone is the supralittoral and is defined as the area reached by spray water. The

range of this zone varies with the degree of wave exposure (Rueness 1977; Lüning 1990). Below the supralittoral is the littoral zone, which is defined by the upper and lower tidal range. The sublittoral zone extends downwards from the lower range of the littoral zone and down to the integrated compensation depth (Lüning 1990). In the upper sublittoral zone the algal vegetation is submerged at all times except for in extreme cases of low water levels (Lüning 1990). The benthic algal vegetation also has a vertical zonation in the euphotic zone. Generally, the upper growth limit for intertidal species is dependent on tolerance to desiccation and thermal stress (Lüning 1990). For sublittoral species the lower depth limit is set by light conditions, or in rare cases grazing events from e.g. sea urchins. (Lüning 1990; Kaiser et al. 2011). The distribution of sublittoral algal species can also be influenced by biological factors such as competition (Kaiser et al. 2011).

Macroalgal species are divided in the three main phyla Chlorophyta (green algae), Rhodophyta (red algae) and Ochrophyta, which includes the class Phaeophyceae (brown algae; Guiry and Guiry 2014). By first appearance, these three groups can be separated based on their color (red, green and brown), which is connected to their different pigment composition. Furthermore, at genus/species level important taxonomical characters used for delimiting species are thallus construction, chloroplast shape, internal structures, size, and reproductive structures among others.

Green, brown and red algae all have the pigment chlorophyll *a*. Members of Chlorophyta have, in addition, important accessory pigments such as chlorophyll *b*, lutein and β-carotene. The green color of the thallus in many chlorophytes is due to that chlorophyll *a* and *b* are not concealed by the accessory pigments (Graham et al. 2009). Green algal species (class Ulvophyceae) show a great variability in morphology, ranging from uniseriate unbranched and branched filaments, siphonous algal species to species with a larger blade-like thallus (Brodie et al. 2007; Graham et al. 2009; Pedersen 2011). Green algal species are mainly inhabitants in freshwater, but also occur in brackish and marine water (Brodie et al. 2007). Green algal species can be an indicator of nutrient rich waters (nutrient pollutions) due to their rapid growth in favorable conditions (Bokn et al. 2002, 2003; Kraufvelin et al. 2006). Along the Norwegian coast there are 99 chlorophytes registered (Rueness 1977).

Red algal species often have a red color, which is due to dominance of the accessory pigment phycoerythrin (Graham et al. 2009; Pedersen 2011). In addition, they also have the blue-green accessory pigments such as phycocyanin and allophycocyanin, and the thallus can vary in color from black to yellow (Bird and McLachlan 1992; Graham et al. 2009). Red algae have low light requirements for saturation of photosynthesis (low light adapted) and are therefore mostly found in the understory vegetation in the sublittoral zone (Gómez et al. 2009). Red algae may grow deeper than green and brown algae (Graham et al. 2009). The class Florideophyceae comprises the majority of the red algal species (Guiry and Guiry 2014). The simplest thallus construction in Florideophyceae is uniseriate branched filaments, and the more complex thallus construction is either uniaxial or multiaxial pseudoparenchyma (Graham et al. 2009; Pedersen 2011). The class Bangiophyceae comprises a small percent (3%) of the red algal species in relation to Florideophyceae (Guiry and Guiry 2014). Thallus construction within Bangiophyceae includes unicells, simple unbranched filaments and species that are blade-like (Graham et al. 2009). The red algal species are predominantly distributed in warm waters, and the diversity of red algal species thus diminishes northwards (Bird and McLachlan 1992; Graham et al. 2009). Along the Norwegian coast a total of 204 red algal species are registered (Rueness 1977).

The brown algal class Phaeophyceae comprises species which are uniseriate branched, pseudoparenchymatic and parenchymatic (Graham et al. 2009; Pedersen 2011). This is a diverse group ranging from small epiphytes (mm) to the large kelp species that can be several meters long. Brown algal species dominates in cold water where the kelp species form underwater forests in the sublittoral zone. These forests are highly important both for the ecosystem and commercially for their alginates (Christie et al. 2003). The pigment composition of brown algal species is comprised of chlorophyll c_1 and c_2, β-carotene, violaxanthin and fucoxanthin. The large amount of fucoxanthin gives the brown color of the thallus (Graham et al. 2009). Along the Norwegian coast a total of 175 brown algal species are registered (Rueness 1977).

1.2 Svalbard

Svalbard is an archipelago located at latitudes 74° and 81°N and longitudes 10° and 35°E. It is composed of three main islands: Spitsbergen, Nordaustlandet and Edgeøya, where Spitsbergen is the largest. Located north of the polar circle, Svalbard has light conditions with midnight sun in the summer and total darkness in the winter. This gives special life conditions for macroalgae, se below.

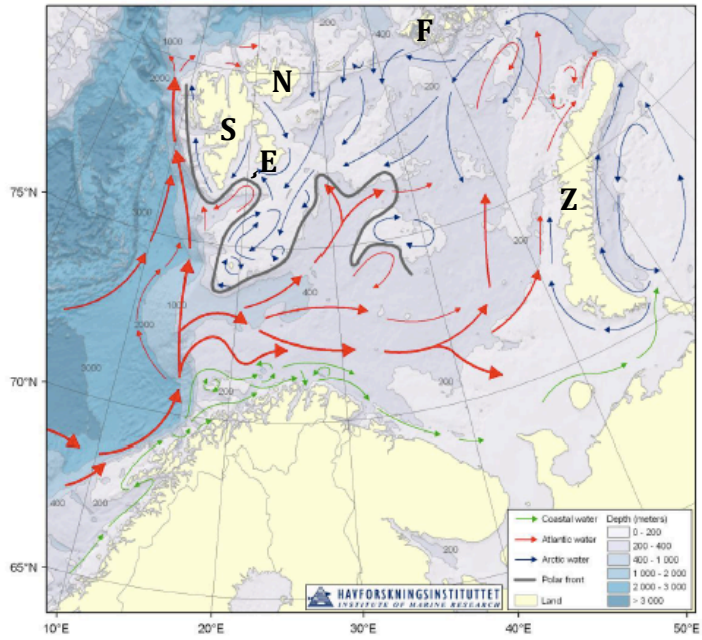


Figure 1. Map of currents around Svalbard (Stiansen and Filin 2007). The red arrows represent the currents carrying warm and salt Atlantic water. The blue arrows represent the cold Arctic water currents and the continuous gray line represents the polar front. S = Spitsbergen, N = Nordaustlandet, E = Edgeøya, F = Franz Josef Land, and Z = Novaja Zemlya.

The marine environment around the coasts of Svalbard has different characteristics due to the different incoming water currents. Atlantic water characterized by warm and salty water (temperature > 3°C and salinity > 34.9) flows northwards along the Norwegian coast as the Norwegian Atlantic Current and splits into two branches outside Troms County (Ingvaldsen and Loeng 2009). One branch enters the Barents Sea, while the other continues northwards along the continental slope on the west coast of Spitsbergen, as the West Spitsbergen Current (Fig. 1). The West Spitsbergen Current reaches the northern part of Spitsbergen before it sinks to intermediate depths (Fig. 1; Aagaard et al. 1987; Svendsen et al. 2002; Ingvaldsen and Loeng 2009). The presence of warm Atlantic water gives fairly stable conditions for

marine organisms along the west coast of Spitsbergen. The presence of warmer water also causes ice-free conditions throughout the year, west of the continental shelf slope, and partially ice-free conditions in the northern part of Spitsbergen (Aagaard et al. 1987; Lüning 1990; Svendsen et al. 2002). Cold Arctic water, which is characterized by lower salinity (34.4-34.7) and temperatures below zero, enters Svalbard from the Arctic Ocean between Nordaustlandet and Franz Josef Land (Fig. 1; Ingvaldsen and Loeng 2009). The Arctic water flows southwards along the east coast of Spitsbergen as the East Spitsbergen Current, rounding the southern tip and flows northwards on the west coast of Spitsbergen, between land and the West Spitsbergen Current (Fig. 1; Svendsen et al. 2002; Cottier et al. 2005; Ingvaldsen and Loeng 2009). The two water masses flowing northward are separated by a polar front. The front boundary between the Atlantic and Arctic water exist because of the difference in temperature and salinity (density), which is dependent on the season, between the Atlantic and Arctic water (Fig. 1; Cottier et al. 2005). The main fresh water supplies within Arctic fjords are from melting of glaciers and icebergs (Svendsen et al. 2002).

1.3 Environmental conditions

The macroalgal vegetation in Svalbard lives under harsh environmental conditions such as constant low temperatures, long periods of ice-covered waters (within fjords and on the east coast of Svalbard) and extreme light conditions. Temperature is of importance for the biogeographical distribution of algal species and there is a reduction in species richness in the Arctic in comparison to lower latitudes, also there are few endemic species for the Arctic (Wulff et al. 2009; Hop et al. 2012). Adaptions to low temperatures and limited light conditions allow the species to complete their life cycles in this environment (Gómez et al. 2009; Wiencke et al. 2009). However, macroalgae in the Arctic are less adapted to the cold environment (higher temperature optimum for photosynthesis than the environment they live in) compared to Antarctic species (Gómez et al. 2009). There are few studies from the Arctic related to temperature optima for macroalgae (Gómez et al. 2009). The Arctic is young in terms of geology and biogeography (Adey et al. 2008). The relatively young age of the Arctic gives a shorter time span for adaption to the cold environment, which might explain the lower number of endemic species in the Arctic compared to the Antarctic (Lüning 1990; Adey et al. 2008). The macroalgal flora today can be described as a poor North Atlantic flora with a few endemic species of north Pacific origin (Hop et al. 2012).

The temporal ice cover has a strong influence on the algal vegetation through ice scouring in the littoral zone and by limiting the availability of light for the algae in the sublittoral zone. The impact of scouring varies with the thickness of sea-ice (Ellis and Wilce 1961). Areas exposed to ice scouring have no or little algal vegetation in the supralittoral and littoral zone (Lüning 1990). In addition, if the ice is covered with snow the transmission of light down to the water column is further reduced (Hop et al. 2002). In late spring/summer when the ice has melted the algal vegetation receives enough light to photosynthesize (Lüning 1990). During the summer season the turbidity in the water increases and the salinity decreases, especially within fjords, due to runoff from land and melting of glaciers (Svendsen et al. 2002). The sublittoral algal vegetation in these conditions may be covered with a layer of silt, which also diminishes the available light for photosynthesis (Lüning 1990). The littoral zone and sublittoral zone are often dominated by annual or pseudoannual species such as *Chordaria flagelliformis*, *Pylaiella littoralis* and *Acrosiphonia* sp. that can survive the winter conditions as microscopic or rhizoidal stages (Hop et al. 2002, 2012). Despite the demanding light conditions of the Arctic region some algal species (e.g. kelp species) can reach a considerable size. The reason for this is that kelp species (e.g. *Laminaria solidungula*) can store photosynthetic products during the light season, which enable them to grow during the dark season when nutrients are available by using the stored carbon reserves. In this way, the new young laminas are ready to photosynthesize when the light season starts (Chapman and Lindley 1980; Dunton 1985; Dunton and Schell 1986; Lüning 1990).

1.4 Previous Research

The earliest studies of the marine benthic vegetation in Svalbard dates back to the 1800s starting with Sommerfelts study in 1832 who received herbarium material sent to him by M. Keilhau (Norwegian geologist) from Svalbard and Sommerfelt described 6 species. Lindblom (1840) compiled research from 5 earlier papers and extended the species list to a total of 16. Agardh (1862, 1868) studied material that was sent to him from Svalbard and described 51 different species. Wittrock (1874), Kjellmann (1875a, 1875b, 1877a) and Eaton (1876) did also contribute to pioneer works of algal vegetation at Svalbard. But the classic work of Kjellmann (1883) *The algae of the Arctic sea* is recognized as the first comprehensive collection on the macroalgal flora in Svalbard (Hop et al. 2012). The material was sampled from the west and north coast of Spitsbergen during the Vega expedition in 1872-1873. These early studies were followed by Per Svendsen's work in 1959. He studied the algal

composition in the outer part of Isfjorden on the west coast of Spitsbergen. In addition, Zinova (1961), Florczyk and Latala (1989), Hansen and Haugen (1989) and Weslawski et al. (1993, 2010) have made contributions to our knowledge on the algal distribution in Svalbard. The most comprehensive checklists of the marine benthic flora (to day) were drawn up by Vinogradova (1995a) and Hansen and Jenneborg (1996). Together with contributions from later studies by Gulliksen et al. (1999), Athanasiadis (2007, 2008), Hop et al. (2012), Fredriksen and Kile (2012) and Fredriksen et al. (2014) there is currently registered a total of 194 species in Svalbard; 49 Chlorophytes, 76 Phaeophytes and 69 Rhodophytes (Fredriksen et al. in prep). Even though there is a long history of surveys in Svalbard large areas of the coast are still unexplored, and only a few of the sites previously studied have been revisited.

1.5 Changes in climate

With a substantial contribution from anthropogenic activity, changes in the global climate are occurring (Larsen et al. 2014). These changes are especially visible in the Arctic (Bartsch et al. 2012 and references therein; Larsen et al. 2014). The observed changes such as the increase in ocean surface temperature, reduction of the sea ice cover at the end of the Arctic summer and melting of glaciers highly influence the habitat of marine organisms with respect to light and temperature regimes (Kortsch et al. 2012; Larsen et al. 2014).

Macroalgae are suitable indicators for changes in the environment because they are sessile organisms and cannot escape from the changes. It is believed that the changes in light conditions due to loss of sea ice and increased temperature may lead to abrupt regime shifts in the benthic community (Kortsch et al. 2012; Clark et al. 2013). To detect any possible changes it is important to perform baseline surveys.

1.6 Objectives

The main goal of this study was to identify the qualitative species composition of the macroalgal vegetation in the littoral and upper sublittoral zone at selected sites at Svalbard. The results from this study will be a contribution to the present knowledge on the macroalgal flora and may serve as a baseline for future studies. In relation to the main goal of this study, relevant questions have been formulated:

- Which species are present in the littoral zone and upper sublittoral zone at the sampling sites?
- Based on the identified taxa, are there similarities and differences in the species composition in the algal flora of the eight sites examined?
- How do the results compare to previous studies?

The present research is mainly based on identifying species using morphological characters observed under the microscope. Due to plasticity found in many species this approach is sometimes very challenging. A second goal was therefore to use DNA-barcoding as an additional method on the genus *Fucus* and *Ceramium,* and digitate kelp specimens.

2. Materials and methods

Sampling was conducted during a ten-day cruise from 1st of July to 10th of July 2013 on M/S Stålbas. The cruise included several research teams and objectives, and my study was defined within this pre-defined survey program around Svalbard (counter clockwise) providing eight sampling days.

2.1 Sampling area

Eight sites located along the coast of Svalbard were sampled during the cruise (Fig. 2; Table 1). The sampling sites were reached by using a small rubber boat deployed from M/S Stålbas.

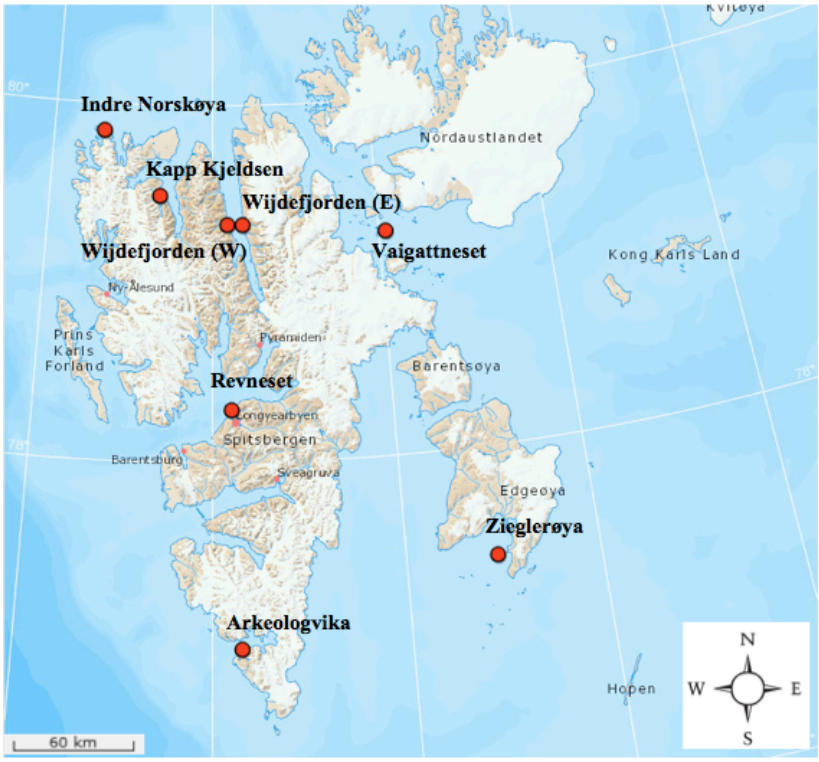


Figure 2. Map of Svalbard showing the sampling sites. Map source: Norwegian Polar Institute (2014)

Table 1. Geographical positions (WGS84), names of the sampling sites, and date of sampling.

Site	Latitude	Longitude	Date of sampling	Name of location
1	76°56`50``N	15°46`26``E	02.07.2013	Arkeologvika, Hornsund
2	77°22′47″N	22°22′83″E	04.07.2013	Zieglerøya, Tjuvfjorden
3	79°15′14″N	20°13′4″E	06.07.2013	Vaigattneset, Sofiaøya
4a	79°19′8″N	15°57′7″E	07.07.2013	Wijdefjorden east
4b	79°19′26″N	15°28′59″E	07.07.2013	Wijdefjorden west
5	79°29’0’’N	13°25’42’’E	08.07.2013	Kapp Kjeldsen, Woodfjorden
6	79°50’38’’N	11°37’51’’E	09.07.2013	Indre Norskøya, Norskøyane
7	78°17’12’’N	15°33’42’’E	10.07.2013	Revneset, Isfjorden

2.1.1 Ice condidions

The ice cover at Svalbard has its largest extent between March and May (Comiso et al. 2008). Figure 3 shows the ice cover the 2nd of April 2013 that represents approximately the maximum ice cover in 2013. Sampling sites are indicated with black dots in the figure. Figure 3 shows in gray color fjords and coastal areas covered with fast ice, and very close drift ice in red color. Orange, yellow and green indicate close drift ice, open drift ice, and very open drift ice, respectively. Blue color shows open water areas. The map shows that Zieglerøya (site 2), Sofiaøya (site 3), Wijdefjorden (site 4a and 4b) and Woodfjorden (Kapp Kjeldsen, site 5) were covered by fast ice and very close drift ice. Hornsund (Arkeologvika, site 1) was influenced by open drift ice and close drift ice. Norskøyane (Indre Norskøya, site 6) north of Spitsbergen was influenced by very open drift ice and open water. That was also the case for Isfjorden (Revneset, site 7).

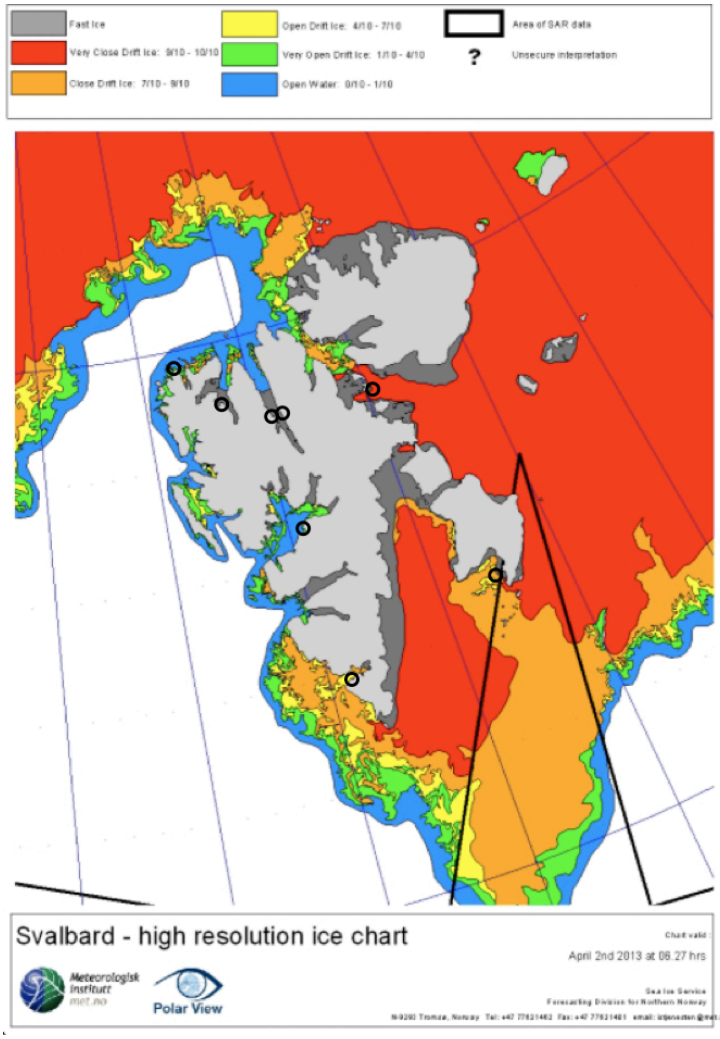


Figure 3. Ice chart of Svalbard at 02.04.2013. The map shows the areas covered with fast ice (gray color), very close drift ice (red color), close drift ice (orange color), open drift ice (yellow color), very open drift ice (green color) and open water (blue color). The black dots indicates the sampling sites. The map is retrieved from met.no.

2.1.2 Description of the sites

Site 1. Arkeologvika, Hornsund

Site 1 was located in the southern part on the west coast of Spitsbergen. The sampling was done in Arkeologvika, Hornsund the 2nd of July 2013 (Fig. 2; Table 1). Hornsund is west-east oriented and Arkeologvika is located in the outer part of the fjord. The area was composed of cliffs and gravel (Fig. 4). During sampling the water turbidity was low (visual judgment) and there was well-developed algal vegetation both in the littoral and in the shallow sublittoral zone at the sampling site (Fig. 4).

Site 2. Zieglerøya, Tjuvfjorden

Zieglerøya is located in Tjuvfjorden in the southern part of Edgeøya. The sampling was conducted in a bay in the southern part of Zieglerøya 4th of July 2013 (Fig. 2; Table 1). A sandy shore with larger boulders characterized the site (Fig. 5). There was little algal growth on the boulders in the littoral zone, indicating that the area had been exposed to ice scouring. The water clarity was relatively good during sampling (visual judgment).

Site 3. Vaigattneset, Sofiaøya

Vaigattneset is located on Sofiaøya in Hinlopenstredet on the east side of Spitsbergen. Sampling was done 6th of July 2013 (Fig. 2; Table 1). The location was composed of a sandy shore with gravel surrounded by large boulders (Fig. 6). The water turbidity was relatively low at the time of sampling (visual judgment). The boulders in the upper littoral zone were scoured free from algae.

Site 4a. Wijdefjorden east

Wijdefjorden is located in the northern part of Spitsbergen, penetrating the island from north to south. Wijdefjorden east was sampled the 7th of July 2013 (Fig. 2; Table 1). The sampling site was a skerry dominated by small stones and gravel and located in close proximity of a river outlet. The water turbidity was high during sampling (visual judgment; Fig. 7).

Site 4b. Wijdefjorden west

The west side of Wijdefjorden was sampled the 7th of July 2013 (Fig. 2; table 1). The area was composed of smaller rocks and cliffs (Fig. 8). The sampling was performed around the cliff showed in Fig. 8. The water turbidity was partly high during sampling and the vegetation

scarce with the exception of a patch of algae just outside the cliffs (visual judgment). The kelp collected were partly covered in a sediment layer.

Site 5. Kapp Kjeldsen, Woodfjorden

Kapp Kjedsen is located in Woodfjorden and the entrance is situated on the northern side of Spitsbergen, close to Wijdefjorden. Woodfjorden is oriented in a north-south direction and the sampling site was in the middle/inner part of the fjord, near the entrance to Bockfjorden (Fig. 2). The sampling was conducted the 8th of July 2013 (Table 1). The area was composed of cliffs, boulders and smaller rocks. The water turbidity was high at the time of sampling (visual jugdment; Fig. 9).

Site 6. Indre Norskøya, Norskøyane

Indre Norskøya is part of a group of smaller islands named Norskøyane, north of Spitsbergen. This was the northernmost site, sampled the 9th of July 2013 (Fig. 2; Table 1). The water turbidity was low and there were few signs of ice scouring (visual jugdment). The area was composed of cliffs and bigger rocks with well-developed algal vegetation, especially in the sublittoral zone (Fig. 10).

Site 7. Revneset, Isfjorden

Revneset is located in Isfjorden near the entrance to Adventfjorden. Isfjorden is oriented in a west-east direction. The sampling was conducted the 10th of July 2013 (Fig. 2; Table 1). The area was composed of soft bottom, smaller rocks, boulders and cliffs (Fig. 11). The water turbidity was very high at the time of sampling (visual jugdment).

Figure 4. The sampling site Arkeologvika in Hornsund.

Figure 5. The sampling site at Zieglerøya, showing the sandy shore with boulders.

Figure 6. The sampling site Vaigattneset at Sofiaøya.

Figure 7. The sampling site Wijdefjorden east.

Figure 8. The sampling site Wijdefjorden west.

Figure 9. The sampling site Kapp Kjeldsen.

Figure 10. The sampling site Indre Norskøya.

Figure 11. The sapling site Revneset in Isfjorden.

2.2 Sampling methods

2.2.1 In the field

At each site benthic macroalgae were sampled from tide pools, the littoral zone and upper sublittoral zone. This was carried out, to the extent that it was possible, during low tide. A tide table for Longyerbyen (downloaded from the Norwegian Mapping Authority's website www.kartverket.no) was used to estimate the time of the day with low tide at each site. In July there is midnight sun in the Arctic and the sampling was carried out both day and night depending on logistical aspects. In tide pools the algae were collected by hand. In the littoral zone algae were collected by hand picking from the shore, hand picking when snorkeling and by use of a throwable rake. In the upper sublittoral zone algae were collected by hand picking and with a throwable rake while snorkeling. Pictures from the sites were taken both over and under water with an Olympus TG3 pocket camera. The samples were stored in buckets with seawater and brought back to M/S Stålbas. The macroalgae sampling was conducted in collaboration with Prof. Stein Fredriksen. In addition, two researchers from the University Stazione Zoologica Anton Dohrn in Naples, Italy, joined the team and collected own material from the shore and also functioned as polar bear guards for the group.

2.2.2 Sorting of the samples

Samples were sorted onboard M/S Stålbas. This was done by going through the collected material using trays for better visualization and tweezers for picking out specimens of the different algal species. The specimens picked out for further identification was preserved with 2% formalin solution in 0.5 L bottles. Smaller algal samples were stored in 25 mL vials, also with 2 % formalin. The samples were labeled with site number and the date of sampling. All samples were shipped to the laboratory at the University of Oslo for morphological identification.

The use of only morphological characters to identify some species of macroalgae can be challenging due to their variability in appearance and similarity to other related species. To improve the identification, DNA barcoding was applied to digitate kelp and species within the genera *Ceramium* and *Fucus*. From six of the sites, samples from individuals within the three groups were collected for molecular identification (Table 2). For this analysis an approximately 2x2 cm piece of tissue was cut out from the individuals. The tissue was stored and dried in 25 mL vials with silica crystals. The vials were labelled with station number,

date and genus/family and stored at room temperature. In addition to own samples specimes identified *in situ* to *Laminaria hyperborea* (labeled 3L-5L) and *Laminaria digitata* (labeled P1) from the Norwegian mainland was included.

Table 2. The number of individuals sampled from each site within the different species groups.

Site	No. of specimens Digitate kelp	No. of specimens *Fucus*	No. of specimens *Ceramium*
2	3	3	-
3	3	3	-
4b	3	6	-
5	3	5	3
6	3	6	-
7	1	3	-

2.3 Morphological identification

The species collected were identified to the lowest taxonomic level possible by use of morphological characters. This was done either in the field or in the laboratory at the University of Oslo. Identification of the kelp species *Alaria esculenta, Saccharina latissima* and *Laminaria solidungula* was done by eye in field. Due to their large size only one or two specimens were brought back to the University of Oslo.

2.3.1 In the laboratory

To prepare the samples for identification the formalin solution was removed and the algae rinsed in fresh water. They were then stored in seawater for at least 24 hours to remove remaining formalin. The material was first examined under a stereo microscope (Nikon smz-10A, Japan), at this stage some of the larger specimens could be identified. The smaller algae were examined with a compound microscope (Nikon eclipse E200, Japan) to have a closer look at the morphological characters (x100-400). If needed transverse sections were made on both the small and large algae to examine the internal structures. One character used to identify some species was cell diameter. This was measured with a ruler in the ocular, which was calibrated to an object micrometer. The compound microscope was also set up with a camera system (DS-5M-L1; Nikon, Tokyo). In this way, the slide with the algae examined could be viewed on a computer screen, measurements taken through the computers tool menu directly on the image and captured in a photo. In green algae the number of pyrenoids per cell is a character used for identification, iodine was therefore added to the slide to stain the starch surrounding pyrenoids.

A permanent collection was made of the identified algae (Appendix VII). This was done by placing the algae on a slide and adding a drop of a mixture containing 20 mL of distilled water, 10 mL of corn syrup, 10 mL 38% formalin and 1 mL 1% aniline. Each slide was numbered and kept in a reference collection. A herbarium was made of the larger specimens. The algae were carefully placed on a piece of cardboard, covered with gauze and placed within a newspaper and then pressed to dryness. Each herbarium sheet was carefully labeled with species name according to the nomenclature of Guiry and Guiry (2014). The permanent collection is deposited at the University of Oslo.

2.3.2 Literature

The species were identified by use of different literature. Literature used for red, green and brown algae were: Pedersen (2011), Rueness (1977), Vinogradova (1995b), Taylor (1957), Lund (1959), Jaasund (1965). Some literature was more specific, such as Flecher (1987) for brown algae, Maggs and Hommersand (1993) and Bird and McLachlan (1992) for red algae and Brodie et al. (2007) for green algae.

2.4 Molecular analyses

To ensure species identification DNA-barcoding was applied to digitate kelp and species within the genera *Ceramium* and *Fucus*. The molecular analysis include several steps of accurate lab work from extracting the DNA, multiplying (amplify) a selected specific region of the DNA, examine the extractions to cleaning the product before the samples are sequenced. The output is analyzed and edited through specific software. The sequences are then compared to GenBank where a search algorithm, basic local alignment search tool (blast), identifies the most similar sequences in this library. A phylegenetic tree is constructed based on the most similar sequences form GenBank and sequences from related species.

2.4.1 DNA extraction

To ensure polymerase chain reaction (PCR)-amplifiable DNA, a cetyltrimethyl ammonium bromide (CTAB) extraction protocol, modified from Doyle and Doyle (1987) was used on all three taxonomic groups (Table 2). Brown algal tissue contains PCR inhibiting compounds such as polysaccharides, tannins and phenols that usually make extraction using DNA extraction kits unsuccessful (Lane et al. 2006; Hoarau et al. 2007; McDevit and Saunders 2009). The extractions were always performed with one blank sample in addition to the

samples containing DNA. This was done to have a negative control for contamination of the extractions.

2-4 mg of silica-dried tissue was transferred to 2 mL safety eppendorph tubes. One Qiagen stainless steel bead (3 mm) was added to each eppendorph tube and the tissue was grinded in a Retsch Mixer Mill MM 301 for 60-75 seconds at frequency 25. The beads were removed by use of a magnet. Cell lysis was done by adding 600 μL of CTAB-buffer consisting of 2% CTAB with 1% β- mercaptoethanol to the grinded tissue. The samples were then vortexed (VWR Analog Vortex Mixer, VM-3000, USA) and incubated on the bench in room temperature for one hour. To remove PCR inhibiting compunds from the DNA, 500 μL chloroform mix consisting of chloroform and isoamylalcohol in the relation 24:1 was added. The samples were shaken regularly for 10 min and vortexed twice. Next, the samples were centrifuged at 12000 rpm for 5 min. This resulted in an organic phase and a water phase (supernatant), the latter containing the DNA. The supernatant, approximately 400 μL, was carefully transferred to a new 2 mL safety eppendorph tube. Then 800 μL of ice-cold isopropanol was added and the samples were flipped gently to mix isopropanol with the supernatant. DNA was precipitated at -20°C for a minimum of 30 min. After incubation, the samples were centrifuged at 13000 rpm for 10 min. The supernatant was carefully poured out leaving only the solid DNA, and the eppendorph tube was then placed upside down on lab-tissue to dry. To clean the DNA 600 μL of 70 % ethanol was added and the samples flipped gently for mixing. The samples were then centrifuged at 12000 rpm for 2 minutes. This step was repeated one time and the eppendorph tubes were then placed upside down on lab tissue until the ethanol had evaporated. 100 μL 0.1 x Tris Ethylene Diamine-Tetra-acetic Acid buffer (TE buffer) was added and samples stored in the fridge overnight.

To examine if the extractions had been successful a gel electrophoresis was performed on the first DNA isolates and their corresponding blank control sample. This was done on a 0.7 % agarose gel with 3 μL GelRed (Biotium, USA). The GelRed binds to the DNA and makes it possible to visualize under UV-light. 4 μL of DNA isolate was mixed with 1 μL loading dye before loading 3 μL into wells in the agarose gel. The loading dye colors the template and therefore visualizes the transfer of DNA into the wells and the migration of DNA when the gel is running. It also helps the sample to sink in the well by making it denser than the running buffer. The ladders Gene ruler 1 kb (Thermo Scientific, Germany) with a 250-10,000

basepair (bp) range and Fast ruler Low Range (LR) with a 50-1500 bp range (Thermo Scientific, Germany) was used as a reference for the size of the DNA-fragments. One ladder was added to the first well while the other was added to the last well. The gel ran for 8 min at 210 V and was then checked under UV light in GeneFlash (Syngene Bio Imaging).

2.4.2 Polymerase chain reaction

Polymerase chain reaction is a method used to synthesize millions of copies a target DNA-region (the wanted marker region, barcode region). This is obtained by using the isolated DNA as a template. Short strands of synthetic nucleate acid (primer), designed to bind to a specific region in the DNA, binds to the 3' ends of single stranded DNA (ssDNA). DNA polymerase binds to the primers and synthesizes a new DNA strand from the 3' ends of both the forward and reverse primer (Watson et al. 2008). Polymerase chain reaction was used to amplify the barcode regions mt COI gene, mtspacer and the plastid rubisco spacer. These regions have been shown to be able to differentiate between species of kelp, *Fucus* and *Ceramium* respectively (Gabrielsen 2002 ; Coyer et al. 2006; McDevit and Saunders 2009).

For each DNA isolate, a master mix was prepared containing 1 x 12.5 μL DreamTaq Green Master Mix (Thermo Scientific, Germany), 0.4 μM forward primer, 0.4 μM reverse primer and 8.5 μL nuclease free water. The PCR-master mix was prepared in 2 mL safety eppendorph tubes and then transferred to a 0.2 mL eppendorph 8-tube strip. 2 μL DNA-template was then added in each tube into the PCR-master mix. In addition to the samples containing DNA, a blank sample was made to have a negative control. This sample contained the master mix, but DNA-template was not added. Due to the PCR inhibiting compounds that often are co-extracted with DNA, a PCR with four different dilutions (DNA stock, 10x, 100x and 1000x) of the DNA isolates was performed to optimize the best dilution. For all three groups a 100 times dilution of the DNA isolates was used in the PCR master mix.

Digitate kelp

The barcoding region used for the digitate kelp was the 5'end of the mitochondrial cytochrome c oxidase I (COI-5P) which is approximately 600-700 bp. This region was amplified using forward primer GazF2 (biomers.net, Ulm, Germany; 5′ CCAACCAYAAAGATATWGGTAC 3′) and reverse primer GazR2 (biomers.net, Ulm, Germany; 5′ GGATGACCAAARAACCAAAA 3′) (Lane et al. 2007). The PCR program

used had an initial denaturation temperature (the temperature where the double stranded DNA separates into single ssDNA) at 94°C lasting for 3 minutes followed by 35 cycles with denaturation at 94°C for 30 sec. The annealing temperature (where the primers attach to the ssDNA) was set at 49°C for 45 sec and elongation at 72°C for 1 min. The elongation step is when the DNA-polymerase attach to the primers and synthesize new DNA-strands based on the templates. The 35 cycles were completed with a final elongation step at 72°C for 10 minutes. The samples were then stored at 4°C until further analyses.

Fucus

The marker chosen for the *Fucus* samples was the mitochondrial intergenic spacer which is approximately 600-700 bp. The intergenic spacer is located between the 23S rRNA and trnk gene. The forward primer was mtDNA spacer-F (biomers.net, Ulm, Germany; 5′ CGTTTGGCGAGAACCTTACC 3′) and the reverse primer was mtDNA spacer-R (biomers.net, Ulm, Germany; 5′ TACCACTGAGTTATTGCTCCC 3′) (Coyer et al. 2006). The PCR program had an initial denaturation temperature at 94°C for 2 min, then 40 cycles of denaturation at 94°C for 30 sec, annealing at 50°C for 1 min and elongation at 72°C for 1 min. The 40 cycles was followed by a final elongation step at 72°C for 5 min. The PCR products were stored at 4°C until further use.

Ceramium

The barcode region used for *Ceramium* was the plastid marker rubisco spacer that is approximately 380-390 bp. The forward primer used for amplification was rbcLspFor (biomers.net, Ulm, Germany; 5′ TGTGGACCTCTACAAACAGC3′) and the reverse primer was rbcLspRev (biomers.net, Ulm, Germany; 5′ CCCATAGTTCCCAAT3′) (Goff et al. 1994). The PCR program had an initial denaturation step at 96 °C for 2 min then 35 cycles with denaturation at 94°C for 45 sec, annealing at 50°C for 45 sec and annealing at 72°C for 1 min. The 35 cycles was followed by a final elongation step at 72°C for 7 min. The samples were stored at 4°C until further analyses.

2.4.3 Agarose gel electrophoresis

To examine if the DNA amplification had been successful and if there had been any contamination the PCR-products were run on a 1.5 % agarose gel with 3 μL GelRed

(Biotium, USA). Because DreamTaq Green Master Mix (Thermo Scientific, Germany) was used in the PCR-master mix, loading dye was not needed. 3 μL of Gene ruler 1 kb and Fast ruler LR was used as ladders. The gel was run for 8 min at 210V and the gel was then checked under UV light. A successful PCR would show a bright band indicating amplified DNA and the negative control without such a band.

2.4.4 Cleaning the PCR products and Sanger sequencing

The PCR products were cleaned for impurities such as primers, enzyme and salts. This was done by using the E.Z.N.A. Cycle Pure Kit (Omega Bio-Tek Inc., Georgia, USA; Omega Bio-Tec Inc. 2009) according to the producer`s recommendation (Omega Bio-Tec Inc. 2009; Appendix I).

The digitate kelp samples were Sanger sequenced at the ABI-lab at the University of Oslo. To prepare the samples for sequencing 3 μL of cleaned PCR product was mixed with 6 μL of MilliQ-water and 0.1 μM primer. The *Fucus* and *Ceramium* samples were sent to GATC Biotech (Germany) for Sanger sequencing. They were prepared by mixing 5 μL of cleaned PCR-product with 2.5 μM primer. Both forward and reverse strands were sequenced. The *Fucus* samples were all sequenced with the reverse primer and then 11 sequences were chosen as representatives. This was done by aligning the reverse sequences with the "De Novo Assembly" option in Geneious 7.0.6 (Biomatters, New Zealand) to examine if they were identical or showed some variation. To capture the differences, two or three sequences representing each variation seen in the alignment was chosen and then sent for sequencing with the forward primer. With this approach high quality sequences could be obtained at a lower cost.

2.4.5 Data analyses

The Sanger sequencing data was edited and analyzed using Geneious v. 7.0.6 (http://www.geneious.com, Kearse et al. 2012). The individual sequences were manually trimmed in both the 5′ and 3′ end to remove low quality bases. The automated trimming option "trim ends" was used as a guideline with the error probability limit set to 0.05. The forward and reverse sequences were then assembled by use of the "De Novo Assemble" option to create high quality consensus sequences. After assembly the sequences were manually inspected to ensure that a good consensus was created. The consensus sequences

were blasted against the National Center for Biotechnology Information's (NCBI) GenBank using Megablast in Geneious. The results were shown in a hit table and the e-value, grade, pairwise identity and the query cover were inspected. The reference sequences used in the phylogenetic analyses were chosen based on the result from the blast search. In addition, reference sequences from closely related species were also downloaded from NCBI's GenBank.

2.4.6 Phylogenetic analyses

Species identification of digitate kelp, *Fucus* and *Ceramium* was ensured using phylogenetic analyses of the obtained COI, mtspacer and rubisco spacer sequences, respectively. For each of the three groups a multiple alignment was prepared in Geneious v. 7.0.6 (http://www.geneious.com, Kearse et al. 2012) based on reference sequences and the sample sequences using the MUSCLE algorithm with 100 iterations. For quality control, the alignments were run through gbloks 0.91b (Castresana 2000; Talavera and Castresana 2007) with less strict selection of blocks (allow for smaller fine blocks, allow for gap positions in finer blocks and less strict flanking positions). The most appropriate evolutionary model for the three alignments were identified using jModeltest 2.1.6 (Darriba et al. 2012, Guindon and Gascuel 2003) with the Bayesian information criteria (BIC). The best-suited model was used in the phylogenetic analyses if possible. The best-suited models for *Fucus* and *Ceramium* was not an option in Geneious and the best model available was therefore chosen (Table 3).

Table 3. Results from the jModeltest for digitate kelp, *Fucus* and *Ceramium*. It also shows which evolutionary model that was chosen for each of the three algal groups.

Algal group	Model no. 1	Model no. 2	Model no. 3	Chosen model
Digitate kelp	HKY+G	-	-	HKY+G
Fucus	TPM1uf+G	TPM1uf	HKY+G	HKY+G
Ceramium	HKY+I	HKY+G	-	HKY+G

Bayesian analysis

Bayesian analysis uses Bayes theorem to obtain the posterior probability distribution of each tree. To find the best inference of phylogeny, MrBayes 3.2.2 (Huelsenbeck and Ronquist 2001) uses a variant of Markov Chain Monte Carlo (MCMC) sampling (Lemey et al. 2009). Phylogenetic analyses were run using MrBayes 3.2.2 (Huelsenbeck and Ronquist 2001) in Geneious for all three algal groups. The alignments including reference sequences and sample sequences were chosen and the analyses were run separately for the three alignments

with the best substitution model available for the data sets (Table 3). The MCMC settings were as follows: chain length was set to 1.100.000 and burn-in length at 100.000. The Molecular clock with uniform branch lengths option in the prior settings was chosen. Consensus trees were constructed based on the output raw tree files from MrBayes using the consensus tree builder in Geneious where the support threshold was set to 60% and the burn-in was set to 25%.

Maximum likelihood

Maximum Likelihood is a method to infer relationships between sequences and it assumes independent evolution of each nucleotide site. Summing all sequence positions generates the likelihood. The tree yielding the highest likelihood is chosen as the best tree (Lemey et al. 2009). However, as testing all possible trees are impossible various heuristics are applied for the topology search (Lemey et al. 2009). A maximum likelihood analysis was performed using the PhyML algorithm (Guindon and Gascuel 2003) in Geneious. The substitution model used for all three data sets is given in table 3. The phylogenetic analyses were tested using 1000 bootstrap replications. Both the nearest-neighbor interchange (NNI) and Subtree Pruning and regrafting (SPR) were included in the topology searches.

2.5 Cluster analysis

A cluster analysis of the eight sites was performed based on the presence/absence of identified taxa. Unidentified green and brown algae and unidentified epiphytes were excluded from the data. The analysis was done using R (2.15.1). The distance matrix was calculated with the Jaccard similarity index (Jaccard 1902; Jaccard 1912), and the cluster analysis was done by using hclust script in R. The default setting for hierarchical clustering in hclust was applied which uses the complete linkage method (Yau 2009-2015). In this method each station starts of as a cluster of its own (dissimilarity = 0) and based on the distance matrix, the shortest distance is combined into a new cluster, the most similar stations with respect to species composition. The clusters are sequentially combined until all stations are included in one big cluster. The combination of clusters in this metod is based on all stations in the clusters and the distance between two clusters equals the distance between station pair (one in each cluster) that is farthest away from each other (Yau 2009-2015).

3.Results

3.1 Mapping

3.1.1 Distribution of identified taxa

A total of 53 different taxa were registered in this survey, 12 green algae, 15 red algae, 25 brown algae and one Xanthophyta, excluding the unidentified brown and green algae and unidentified epiphytes (Fig. 12). The brown algae were dominating at all eight sites. The highest number of taxa (34) was identified from site 6 (Indre Norskøya) with 10 green algae, 6 red algae, 17 brown algae and one Xanthophyta. Site 4a (Wijdefjorden east) had the lowest number of taxa (4 brown algae, 2 green algae and one Xanthophyta; Fig. 13). A complete list of species is given in Appendix III.

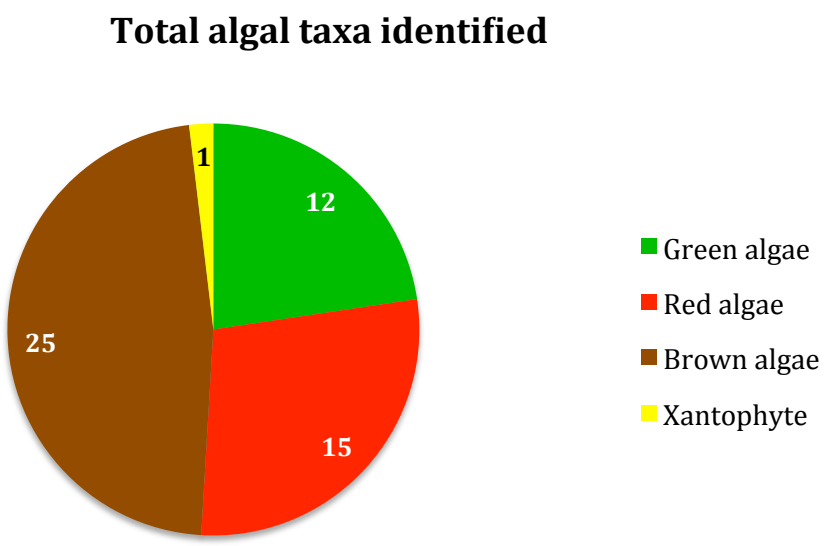


Figure 12. Pie chart showing the total number of identified algal taxa excluding the unidentified specimens.

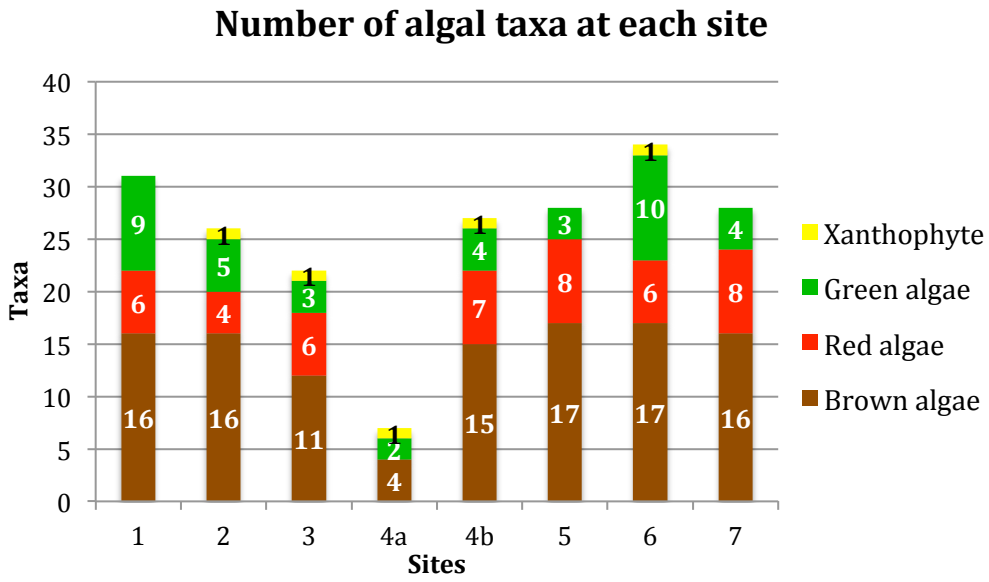


Figure 13. Bar chart showing the number of identified taxa of brown algae (brown color), red algae (red color), green algae (green color) and the xanthophyte (yellow color) at the sampling sites 1 (Arkeologvika), 2 (Zieglerøya), 3 (Vaigattneset), 4a (Wijdefjorden east), 4b (Wijdefjorden west), 5 (Kapp Kjeldsen), 6 (Indre Norskøya) and 7 (Revneset). The unidentified algal specimens are not included.

Locations

Site 1 and 6 had well developed algal vegetation in the littoral zone composed of *Fucus distichus* and various filamentous green and brown algae. The sublittoral zone at site 1 and 6 was a kelp canopy of *Alaria esculenta*, *Saccharina latissima* and digitate kelp (*Saccharina groenlandica* site 6). The littoral zone at site 2 and 3 was poor. The upper sublittoral at site 2 and 3 was mainly composed of *Fucus distichus*, filamentous green and brown algae and red algae such as *Palmaria palmata* and *Devaleraea ramentacea.* In addition, a belt of kelp species (*Alaria esculenta, Saccharina latissima* and *Saccharina groenlandica*) was present in the upper sublittoral zone. At site 4a *Fucus distichus* and filamentous green and brown algae was sampled from small tide pools. The water turbidity at site 4a was high at the time of sampling and the upper sublittoral zone was therefore not visible. Site 4b had little algal growth in the littoral zone. The upper sublittoral zone was dominated by filamentous green and brown algae and a pach of kelp species. Site 5 and 7 had poor algal vegetation in the littoral zone mainly filamentous algal species in cracks on the cliffs. The water turbidity at site 5 and 7 was high and the algal vegetation in the upper sublittoral zone was therefore not visible.

3.1.2 Cluster analysis

Result from the cluster analysis based on presence-absence of the identified taxa is given in Fig. 14. Site 5 (Kapp Kjeldsen) and site 7 (Revneset) showed the highest similarity (least dissimilarity) by forming the first clade in the dendrogram (Fig. 14). The next clade was formed by site 2 (Zieglerøya) and 3 (Vaigattneset) that clustered together with site 4b (Wijdefjorden west). The next sites to form a clade were site 1 (Arkeologvika) and site 6 (Indre Norskøya). Site 4a (Wijdefjorden east) is the least similar site to the other sites (Fig. 14).

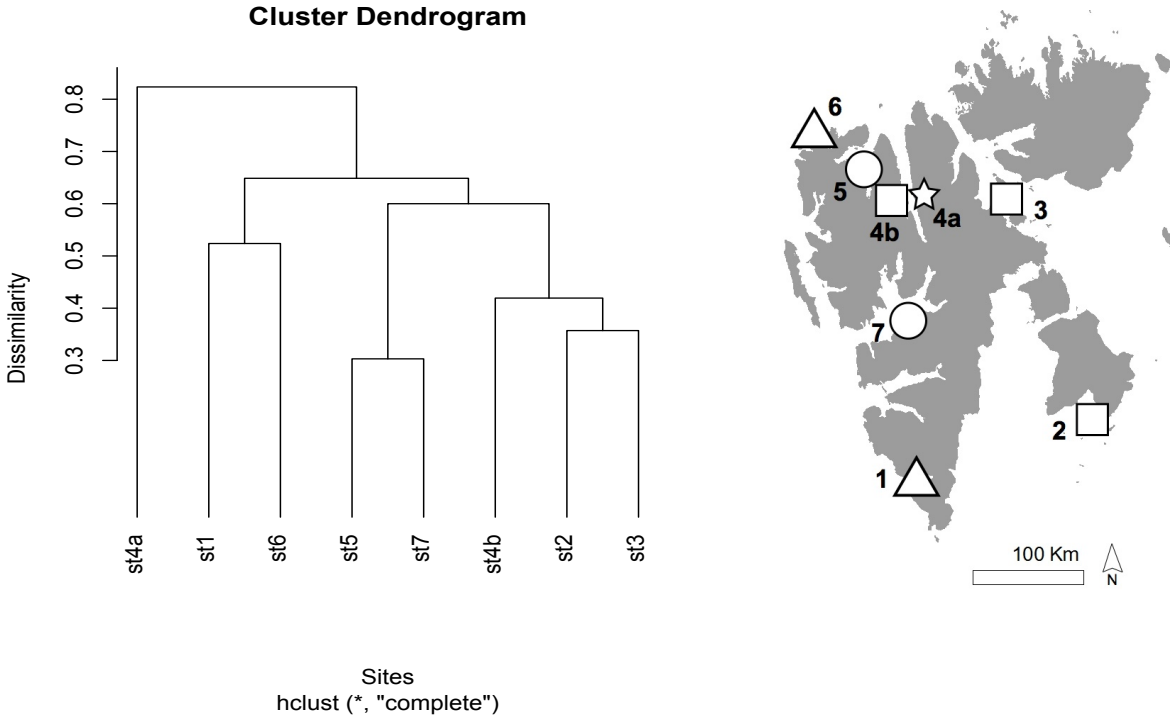


Figure 14. Cluster dendrogram based on presence-absence of the species identified from this survey using Jaccard similarity index and the complete linkage method for hierarchical clustering. The y-axis show the dissimilarity from 0-1, 1 being the most dissimilar. The map of Svalbard visualizes the sites that clustered together in the dendrogram. The sites with equal symbols were similar according to the cluster analysis.

3.2 Taxonomic overview

The following section is a taxonomic overview of the identified species with a description and references to relevant literature. The identification is based on morphological characters and ensured by DNA-barcoding of digitate kelp, *Fucus* and *Ceramium*.The taxonomic overview follows the nomenclature of Guiry and Guiry (2014). Each species description has an adjacent map of Svalbard visualizing where the species was identified. The black dots represent the sites where the species were found. The white dots represent the other sites in the survey where the specimens were not found. The presence or absence of fertile structures was registered for each species because this is an important character when identifying many algal species. The presence of fertile structures also shows that the specimens may be reproducing sexually in this environment and are not only dependent on vegetative formation such as fragmentation.

Phylum: Chlorophyta

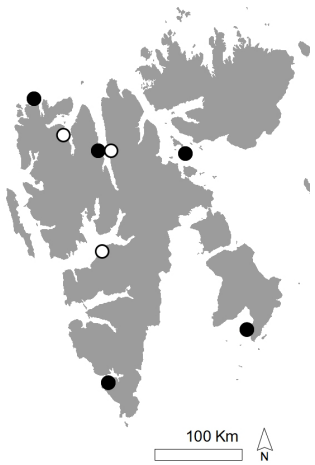
When identifying species in the phylum Chlorophyta the number of pyrenoids per cell is an important character. There were some difficulties with coloring the starch around the pyrenoids. In some specimens the entire cell turned black and the number of pyrenoids was therefore difficult to visualize.

Class: Ulvophyceae

Order: Cladophorales

Family: Cladophoraceae

Chaetomorpha melagonium (F. Weber & Mohr) Kützing



Description: The filaments were straight, uniseriate and unbranched with a cell diameter of approximately 350 μm. The filaments had a dark green color. The cells were elongated and cylindrical near the base and barrel shaped in the middle part. According to the literature *C. melagonium* has a cell diameter between 210-1050 μm (Brodie et al. 2007), The shape of the cells also fits with the description by Brodie et al. (2007).

Site: Identified from Arkeologvika, Zieglerøya, Vaigattneset,

Wijdefjorden west and Indre Norskøya.

Fertile structures: Not found

Permanent collection: Plate 1: A and herbarium specimen 1.

Order: Ulotrichales

Family: Ulotrichaceae

Acrosiphonia arcta (Dillwyn) Gain

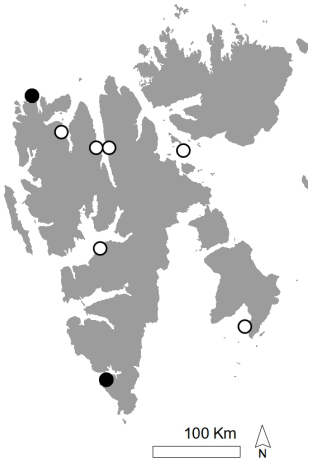
Description: *Acrosiphonia arcta* is composed of many irregularly branched uniseriate filaments with rounded tips. This species can have branches shaped like a hook (Rueness 1977; Brodie et al. 2007; Pedersen 2011). The specimens in this survey lacked such hook-shaped branches. The specimes were identified to *Acrosiphonia arcta* based on the brancing pattern and cell size. The chloroplast is parietal with several pyrenoides per cell (Brodie et al. 2007). Rueness (1977) describes this species with a cell diameter from 40-80 μm, Pedersen (2011) from 82-106 μm and Brodie et al. (2007) covers the whole size range from 40-120 μm. The cell diameter of the specimens from this survey were up to 100 μm.

Site: Identified from all eight stations

Fertile structures: Not found

Permanent collection: Permanent slide 1 and plate 1: B.

Acrosiphonia sonderi (Kützing) Kornmann



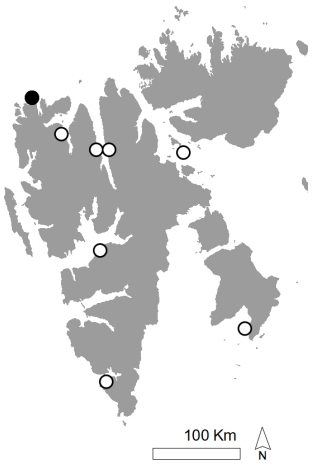
Description: The species resembles the latter but the diameter of the cell is larger, 129-196 μm according to Pedersen (2011) and 120-300 μm according to Rueness (1977). The specimens identified had a cell diameter ranging from 130 to 250 μm. *Acrosiphonia sonderi* also lacks the hook shaped branches that may occur in *A. arcta* (Pedersen 2011). The gametangia occurs as darker green cells within the filament (Pedersen 2011).

Site: Identified from Arkeologvika and Indre Norskøya

Fertile structures: Gametangia was found.

Permanent collection: Permanent slide 2 and plate 1: C.

Spongomorpha aeruginosa (Linnaeus) Hoek



Description: *Spongomorpha aeruginosa* is composed of uniseriate branched filaments, several being entangled together. The diameter of the cell is 25-30 μm and the branching of the filaments can be sparse or dense according to Brodie et al. (2007). Specimens identified had a cell diameter up to 35 μm, and were sparsely branched. In addition, the branches were lying at a wide angle. *Spongomorpha aeruginosa* has a parietal chloroplast with several pyrenoides per cell (Brodie et al. 2007). The gametes develop within the cells of the vegetative filament and there are 25-30 gametes per cell (Brodie et al. 2007). This species can resemble *A. arcta* but has a smaller cell size (Brodie et al. 2007).

Site: Identified from Indre Norskøya.

Fertile structures: Cells with gametes.

Permanent collection: Permanent slide 3 and plate 1: D-E.

Ulothrix Kützing, 1883

Description: Uniseriate unbranched filament, straight or curled with a girdle-shaped and parietal chloroplast. The filament is attached to the substrate by a basal cell, a rhizoid-like cell or downward growing rhizoids. The cells are cylindrical or barrel shaped (Brodie et al. 2007).

Identification of species within the genus *Ulothrix* can be challenging due to different species perception in the literature. Pedersen (2011) describes three species of *Ulothrix* from Greenland *U. speciosa, U. flacca* and *U. scutata.* The latter is regarded as *U. flacca* in Guiry and Guiry (2014). The species *U. pseudoflacca, U. subflaccida* and *U. consociata* are all regarded as *U. flacca* in Pedersen (2011). In Guiry and Guiry (2014) *U. subflaccida* is still recognized as a taxonomically accepted species. There are five species of *Ulothrix* recognized in Svalbard, *U. flacca*, *U. speciosa, U. discifera, U. implexa,* and *U. subflaccida* (Vinogradova 1995a; Hansen and Jenneborg 1996). The latter two are described in Brodie et al. (2007). Difficulties of delimiting species are due to lack of good morphological

characters. For instance, the cell diameter is a character used in both Brodie et al. (2007) and Pedersen (2011). This character is difficult to use because the size range within the different species is overlapping. This genus is in need of a thorough morphological and molecular taxonomic review. To identify specimens in this study the *Ulothrix* species with a cell diameter over 40 μm were regarded as *U. speciosa* while the species with a cell diameter between 5-40 μm and with cells that are shorter than broad were regarded as *U. flacca*.

Ulothrix flacca (Dillwyn) Thuret

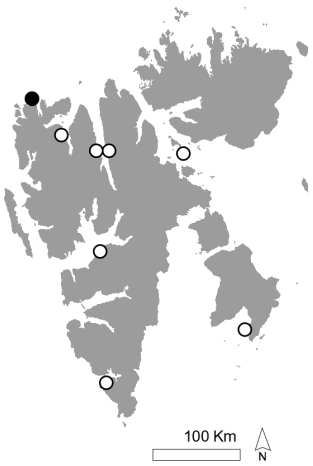
Description: Uniseriate unbranched filament with a girdle-shaped parietal chloroplast. The diameter of the cells is between 5-44 μm according to Brodie et al. (2007) and between 7-21 μm according to Pedersen (2011). Specimens in this survey had a cell diameter between 10-18 μm and they were shorter than broad. The number of pyrenoids per cells also differs in the literature. Brodie et al. (2007) describes the species as having 1-3 (8) pyrenoids per cell, while Pedersen (2011) only characterize the species as having one pyrenoid per cell. Specimens identified to *U. flacca* in this survey had 1-2 pyrenoids per cell. Almost all of the cells can be transformed into gametangia (Pedersen 2011).

Site: Identified from all eight sites.

Fertile structures: Filaments with gametes were identified.

Permanent collection: Permanent slide 4 and plate 1: F.

Ulothrix speciosa (Carmichael) Kützing



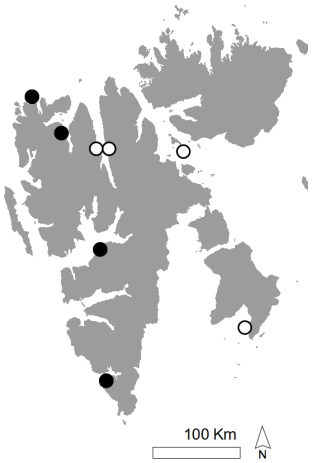
Description: Uniseriate unbranched filament that was either straight or curled. Each cell contained a girdle-shaped parietal chloroplast. The diameter of the cell is according to Brodie et al. (2007) (10-) 30-70 (-85) μm and Pedersen (2011) up to 75 μm. The number of pyrenoids per cell is 1-3 (Brodie et al. 2007; Pedersen 2011). Specimens in this survey had a cell diameter up to 50 μm and 1-3 pyrenoids per cell. Almost all of the cells can be transformed into gametangia (Pedersen 2011).

Site: Identified from Indre Norskøya.

Fertile structures: Not found.

Permanent collection: Permanent slide 5 and plate 1: G.

Urospora penicilliformis (Roth) Areschoug



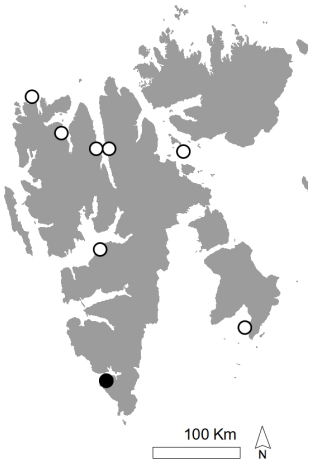
Description: *Urospora penicilliformis* has unbranched, uniseriate filaments. The cell diameter is, according to Brodie et al. (2007), 25-80 (-100) μm, while Pedersen (2011) describes it as <50 μm. Specimens identified to *U. penicilliformis* had a cell diameter between 20-70 μm. The shape of the cells varied from short and cylindrical to more elongated. The chloroplast is perforated and there are several pyrenoids per cell (Brodie et al. 2007). All the cells within the filament can be transformed to gametangia, which have very characteristic drop-like gametes, several occurring within one cell (Pedersen 2011).

Site: Identified from Arkeologvika, Kapp Kjeldsen, Indre Norskøya and Revneset.

Fertile structures: Characteristic drop-like gametes were found.

Permanent collection: Permanent slides 6 and 7 and plate 1: H.

Urospora wormskioldii (Mertens ex Hornemann) Rosenvinge



Description: Uniseriate unbranched filaments with a cell diameter ranging from 100-500 μm according to Brodie et al. (2007). The basal cells are cylindrical and becoming more barrel shaped towards the apical part (Brodie et al. 2007). It has a parietal chloroplast appearing as a perforated plate with several pyrenoids per cell (Brodie et al. 2007). The filaments found were barrel shaped, although some were highly compressed. Specimens identified had a cell diameter between 100-150 μm. All the cells in the filament can be transformed to gametangia, each containing the same characteristic gametes as *U. penicilliformis* (Pedersen 2011).

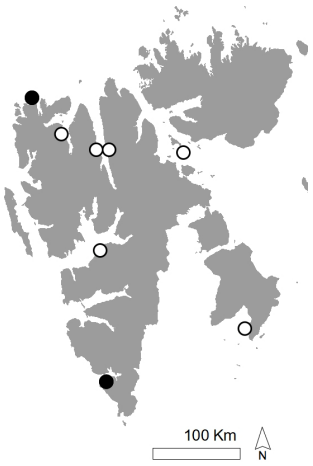
Site: Identified from one station Arkeologvika.

Fertile structures: Not found

Permanent collection: Permanent slide 8 and plate 1: I.

Family: Gomontiaceae

Monostroma grevillei (Thuret) Wittrock



Description: The thallus was monostromatic, leaf-like in shape and lacked a distinct stipe. According to the literature the cells have varying shape throughout the blade. In the basal part of the thallus the cells are very elongated up to 40 μm long and 5-10 μm wide, with 1-3 pyrenoides per cell. In mid thallus the cells become more rectangular or polygonal up to 10-25 μm long and one pyrenoid per cell. In the apical part, the cells are rounded and about 5-20 μm wide with one pyrenoid per cell (Brodie et al. 2007). Specimens identified from this survey varied highly in size in the basal part with the length of the cells ranging from 20-80 μm. In the mid part of thallus the cells had a rectangular or polygonal shape and the size of the cells were between 10-12 μm. In the apical part the cells were rounded and between 10-12 μm. The number of pyrenoids was quite difficult to visualize because the iodine colored the entire cells black. However, 1-2 pyrenoids per cell were seen in the lower part of the thallus.

Site: Identified from Arkeologvika and Indre Norskøya.

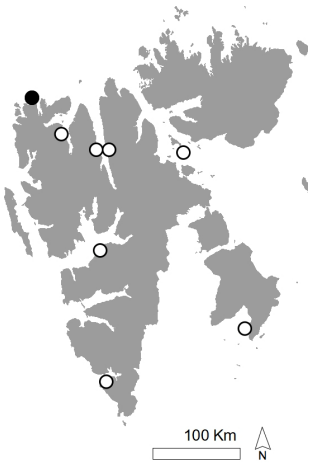
Fertile structures: Not found.

Permanent collection: Permanent slides 9 and 10 and plate 2: A-C.

Order: Ulvales

Family: Kornmanniaceae

Blidingia minima (Nägel ex Kützing) Kylin



Description: The thallus has a tubular shape and the degree of branching varies with salinity (Brodie et al. 2007). In the lower part of thallus the cells are arranged in longitudinal rows and become more irregularly organized in the wider part of the thallus. The cell size throughout the thallus is small, 5-10 μm in diameter. The chloroplast is central with one pyrenoid per cell (Brodie et al. 2007). Specimens identified from this survey had a cell diameter between 5-10 μm and were irregularly organized.

The thallus was mainly unbranched and had one pyrenoid per cell.

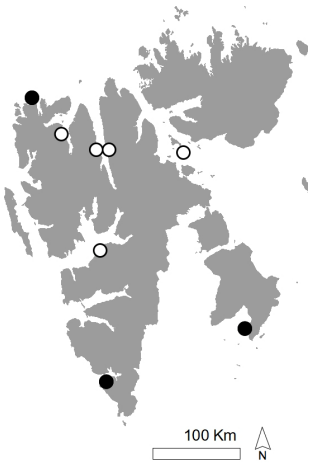
Site: Identified from Indre Norskøya.

Fertile structures: Not found

Permanent collection: Permanent slide 11 and plate 2: D.

Family: Ulvaceae

Ulva prolifera O.F. Müller



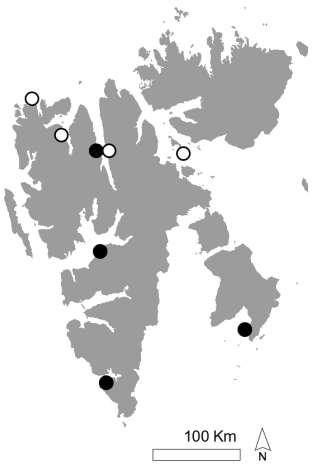
Description: Monostromatic, tubular thallus, which is either either abundantly or sparsely branched (Vinogradova 1995b). The size and morphology of the thallus vary with the degree of wave exposure (Pedersen 2011). Cells in surface view are rectangular or polygonal 10-22 (-35) x 7-12 (-30) μm, with one pyrenoid per cell and they are arranged in distinct longitudinal and transverse rows (Brodie et al. 2007). The thallus has a light green color (Vinogradova 1995b). The specimens identified had a monostromatic and tubular branched thallus. The cells were rectangular or polygonal 15 x 7 μm and arranged in longitudinal rows. Each cell contained one pyrenoid.

Site: Identified from Arkeologvika, Zieglerøya and Indre Norskøya.

Fertile structures: Not found.

Permanent collection: Permanent slides 12 and 13 and plate 2: E-F.

Ulvaria splendens (Ruprecht) Vinogradova



Description: The thallus was monostromatic and leaf-like with a distinct stipe. The cells were rectangular to polygonal 12 x 22 μm. The number of pyrenoids per cell was difficult to visualize because the iodine colored the entire cell black. In the literature the species is described with 1-6 pyrenoids per cell (Brodie et al. 2007). The cells in surface view are described as polygonal, (5-) 12 x 25 (-35) μm in size and with a parietal chloroplast (Brodie et al. 2007).

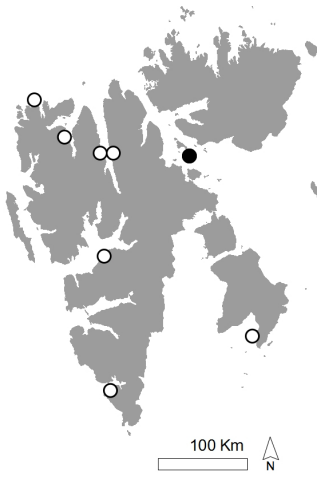
Site: Identified from Arkeologvika, Zieglerøya, Wijdefjorden

west and Revneset.

Fertile structures: Not found.

Permanent collection: Permanent slides 14 and 15, plate 2: G-H and herbarium specimen 2.

Unidentified green algae:



From site 3 (Vaigattneset) a green algae with a blade like thallus was found. A transverse section of the thallus was not possible to make and the thickness of the thallus could therefore not be examined. The cells in surface view were small and rectangular, approximately 7.5 μm in diameter. In addition, only a fragment of the blade was found. Based on the cell size and shape this specimen could be identified as *Kornmannia leptoderma.*

Site: Sampled at Vaigatneset.

Fertile structures: not found

Permanent collection: Permanent slide 16 and plate 2: I.

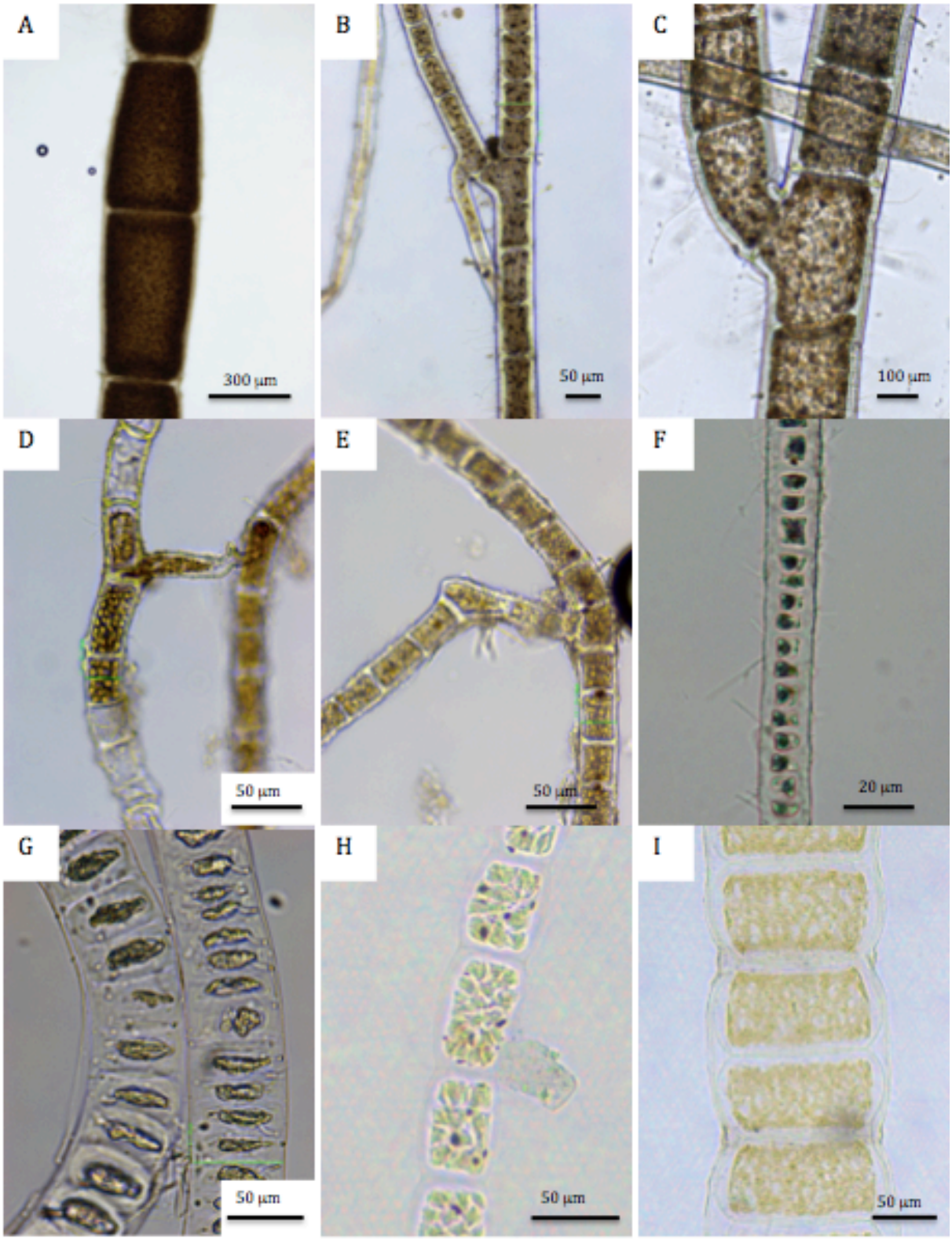


Plate 1. A: *Chaetomorpha melagonium*. B: *Acrosiphonia arcta*. C: *Acrosiphonia sonderi*. D: *Spongomorpha aeruginosa* (gametes), E: *Spongomorpha aeruginosa*, F: *Ulothrix flacca* (colored pyrenoids). G: *Ulothrix speciosa*, H: *Urospora penicilliformis*. I: *Urospora wormskioldii.*

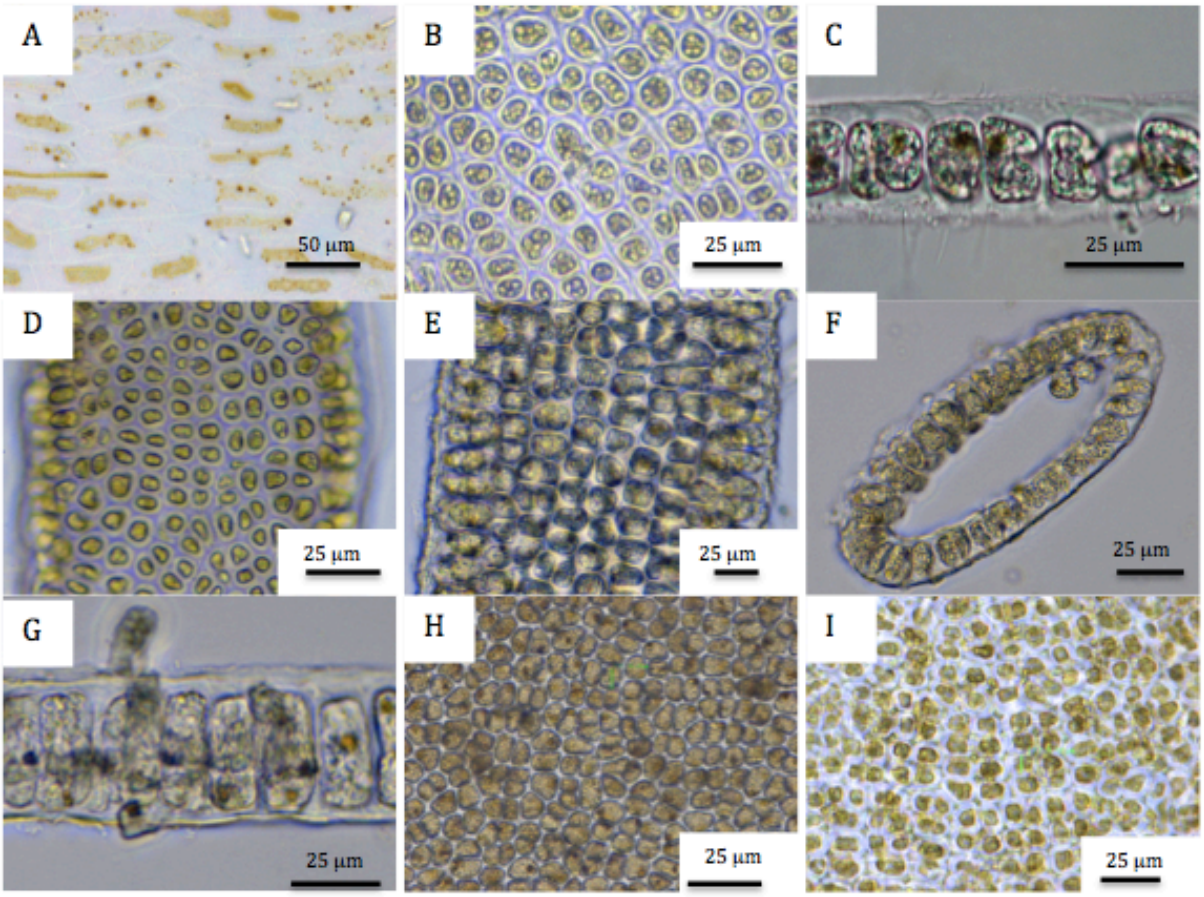


Plate 2. A: *Monostroma grevillei* (basal part). B: *Monostroma grevillei* (apical part). C: *Monostroma grevillei* (cross section). D: *Blidingia minima*. E: *Ulva prolifera*. F: *Ulva prolifera* (cross section). G: *Ulvaria splendens* (cross section). H: *Ulvaria splendens*. I: unidentified green algae.

Phylum: Ochrophyta

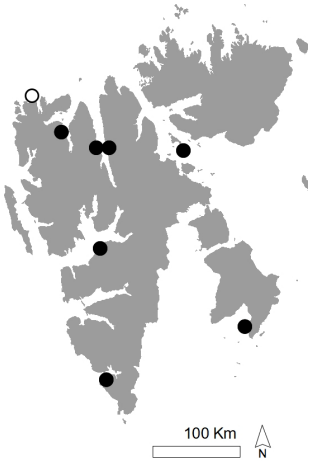
Class Phaeophyceae

Order: Desmarestiales

Family: Desmarestiaceae

Two types of fertile structures are known within the brown algal species; unilocular zoidangia and plurilocular zoidangia. The unilocular zoiadangia produce spores while the plurilocular zoidangia can contain gametes or spores. In this section the term -zoidangia is used rather than -sporangia or -gametangia. This term does not indicate which function the fertile structures have and can therefore be correctly used when describing these structures.

Desmarestia aculeata (Linnaeus) J.V. Lamouroux



Description: The specimens identified were up to 20 cm long. The thallus was rounded and irregularly branched and the branches had distinct central axes. In early spring/summer the alga carries short hair like branches that later in the season are shed leaving short and spine-like branches (Fletcher 1987, Rueness 1977). This hair-like branches were found on one specimen.

Site: Identified from Arkeologvika, Zieglerøya, Vaigattneset, Wijdefjorden east and west, Kapp Kjeldsen and Revneset.

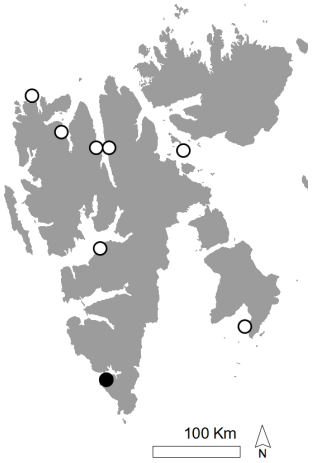
Fertile structures: Not found

Permanent collection: Permanent slides 17 and 18, plate 3: A-B and herbarium specimen 3

Order: Ectocarpales

Family: Acinetosporaceae

Pogotrichum filiforme Reinke



Description: The thallus is uniseriate in the basal part, with quadrate to rectangular cells (Fletcher 1987). The thallus becomes pluriseriate and parenchymatous with rounded or irregularly shaped cells towards the apical part (Fletcher 1987). When fertile, the surface cells are transformed to round

plurilocular zoidangia. The species lacks real brown algal hairs and has discoid chloroplasts (Pedersen 2011). The specimen identified were pluriseriate with rounded and irregularly shaped cells and no hairs. Parts of the thallus were transformed to plurilocular zoidangia where some had been emptied.

Site: Identified from Arkeologvika.

Fertile structures: Identified with plurilocular zoidangia

Permanent collection: Permanent slide 19 and plate 3: C.

Pylaiella littoralis (Linnaeus) Kjellmann

Description: The specimens were uniseriate, irregularly or opposite branched filaments with discoid chloroplasts. The species is common as an epiphyte on other brown algae such as *Fucus* (Pedersen 2011). When fertile, the vegetative cells can be transformed to unilocular zoidangia located intercalary in the branches (Rueness 1977). The plurilocular zoidangia are formed intercalary or terminally in the branches (Rueness 1977). Both unilocular and plurilocular zoidangia were present in the specimens, though the unilocular zoidangia were most common.

Site: This species was identified from all eight stations.

Fertile structures: Both uni- and plurilocular zoidangia were found.

Permanent collection: Permanent slide 20 and plate 3: D.

Pylaiella varia Kjellmann

Description: Uniseriate branched filaments with discoid chloroplasts. The branching pattern differs from the former species by having predominantly unilateral and almost perpendicular branches, they are seldom opposite and can occur in clusters of three or four (Pedersen 2011). Specimens were identified based on the occurrence of branches occurring in clusters and that many were lying at a wide angle to the main axis. Plurilocular and unilocular zoidangia were found intercalary or on short branches.

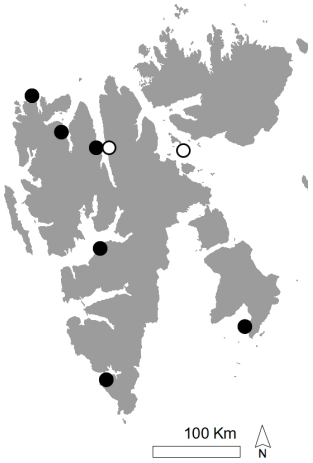
Site: Identified from all eight stations

Fertile structures: both uni- and plurilocular zoidangia were found.

Permanent collection: Permanent slide 21 and plate 3: E-F.

Family: Chordariaceae

Chordaria flagelliformis (O.F. Müller) C. Agardh



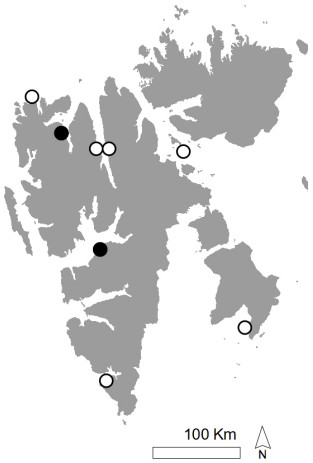
Description: The thallus is a branched rounded multiaxial syntagma. The surface is covered with assimilatory filaments composed of fours cells, and the outer most cells have an oval shape. According to the literature, the unilocular zoidangia can be seen in a surface view with a rounded or oval shape (Rueness 1977).

Site: Identified from Arkeologvika, Zieglerøya, Wijdefjorden west, Kapp Kjeldsen, Indre Norskøya and Revneset.

Fertile structures: Unilocular zoidangia were found.

Permanent collection: Permanent slides 22 and 23 and plate 3: G.

Climacosorus mediterraneus Sauvageau



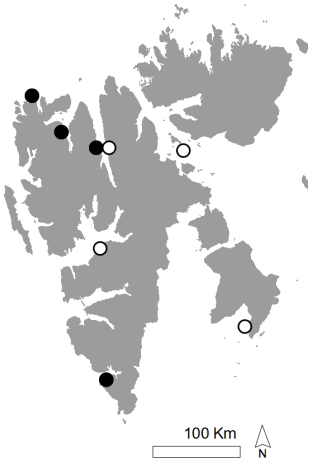
Description: The thallus is predominantly uniseriate, though some parenchymatic sections occur (Pedersen 2011). The specimens were sparingly branched filaments with a cell diameter of approximately 18 μm. From the parenchymatic sections, clusters of unilocular zoidangia occured. The zoidangia in these clusters can vary in size due to different age and the branches are also developed from these parenchymatic sections (Pedersen 2011).

Site: Identified from Kapp Kjeldsen and Revneset

Fertile structures: Unilocular zoidangia were found

Permanent collection: Permanent slide 24 and plate 3: I.

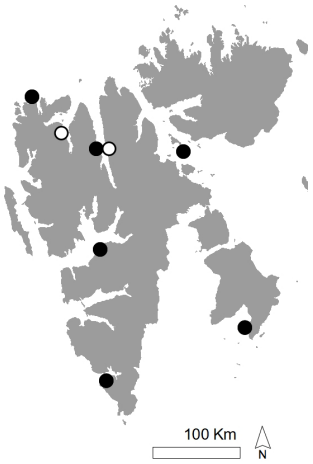
Dictyosiphon foeniculaceus (Hudson) Greville



Description: The thallus was rounded and abundantly branched with a brown color and one apical cell. The surface was covered by a cortex of rounded cells, and the central part was composed of large colorless cells. The thallus also had numerous of hairs on

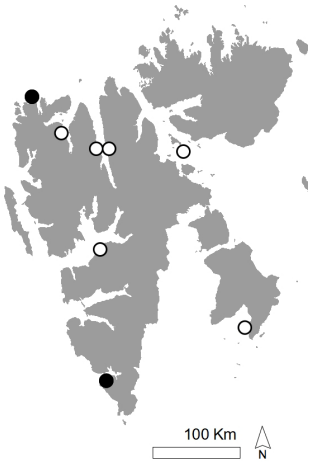
the surface. In the litterature the species is describes as obove (Pedersen 2011). Unilocular zoidangia is embedded within the cortex (Rueness 1977; Vinogradova 1995b).
Site: Identified from Arkeologvika, Wijdefjorden west, Kapp Kjeldsen and Indre Norskøya.
Fertile structures: Not found
Permanent collection: Permanent slides 25 and 26 and plate 3: H.

Elachista fucicola (Velley) Areschoug



Description: *Elachista fucicola* is an epiphytic alga forming brown tufts on different hosts (Fletcher 1987). Uniseriate unbranched filaments (10-43 x 23-40 μm) arise from a pseudoparenchymatic basal cushion (Fletcher 1987). Unilocular zoidangia occur in the basal part and have a drop-like shape (Fletcher 1987; Pedersen 2011). The specimens identified had erect filaments that were up to 35 μm wide and the characteristic drop-like zoidangia.
Site: Identified from Arkeologvika, Zieglerøya, Vaigattneset, Wijdefjorden west, Indre Norskøya and Revneset.
Fertile structures: Unilocular zoidangia were found.
Permanent collection: Permanent slide 27 and plate 3: J.

Halothrix lumbricalis (Kützing) Reinke



Description: Epiphytic algae forming small tufts on the host species (Fletcher 1987). The specimens identified had erect filaments that were uniseriate with some pluriseriate sections. The filaments were narrower in the basal part and predominantly unbranched, but some branching occured in the basal part. The cells were barrel-shaped to rectangular and approximately 25 μm wide. The growth zone was located in the basal part and was seen as rows of slightly compressed cells. Plurilocular zoidangia occurs intercalary or in the apical part of the filaments (Fletcher 1987). Sections resembeling the description of plurilocular zoidangia were seen in the specimens. They occurred intercalary and in the apical parts. This species can be separated from *Leptonematella fasciculata* based on the larger cell diameter. *Leptonematella fasciculata* is described by

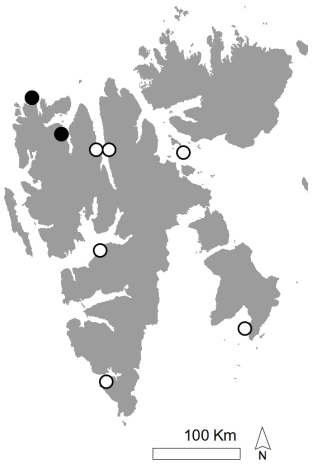
Fletcher (1987) with a diameter from 7-17 μm, while *H. lumbricalis* is described with a cell diameter from 25-65 μm. Rueness (1977) describes *L. fasciculata* with cell diameter 7-15 (20) μm, and *H. lumbricalis* with cell diameter 20-40 μm.

Site: This species is not previously identified from Svalbard. In this survey it was identified from Arkeologvika and Indre Norskøya.

Fertile structures: Sections resembeling the description of plurilocular zoidangia were found.

Permanent collection: Permanent slide 28 and plate 3: K.

Litosiphon laminariae (Lyngbye) Harvey



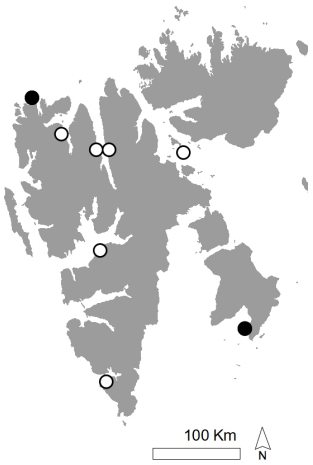
Description: Epiphytic algae forming dense tufts on the host composed of pluriseriate erect filaments 50-180 μm wide (Fletcher 1987). The unilocular zoidangia are formed in surface cells and are round or elliptical in shape (Fletcher 1987). Specimens identified were predominantly pluriseriat with quadrate or rectangular cells. In fertile sections big rounded cells was seen. The tallus were 120-170 μm in diameter and hairs were present.

Site: Identified from Kapp Kjeldsen and Indre Norskøya.

Fertile structures: Unilocular zoidangia were found.

Permanent collection: Permanent slides 29 and 30 and plate 3: L.

cf. *Myrionema* sp.



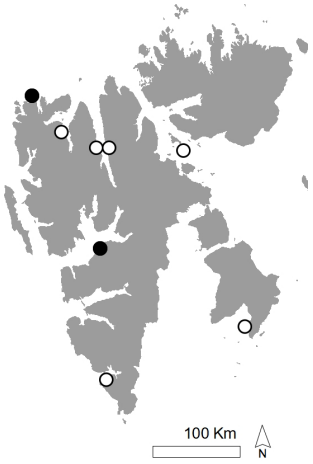
Description: Epiphytic algal species forming dark, circular spots on the host (Fletcher 1987). Characterized by a monostromatic discoid base, and from this base unbranched filaments arise (Fletcher 1987). The cells have 1-3 chloroplasts. Hairs, ascocystes and zoidangia are usually sessile. The hairs have a basal meristem and sheath (Fletcher 1987). The specimens were epiphytes composed of erect uniseriate filaments and hairs. The basal part was not visible and the specimens were not fertile, thus the abbrivation cf is used to highlight the unsecure identification.

Site: Identified from site Zieglerøya and Indre Norskøya.

Fertile structures: Not found.

Permanent collection: Permanent slide 31.

Saundersella simplex (De A. Saunders) Kylin



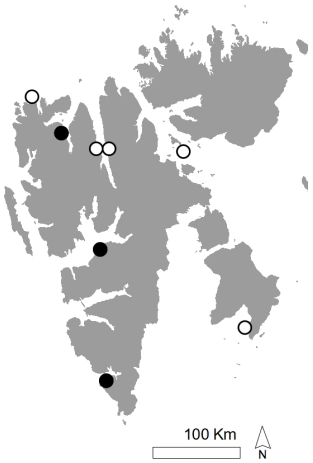
Description: Unbranched thallus predominantly epiphyte on *Chordaria flagelliformis* and resembles the branches of *Chordaria* (Vinogradova 1995b; Pedersen 2011). *Saundersella simplex* is composed of a multiaxial syntagma with assimilatory filaments of three to four cells covering the surface. The apical cells in these assimilatory filaments are quite big and round (Vinogradova 1995b; Pedersen 2011). Specimens identified were epiphytes on *Chordaria flagelliformis* and were identified to *S. simplex* based on the bigger rounded apical cells in the syntagma.

Site: Identified from Indre Norskøya and Revneset

Fertile structures: Not found.

Permanent collection: Permanent slides 32 and 33 and plate 3: M.

Stictyosiphon tortilis (Gobi) Reinke



Description: Parenchymateous thallus, which were irregularly branched and growing branches end in a hair. The axial cells were rectangular and gave the algae a joint appearance. The surface was covered with smaller, often rectangular cortex cells. The observed morphological traits fits with the description by Rueness (1977) and Pedersen (2011).

Site: Identified from Arkeologvika, Kapp Kjeldsen and Revneset.

Fertile structures: Not found.

Permanent collection: Permanent slides 34 and 35 and plate 4: A-B.

Family: Ectocarpaceae

Ectocarpus fasciculatus Harvey

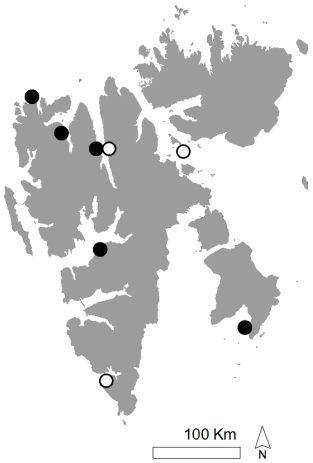
Description: The thallus is uniseriate and irregularly branched. The branching is never opposite, but can form clusters. The main axis is between 20-30 μm wide. Each cell contains several band-shaped chloroplasts and the plurilocular zoidangia are situated laterally in the

apical part of branches (Rueness 1977; Pedersen 2011). Specimens identified were described as above, by Rueness (1977) and Pedersen (2011).

Site: Identified from Zieglerøya, Wijdefjorden west, Kapp Kjeldsen, Indre Norskøya and Revneset.

Fertile structures: Plurilocular zoidangia were found.

Permanent collection: Permanent slide 36 and plate 4: C.



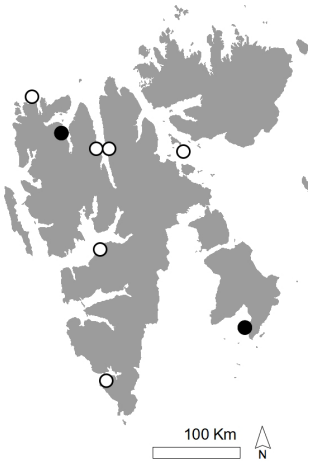
Ectocarpus siliculosus (Dillwyn) Lyngbye

Description: Similar morphology as the former, but the plurilocular zoidangia end into a pseudo hair (Pedersen 2011, Rueness 1977).

Site: Identified from Zieglerøya and Kapp Kjeldsen.

Fertile structures: Plurilocular zoidangia.

Permanent collection: Permanent slide 37 and plate 4: D.



Order: Fucales

Family: Fucaceae

Fucus distichus Linnaeus

Description: The specimens had a dichotomously branched thallus up to 15 cm tall, with a clear midrib and a brown color. The receptacles were located in the apical parts and were cylindrical in shape. Characteristic for this species is caecostomata, which are hollow structures in the cortex (Rueness 1977). *Fucus distichus* is monoecious, meaning both oogonia and antheridia occur on the same individual (Rueness 1977).

Site: Identified morphologically from all eight stations and verified by DNA-barcoding from sites 2, 3, 4b, 5, 6 and 7.

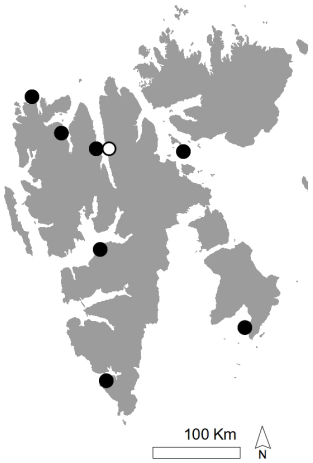
Fertile structures: Receptacles with both oogonia and antheridia

Permanent collection: Permanent slides 38 and 39, plate 4: E and herbarium specimen 4.

Order: Laminariales

Family: Alariaceae

Alaria esculenta (Linnaeus) Greville



Description: Specimens consisted of a branched hapter, an oval or rounded stipe and a lamina that had folded margins. The stipe continued throughout the lamina as a distinct mid rib. *Alaria esculenta* is 10-20 cm in width and up to several meters long (Rueness 1977). When fertile the unilocular zoidangia develop on own lanceolate blades (sporophylls) at the upper part of the stipe (Rueness 1977, Vinogradova 1995b).

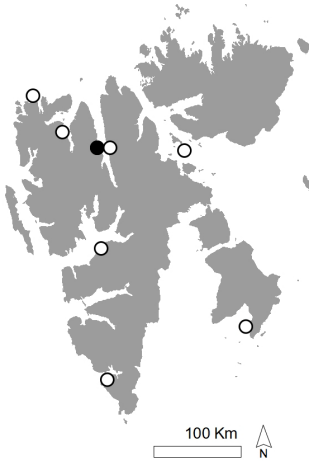
Site: Identified from Arkeologvika, Zieglerøya, Vaigattneset, Wijdefjorden west, Kapp Kjeldsen, Indre Norskøya and Revneset

Fertile structures: Sporophylls were registered in specimens at Kapp Kjeldsen.

Permanent collection: Plate 4: F and herbarium specimen 5.

Family: Laminariaceae

A character previously used to differentiate between the species *Laminaria digitata*, *Saccharina groenlandica* and *Saccharina latissima* is the presence or absence of mucilage ducts in the stipe and lamina. The utility of this character is discussed in previous research with different outcomes. Wilce (1965) concluded that this was a plastic trait and could not be used as a taxonomic character, while McDevit and Saunders (2010) believe that this is a valid character, at least for the species in eastern Canadian waters (McDevit and Saunders 2010). DNA-barcoding was therefore included to ensure the species identification of *Laminaria digitata* and *Saccharina groenlandica*. Digitate kelp specimens were found at Arkeologvika. Tissue samples were not tanken, thus these specimens are recorded as *L. digitata*/*S. groenlandica* (Appendix III).



Laminaria digitata (Hudson) J.V. Lamouroux

Description: Specimens consisted of a branched hapter, rounded stipe and a digitate lamina. The shape, width and thickness of lamina may vary depending on the habitat (Rueness 1977).

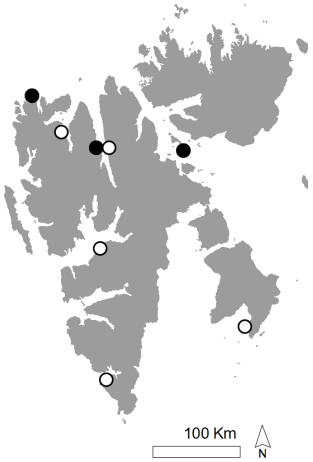
Described with mucilage ducts only in the lamina (Rueness 1977; McDevit and Saunders 2010).

Site: Identified form Wijdefjorden west and verified by DNA-barcoding.

Fertile structures: Not found

Permanent collection: Plate 4: H.

Laminaria solidungula J. Agardh



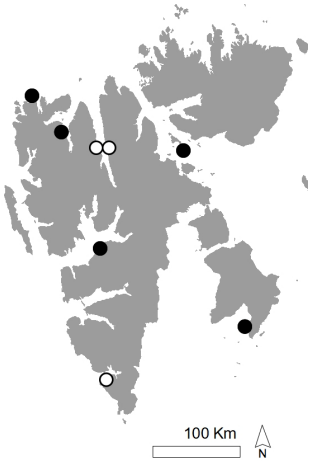
Description: The specimens had a discoid holdfast, rounded stipe and a broad lamina. *Laminaria solidungula* can, according to the litterature, be up to 120 cm long and 5-20 cm wide (Vinogradova 1995b). When fertile, an oval sorus forms on the surface of the lamina. After the zooids are released, this can be seen as a bright yellow area on the lamina (Pedersen 2011). This was observed in a specimen sampled.

Site: Identified from Vaigattneset, Wijdefjorden west and Indre Norskøya.

Fertile structures: A specimen with the bright area on the lamina was found.

Permanent collection: Permanent slide 40 and herbarium specimen 6.

Saccharina groenlandica (Rosenvinge) C.E. Lane, C. Mayes, Druehl and G.W. Saunders



Description: This species has previously been described under different names, such as *Laminaria groenlandica* (Rosenvinge), *Laminaria cuneifolia* (J. Agardh), *Saccharina subsimplex* (Setchell & N.L.Gardner) Widdowson, S.C.Lindstrom & P.W.Gabrielson and *Saccharina bongardiana* f. *subsimplex* (Setchell & N.L.Gardner) Selivanova, Zhigadlova & G.I.Hansen (Guiry & Guiry 2014). These species is now regarded as *S. groenlandica* (Guiry & Guiry 2014). Taylor (1957) described *L. groenlandica* based on Rosenvinges original description in 1893 as kelp with a branched hapter and a solid and rounded stipe, 30-75 cm long, which is to some degree flattened in the upper part. The lamina is linear oblong (oval) and up to 1 m long and 25-80 cm wide with undulate (folded) margins. The base of the lamina is cuneate or cordate (heart shaped) with depressions near the center (Taylor (1957). Rosenvinge (1893) describe the species with mucilage ducts in both the lamina and stipe (McDevit and Saunders

2010). The morphology of the lamina is now known to show a high degree of plasticity, from an elongated solid blade (*S. latissima*-like) to a digitate blade (*L. digitata*-like; McDevit and Saunders 2010). Specimens identified as *Saccharina groenlandica* in this study had a digitate lamina and were approximately 1-1.5 m long with a thin and rounded stipe.

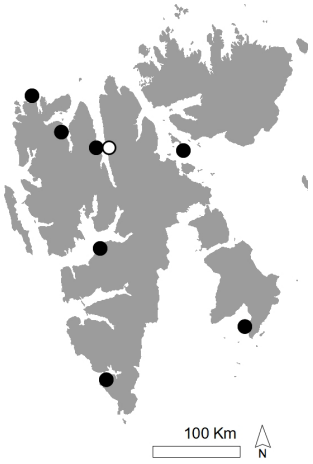
Site: Identified from Zieglerøya, Vaigattneset, Kapp Kjeldsen, Indre Norskøya and Revneset, verified by DNA-barcoding.

Fertile structures: Not found.

Permanent collection: Plate 4: I and herbarium specimen 7.

Saccharina latissima (Linnaeus) C.E. Lane, C. Mayes, Druehl and G.W. Saunders

Description: The specimens were identified with a branched hapter and a thin and rounded stipe. The lamina was long and solid, had undulate margins and a bullate middle section. *Saccharina latissima* is described with no mucilage ducts in the stipe or the lamina (McDevit and Saunders 2010).



Site: Identified from Arkeologvika, Zieglerøya, Vaigattneset, Wijdefjorden west, Kapp Kjeldsen, Indre Norskøya and Revneset.

Fertile structures: Not found.

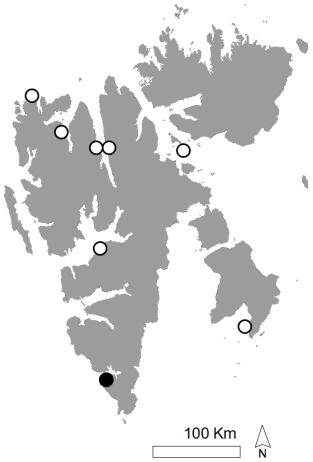
Permanent collection: Plate 4: G and herbarium specimen 8.

Order: Sphacelariales

Family: Sphacelariaceae

Sphacelaria sp.

Description: A small specimen was found that could be assigned to the family Sphacelariaceae based on the structure of the thallus and one apical cell (Rueness 1977). However, the specimen was only a fragment and could not be identified to genus or species.

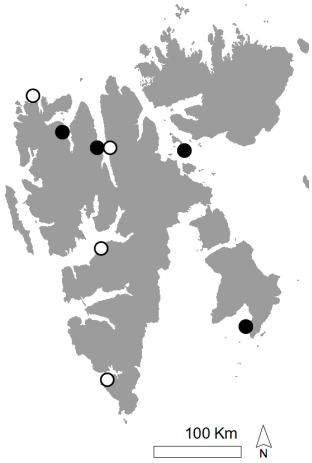


Site: Identified form Arkeologvika

Fertile structures: Not found.

Permanent collection: Permanent slide 41.

Battersia arctica (Harvey) Draisma, Prud'homme and H. Kawai



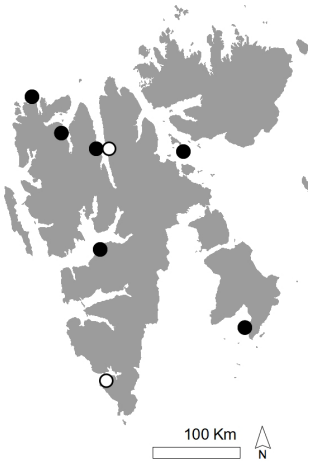
Description: Parenchymateous irregularly branched algae with distinct apical cells in accordance with Pedersen (2011) and Vinogradova (1995b). The main axis was partly covered with rhizoidal filaments and was up to 100 µm in diameter. The branches were 50 µm in diameter. Both unilocular and plurilocular zodangia are located in the apical part of short secondary branches (Rueness 1977).

Site: Identified from Zieglerøya, Vaigattneset, Wijdefjorden west and Kapp Kjeldsen.

Fertile structures: Both uni and plurilocular zodangia were found.

Permanent collection: Permanent slides 42 and 43 and plate 5: A-B.

Chaetopteris plumosa (Lyngbye) Kützing



Description: Parenchymateous irregularly branched algae with distinct apical cells. The main axis is fully corticated by densely packed rhizoidal filaments. The branching pattern gives the algae a featherlike appearance. Unilocular and plurilocular zodangia occur on separate individuals (Pedersen 2011). Plurilocular zoidangia on short branches were found.

Site: Identified from Zieglerøya, Vaigattneset, Wijdefjorden west, Kapp Kjeldsen, Indre Norskøya and Revneset.

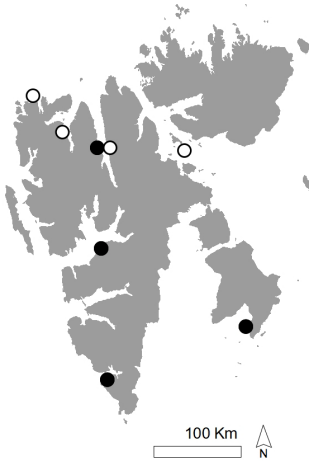
Fertile structures: Plurilocular and unilocular zoidangia.

Permanent collection: Permanent slides 44 and 45, plate 5: C-D and herbarium specimen 9.

Order: Tilopteridales

Family: Phyllariaceae

Saccorhiza dermatodea (Bachelot de la Pylaie) J. Agardh

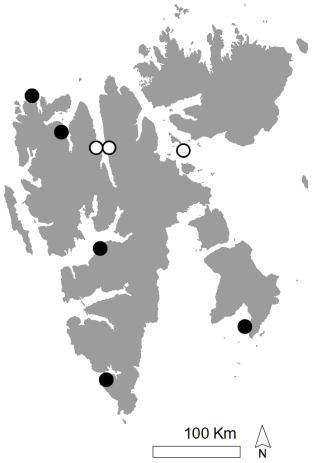


Description: The holdfast is a conical disk that can eventually be covered with outgrowths from the stipe (Rueness 1977). According to Taylor (1957) the stipe can be 15-60 cm long, while Rueness (1977) describes it as up to 25 cm long. The lamina is oval and

between 0.3-2 m long (Rueness 1977). Hairs are present in cryptostomata in the young lamina. The hairs later become more obscure (Taylor 1957). Fertile structures occur in the basal part of the lamina (Taylor 1957). The specimens identified had a stipe up to 20 cm long and a narrow lamina with hairs present and outgrowths from the stipe was observed.
Site: Identified from Arkeologvika, Zieglerøya, Wijdefjorden west and Revneset.
Fertile structures: Not found.
Permanent collection: Herbarium specimen 10.

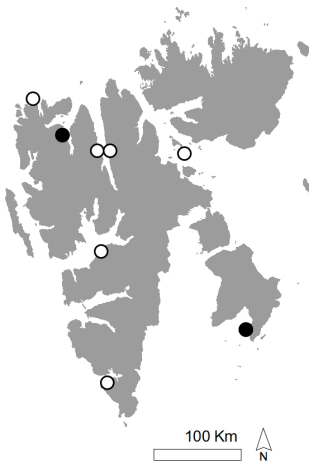
Family: Tilopteridaceae

Haplospora globosa Kjellmann



Description: The thallus was a branched filament that was predominantly uniseriat, but longitudinal segmented cells occured. The basal part of the main axis was approximately 75-130 μm wide and the apical part 50-100 μm wide. *Haplospora globosa* has an isomorphic diplohaplontic life cycle (Rueness 1977). The sporophyte has round unilocular zoidangia on short branches. The gametophyte has both oogonia and antheridia. The oogonia are usually rounded, while the antheridia have a cylindrical shape. (Rueness 1977)
Site: Identified from Arkeologvika, Zieglerøya, Kapp Kjeldsen, Indre Norskøya and Revneset.
Fertile structures: Both the sporophyte and the gametophyte were found with fertile structures.
Permanent collection: Permanent slides 46 and 47 and plate 5: E-F.

Unidentified brown algae:



Description: Branched parenchymatic specimens of brown algae were sampled from site 2 (Zieglerøya) and 5 (Kapp Kjeldsen). The thallus construction resembled species within the genera *Dictyosiphon* and *Stictyosiphon*. The branches were not ending in a hair or a single cell therefore this character could not be used assign the specimens to a genus. The cortex was comprised of

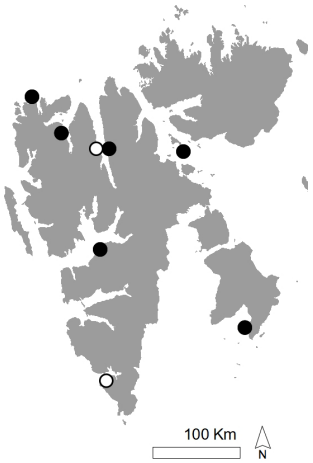
small rounded cells, which fits with the genus *Dictyosiphon.* The cortex cells of *Stictyosiphon* are thought to be more rectangular in shape. The internal structure was comprised of large colorless elongated cells, or in some parts rounded colorless cells that resembled the internal structure of *Stictyosiphon*. No hair was seen in any of the specimens. The thallus was in some part densely covered with small uniseriate filaments. Whether these were young shoots or epiphytic growth could not be decided. Due to the contradicting features of the specimens these were not assigned to a genus/species.

Site: sampled at Zieglerøya and Kapp Kjeldsen.

Fertile structures: Not found

Permanent collection: Permanent slides 48-50 and plate 5: H-J.

Unidentified epiphytes:



Description: Brown algal epiphytes were found on species such as *Chaetomorpha melagonium, Devaleraea ramentacea* and the kelp species *Alaria esculenta* and *Saccharina groenlandica*. Epiphytes on the kelp species and *D. ramentacea* had an erect part, which could bee seen as uniseriate filaments. However, basal structures and fertile structures were not seen in any of the specimens. There is a wide range of brown algal epiphytes with erect filaments (e.g. *Pseudolithoderma* sp.). Due to the lack of characters, the specimens could not be assigned to species or genus. The epiphytes on *Chaetomorpha melagonium* were encrusting and thus no erect filaments were seen. Diagnostic characters were difficult to find and the epiphytes were not assigned to a species or genus. Although epiphytes were not recorded from site 1 and 4b, such epiphyes are most likely also present at these sites.

Site: Recorded at Zieglerøya, Vaigattneset, Wijdefjorden east, Kapp Kjeldsen, Indre Norskøya and Revneset.

Fertile structures: Not found.

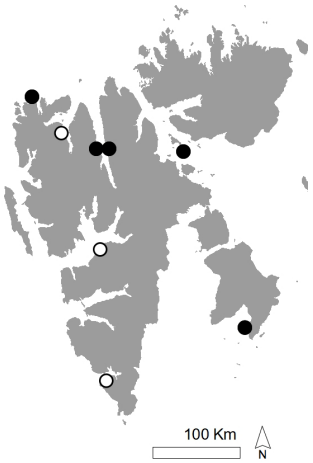
Permanent collection: Permanent slides 70-73.

Class: Xanthophyceae

Order: Vaucheriales

Family: Vaucheriaceae

Vaucheria sp.



Description: Uniseriate branched filaments 13 μm wide and the cells were cylindrical and elongated. No fertile structures were found. The only species described in Christensen (1995) with filaments less than 20 μm in width is *Vaucheria minuta*. However, due to the lack of fertile structures this species was only identified to genus.

Site: identified from Zieglerøya, Vaigattneset, Wijdefjorden west and east and Indre Norskøya.

Permanent collection: Permanent slide 51.

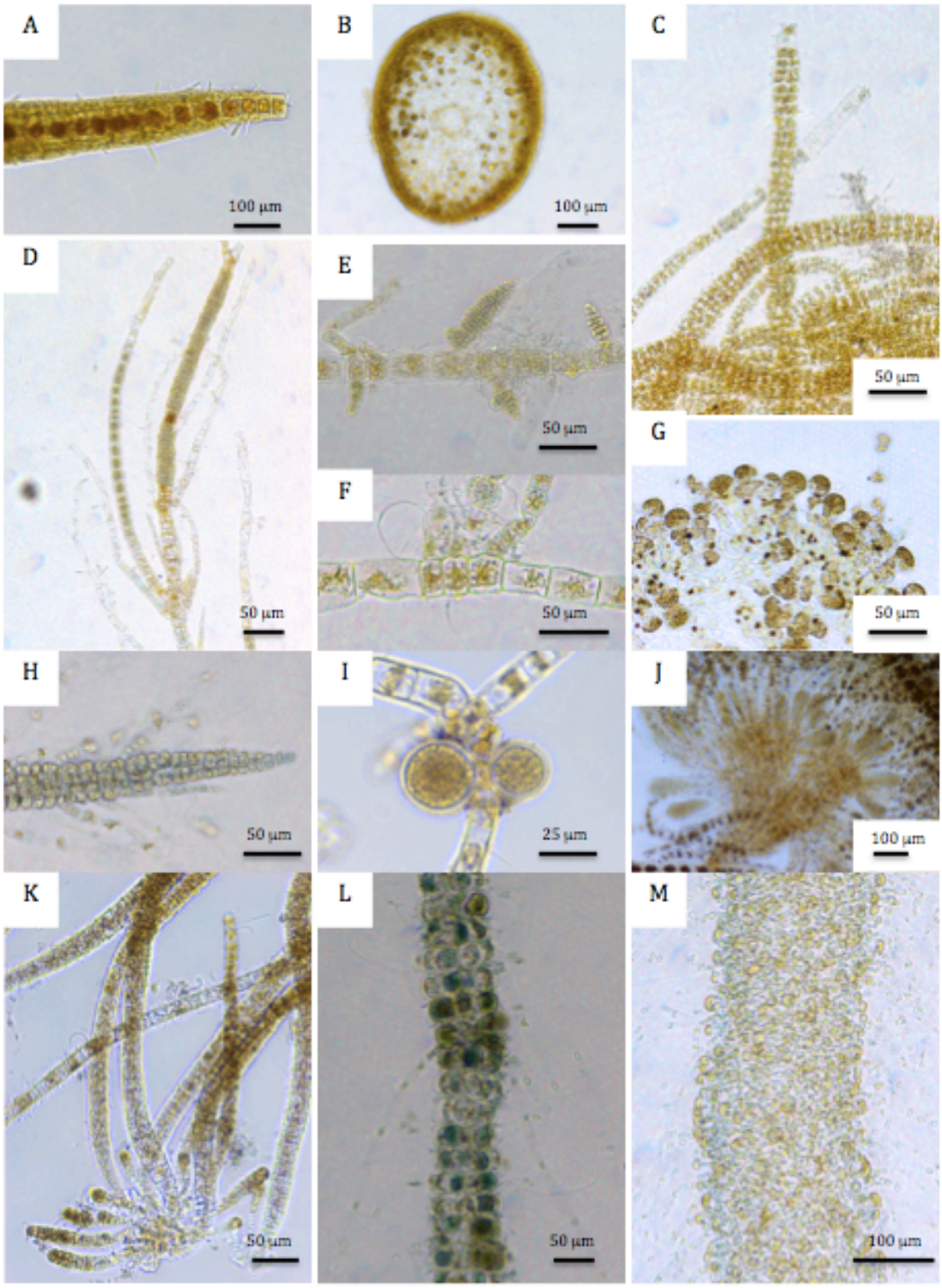


Plate. 3. A: *Desmarestia aculeata.* B: *Desmarestia aculeata* (cross section). C: *Pogotrichum filiforme.* D: *Pylaiella littoralis* (unilocular zoidangia and plurilocular zoidangia). E: *Pylaiella varia* (plurilocular zoidangia). F: *Pylaiella varia.* G: *Chordaria flagelliformis* (assimilatory filaments). H: *Dictyosiphon foeniculaceus*. I: *Climacosorus mediterraneus* (unilocular zoidangia). J: *Elacista fucicola* (unilocular zoidangia). K: *Halothrix lumbricalis.* L: *Litosiphon laminariae.* M: *Saundersella simplex.*

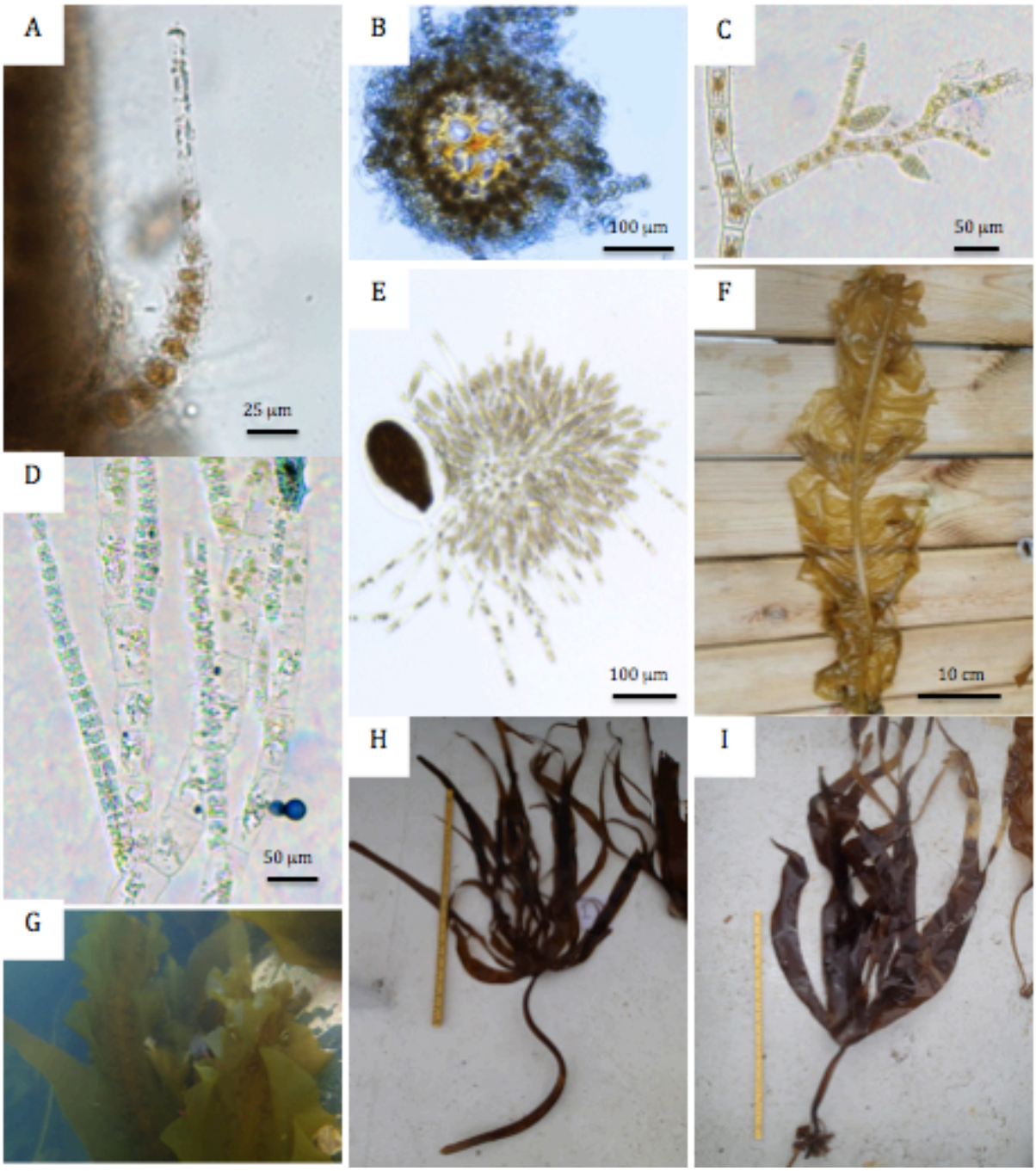


Plate 4. A: *Stictyosiphon tortilis*. B: *Stictyosiphon tortilis* (cross section). C: *Ectocarpus fasciculatus.* D: *Ectocarpus siliculosus.* E: *Fucus distichus* (antheridia and oogonia). F: *Alaria esculenta.* G: *Saccharina latissima.* H: *Laminaria digitata.* I: *Saccharina groenlandica.*

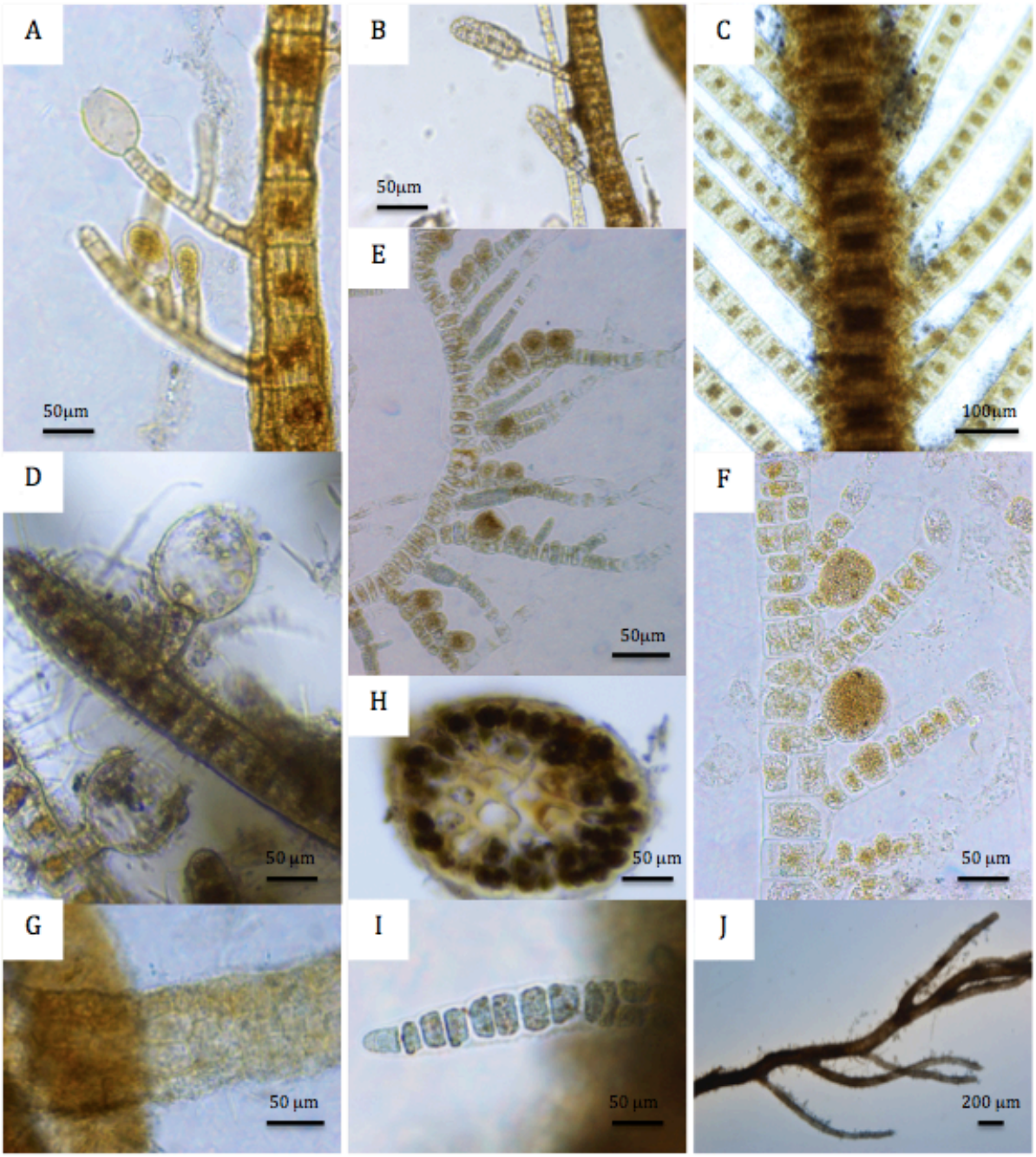


Plate 5. A: *Battersia arctica* (unilocular zoidangia). B: *Battersia arctica* (plurilocular zoidangia). C: *Chaetopteris plumosa.* D: *Chaetopteris plumosa* (unilocular zoidangia). E: *Haplospora globosa* (gametophyte). F: *Haplospora globosa* (sporophyte). G-J: Unidentified brown algae.

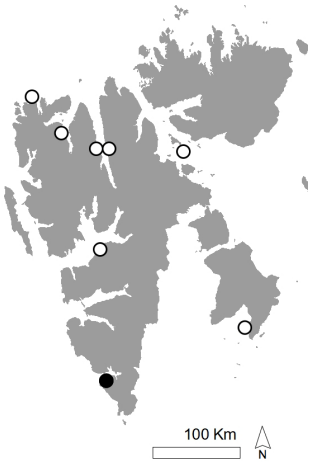
Phylum: Rhodophyta

Class: Bangiophyceae

Order: Bangiales

Family: Bangiaceae

Porphyra sp.



Description: The gametophyte has a blade-like thallus that is either one or two cell layers thick. It has a short stipe that is attached by a small disc. The cells have a stellate chloroplast with a single central pyrenoid. The color of the thallus varies from red, reddish brown to olive green (Bird and McLachlan 1992). The specimen found was pressed to dryness for the herbarium collection in field. This made it impossible to examine the thickness of the thallus, the shape of the cells and thus, the specimen collected are not identified to species.

Site: Identified from one site, Arkeologvika

Fertile structures: Not found.

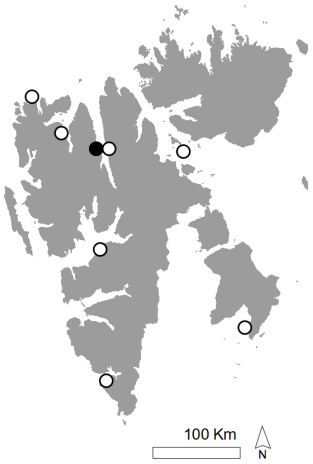
Permanent collection: Herbarium specimen 11.

Class: Florideophyceae

Order: Acrochaetiales

Family: Acrochaetiacea

Acrochaetium sp. Nägeli (1858)



Description: The thallus was uniseriate branched. The diameter of the cell was 5 μm and the length was 12 μm. The chloroplast is located in the upper part of the cell (Pedersen 2011) giving the algae a joint appearance. Pedersen (2011) described two species within the genus *Acrochaetium*. These two species are separated by either having a single cell basis or a multicellular basal structure. Due to lack of diagnostic characters, there were

difficulties with delimiting species within this genus. The basal part was not visible in the specimens collected and they were only identified to genus.

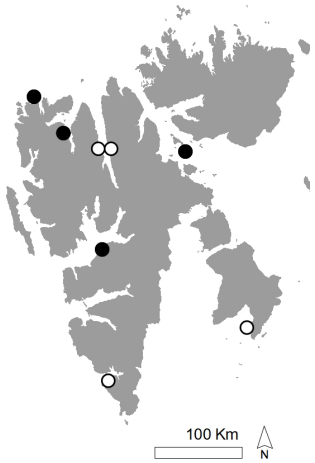
Site: Identified from Wijdefjorden west.

Fertile structures: Not found.

Permanent collection: Permanent slide 52 and plate 6: A.

Rhodochorton purpureum (Lightfoot) Rosenvinge

Description: Uniseriate branched filaments which is 10 μm in diameter. The cells are 2-3 times longer than broad and have many parietal discoid chloroplasts (Pedersen 2011). Cruciate tetrasporangia are occurring in clusters in the apical part of the algae (Rueness 1977). Specimens identified were uniseriate branched with a diameter between 5 and 10 μm. The cells were elongated.



Site: Identified from Vaigattneset, Kapp Kjeldsen, Indre Norskøya and Revneset.

Fertile structures: Not found.

Permanent collection: Permanent slide 53 and plate 6: B.

Order: Ceramiales

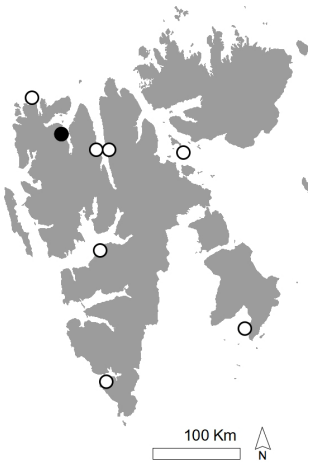
Family: Ceramiaceae

Ceramium Roth

Species within the genus *Ceramium* show a high degree of variability in morphology. Nomenclatural and taxonomic confusion has been severe due to the lack of criteria that can distinguish between species with similar morphology. Species with the same genetic code may show a high degree of phenotypic plasticity. The illegitimate name *Ceramium rubrum* (Hudson) C. Agardh has been widely used for a group of species that lack spines and are fully corticated (Maggs et al. 2002). Maggs and Hommersand (1993) recognized four species from the British Isles that were fully corticated: *C. botryocarpum*, *C. pallidum*, *C. secundatum* and *C. nodulosum*. The latter name later showed not to be available, and was therefore named *Ceramium virgatum* (Maggs et al. 2002). There are two species of *Ceramium* recorded from Svalbard; *Ceramium virgatum* and *Ceramium circinatum*. The

latter species have been distinguished form other *Ceramium* species by the prescence of 10 peraxial cells (Maggs and Hommersand 1993). DNA-barcoding was used to ensure the species identification of *Ceramium* specimens.

Ceramium virgatum Roth



Description: Thallus consisting of several irregularly branched erect axes that are attached to the substratum by rhizoidal filaments (Maggs and Hommersand 1993). Epiphytic or epilithic algae are forming small tufts with a brownish-red color (Maggs and Hommersand 1993). The main axes were approximately 300 μm in diameter and composed of 7 periaxial cells at each joint between two axial cells. The thallus was fully corticated and lacked spines.

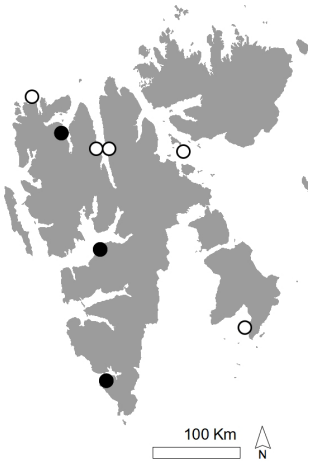
Site: Identified from Kapp Kjeldsen by DNA-barcoding

Fertile structures: Not found.

Permanent collection: Permanent slide 54, plate 6: C-D and herbarium specimen 12.

Family: Delesseriaceae

Phycodrys rubens (Linnaeus) Batters



Description: The thallus was composed of a short stipe with leaf-like blades that had distinct midribs, opposite lateral veins and toothed margins. The algae were up to 13 cm tall and the leaf like blades were up to 2.5 cm wide. Tetrasporangia occur in outgrowths from the margins, while cystocarps are formed within the thallus near the margin (Rueness 1977). New thallus is formed from the margins of the old blades (Rueness 1977).

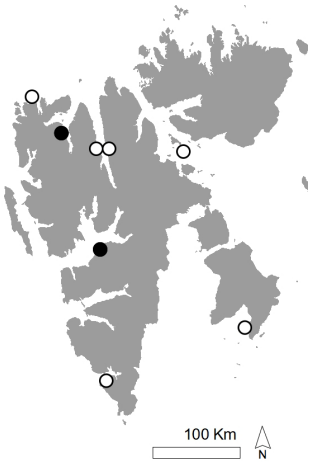
Site: Identified from Arkeologvika, Kapp Kjeldsen and Revneset.

Fertile structures: Not found.

Permanent collection: Permanent slides 55 and 56, plate 6: E and herbarium specimen 13.

Family: Rhodomelaceae

Odonthalia dentata (Linnaeus) Lyngbye



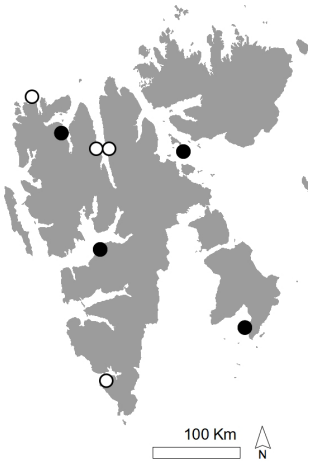
Description: The thallus was unregulary branched and had a slightly visible midrib with toothed margins. The thallus was between 10-20 cm long and 3-5 mm wide. Both tetrasporangia and cystocarps develop from the margin of the thallus (Rueness 1977), however such structures was not observed. *Odonthalia dentata* can grow both epiphytic and epilithic (Rueness 1977).

Site: Identified from Kapp Kjeldsen and Revneset.

Fertile structures: Not found.

Permanent collection: Permanent slide 57 and herbarium specimen 14.

Polysiphonia arctica J. Agardh



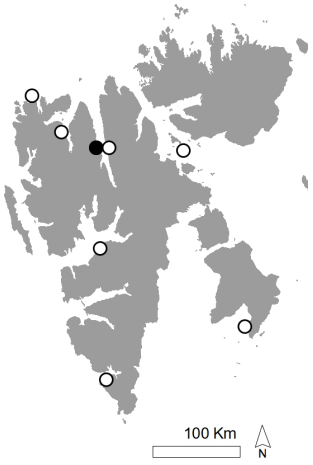
Description: Irregularly branched algae without cortial cells and has 4-7 periaxial cells (Rueness 1977). Specimens identified in this survey lacked cortial cells and had 6 periaxial cells, which were often twisted in basal parts. Cystocarps were found on short branches and were round in shape.

Site: Identified from Zieglerøya, Vaigattneset, Kapp Kjeldsen and Revneset.

Fertile structures: Cystocarps were found.

Permanent collection: Permanent slides 58 and 59 and plate 6: G-H.

Polysiphonia stricta (Dillwyn) Greville



Description: Irregularly branched algae that form small tufts on other algae and rocks (Maggs and Hommersand 1993). The thallus construction is composed of a single axial cell, which is surrounded by 4 periaxial cells. The periaxial cells can either be straight or twisted and the species do not have cortical cells (Maggs and Hommersand 1993). The specimen identified had 4

periaxial cells and did not have cortical cells and was therefore identified to *P. stricta*.

Site: Identified from Wijdefjorden west.

Fertile structures: Not found.

Permanent collection: Permanent slide 60 and plate 6: I-J.

Rhodomela C.Agardh

There are currently two species in the genus *Rhodomela* that are recorded form Svalbard: *Rhodomela confervoides* and *Rhodomela lycopodioides*. The latter species is described as an epiphyte on kelp stipes, with lateral branches being equal in length (Maggs and Hommersand 1993). However, the distiction of these two species is uncertain (Pedersen 2011), and Pedersen (2011) describes the latter species with a varying morphology. The specimens in the present study were not epiphytes on kelp stipes and were all identified to one species *Rhodomela confervoides*.

Rhodomela confervoides (Hudson) P.C. Silva

Description: Specimens were composed of a round pseudoparenchymatic thallus, abundantly branched and 200 μm wide. Trichoblasts were present in the apical part of branches. Tetrasporangia were tetrahedral and often organized in pairs of two in the main branches. The cystocarps were oval in shape and on short branches. The structure of the thallus coincide with the literature by having one axial cell that is surrounded by (usually) 6-7 periaxial cells and then covered by several layers of cortical cells (Bird and McLachlan 1992, Rueness 1977). The color of the specimens identified varied from dark red to brown.

Site: Identified from Arkeologvika, Zieglerøya, Vaigattneset, Wijdefjorden west, Kapp Kjeldsen, Indre Norskøya and Revneset.

Fertile structures: Specimens with cystocarps and tetrasporangia were found.

Permanent collection: Permanent slides 61-63, plate 6: K, plate 7: A-B and herbarium specimen 15.

Family: Wrangeliaceae

Ptilota serrata Kützing

Description: The specimens had a feather-like apperance. The thallus was flatteded and either alternate or dichotomously branched. *Ptilota serrata* is separated from *Ptilota gunneri* based on the branching pattern. The main branchlets are paired with opposite dwarf branchlets within the species *P. serrata* (Bird and McLachlan 1992). Fertile specimens were found with either cystocarps or tetrasporangia on the dwarfed branchlets. The algae are bright red to brownish- red in color, uniaxial and fully corticated, except for the apical cells (Bird and McLachlan 1992).

Site: Identified from Wijdefjorden west, Kapp Kjeldsen, Indre Norskøya and Revneset

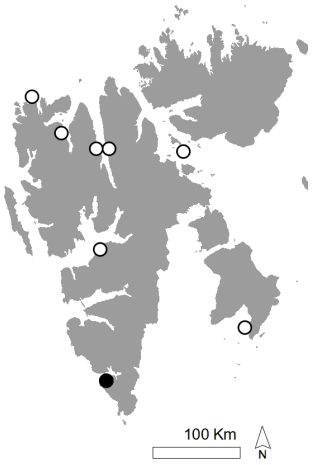
Fertile structures: Both specimens with cystocarps and tetrasporangia were found.

Permanent collection: Permanent slides 64 and 65, plate 7: C-D and herbarium specimen 16.

Order: Gigartinales

Family: Kallymeniaceae

Euthora cristata (C. Agardh) J. Agardh



Description: The main axis and branches were flattened and the branching pattern was irregular and occured in one plane. The branches and main axes were approximately 1-2 mm wide. The alga is bright red in color. The spermetangia occur in sori at the surface, cystocarps are formed from the margins of the thallus and cruciate tetrasporangia are embedded in the cortex (Bird and McLachlan 1992).

Site: Identified from Arkeologvika.

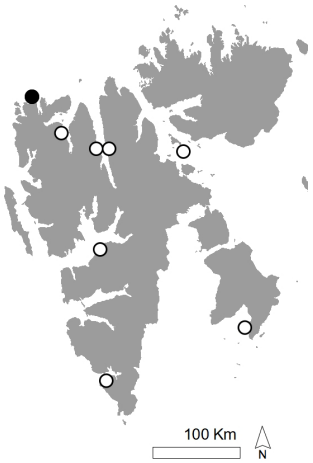
Fertile structures: Not found.

Permanent collection: Herbarium specimen 17.

Order: Hildenbrandiales

Family: Hildenbrandiaceae

Hildenbrandia rubra (Sommerfelt) Meneghini



Description: Crustose algae which can bee seen as a brownish - red layer on rocks and cliffs. It is a thin layer of basal filaments that supports vertical filaments, which form a firm tissue (Bird and McLachlan 1992, Rueness 1977). This species was identified on cliffs and rocks in field by its dark red color.

Site: Identified from Indre Norskøya.

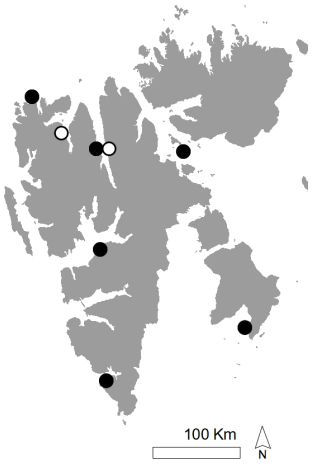
Fertile structures: Not found.

Permanent collection: Plate 7: E.

Order: Palmariales

Family: Palmariaceae

Devaleraea ramentacea (Linnaeus) Guiry



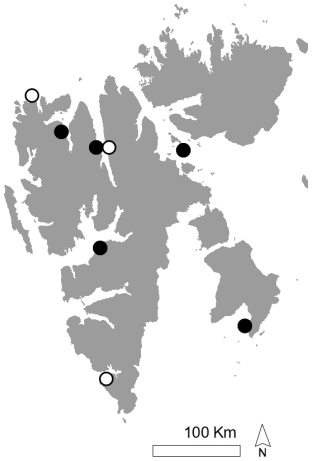
Description: Cylindrical and narrow thallus, hollow or compressed that arise from a small discoid holdfast. The thallus is up to 40 cm tall and the branches are up to 2 cm wide (Rueness 1977). Spermatangia occur in sori on the surface of younger branches. The tetrasporangia are cruciate and embedded in the cortex (Bird and McLachlan 1992). Specimens identified were hollow, up to 10 cm tall and unregularly branched. The long branches were tapered at the base and apex. *Devaleraea ramentacea* is highly variable in morphology.

Site: Identified from Arkeologvika, Zieglerøya, Vaigattneset, Wijdefjorden west, Indre Norskøya and Revneset.

Fertile structures: Not found.

Permanent collection: Permanent slides 66 and 67, plate 7: F and herbarium specimen 18.

Palmaria palmata (Linnaeus) Weber and Mohr

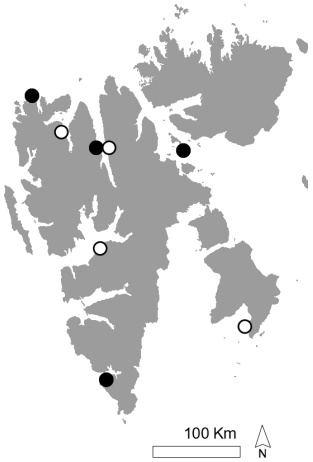


Description: *Palmaria palmata* has a discoid holdfast and a short stipe from which several individuals arise (Rueness 1977). The lamina has a leafy or palmate appearance, which is branched dichotomously or trichotomously (Bird and McLachlan 1992). The lobes are ellipsoid to oblong (Bird and McLachlan 1992). The lamina often has several lateral proliferations from the margins in the basal part (Bird and McLachlan 1992). Superficial sporangia in sori appear as yellow patches on the lamina. Cruciate tetrasporangia are embedded in the cortex of the lamina on the tetrasporophyte (Bird and McLachlan 1992). The specimens identified were up to 25 cm tall and the lobes were up to 4 cm broad and had a deep red color. In transverse sections big rounded cells could be seen.

Site: Identified from Zieglerøya, Vaigattneset, Wijdefjorden west Kapp Kjeldsen and Revneset.

Fertile structures: Specimens with tetrasporangia were found.

Permanent collection: Permanent slides 68 and 69, plate 7: G and herbarium specimen 19.



Calcearous crusts: From four sites calcarous crusts were observed on cliff. Collecting specimens of these crusts were not possible and they are thus only recorded and documentet with a photo.

Site: Observed at Arkeologvika, Vaigattneset, Wijdefjorden west and Indre Norskøya.

Permanent collection: Plate 7: H.

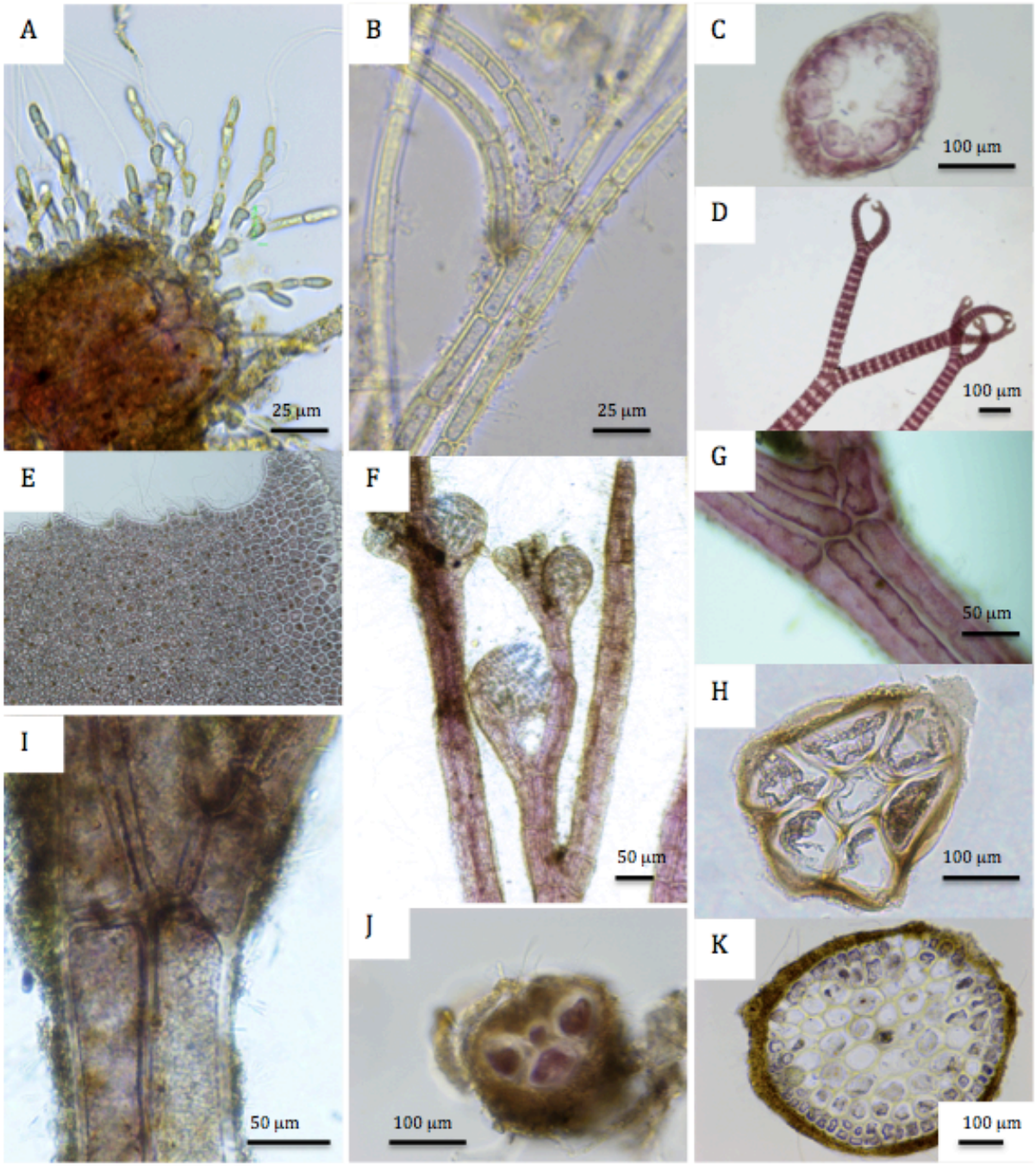


Plate 6. A: *Acrochaetium* sp. B: *Rhodocorton purpureum.* C: *Ceramium virgatum* (cross section). D: *Ceramium virgatum.* E: *Phycodrys rubens*. F: *Polysiphonia arctica.* G: *Polysiphonia arctica.* H: *Polysiphonia arctica* (cross section). I: *Polysiphonia stricta.* J: *Polysiphonia stricta* (cross section). K: *Rhodomela confervoides* (cross section).

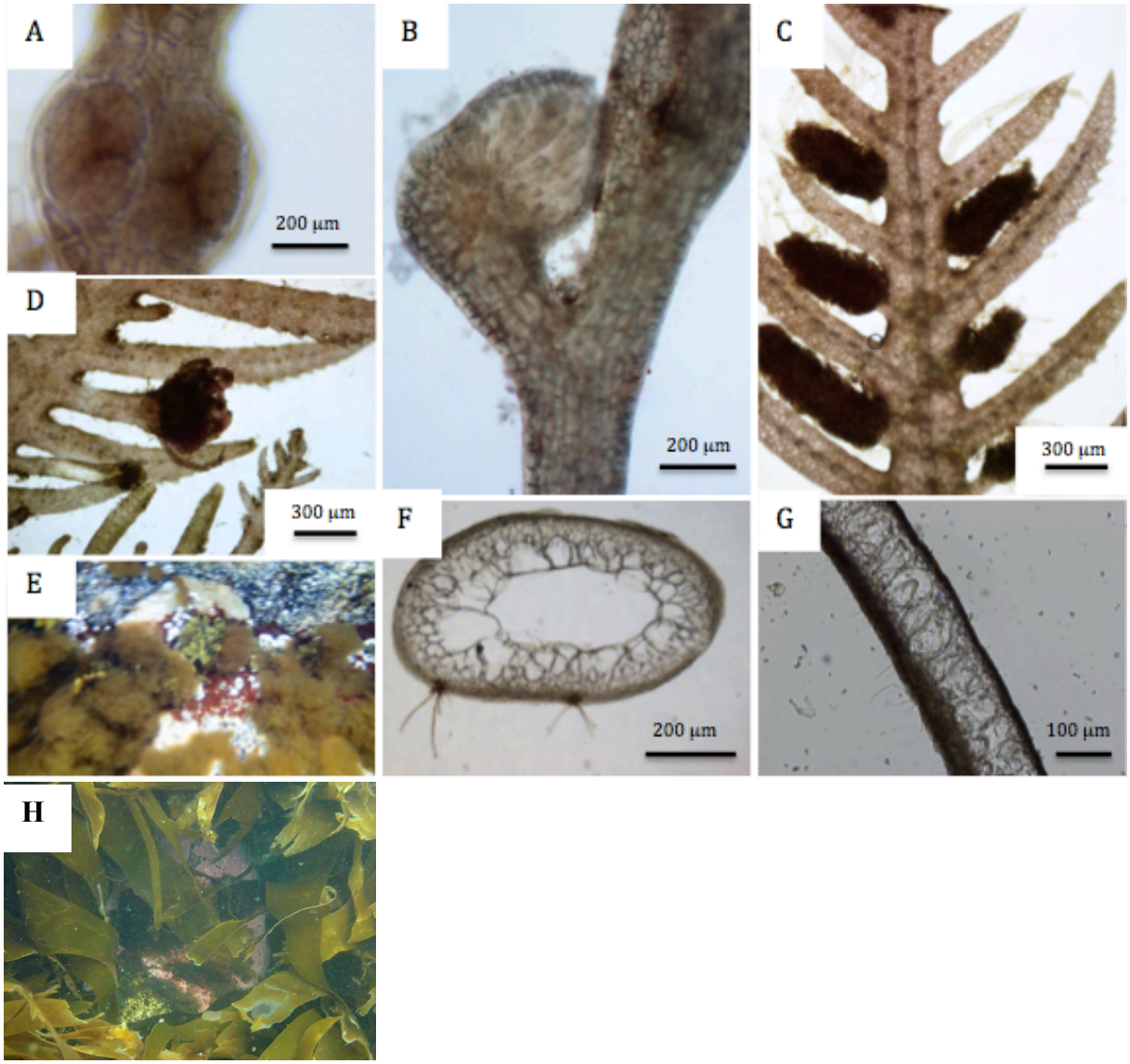


Plate 7. A: *Rhodomela confervoides* (tetrasporangia). B: *Rhodomela confervoides* (cystocarp). C: *Ptilota serrata* (tetrasporangia). D: *Ptilota serrata* (cystocarp). E: *Hildenbrandia rubra*. F: *Devaleraea ramentacea* (cross section). G: *Palmaria palmata* (cross ection). H: Calcearous crusts (.

3.3 Molecular analyses

The results from the molecular analyses are given in the following section. The present research is mainly based on identifying species using morphological characters observed under the microscope. Due to plasticity found in many species this approach is sometimes insufficient. Therefore DNA-barcoding methods were used to ensure the identification in the genus *Fucus* and *Ceramium,* and on digitate kelp specimens.

3.3.1 Digitate kelp

Bayesian analysis

The result from the Bayesian analysis based on the COI sequences assigned the specimens to *Saccharina groenlandica* or *Laminaria digitata* (black font; Fig. 15). The additional specimens from the Norwegian mainland were identified to *Laminaria digitata* and *Laminaria hyperborea* (Fig. 15). *Saccharina groenlandica*, *L. digitata* and *L. hyperborea* formed well supported clades with their respective reference sequences retrieved from the NCBI's GenBank (red font), with a posterior probability of 1 (Fig. 15).

Maximum likelihood

The result from the Maximum likelihood analysis based on COI sequences showed similar results as the Bayesian analysis. The sequenced specimens (black font) were identified to *S. groenlandica*, *L digitata* and *L. hyperborea.* All three groups formed supported clades with the reference sequences retrieved form the NCBI's GenBank (red font; Fig. 16). The clades are well supported with bootstrap values of 97, 100 and 99, respectively (Fig. 16).

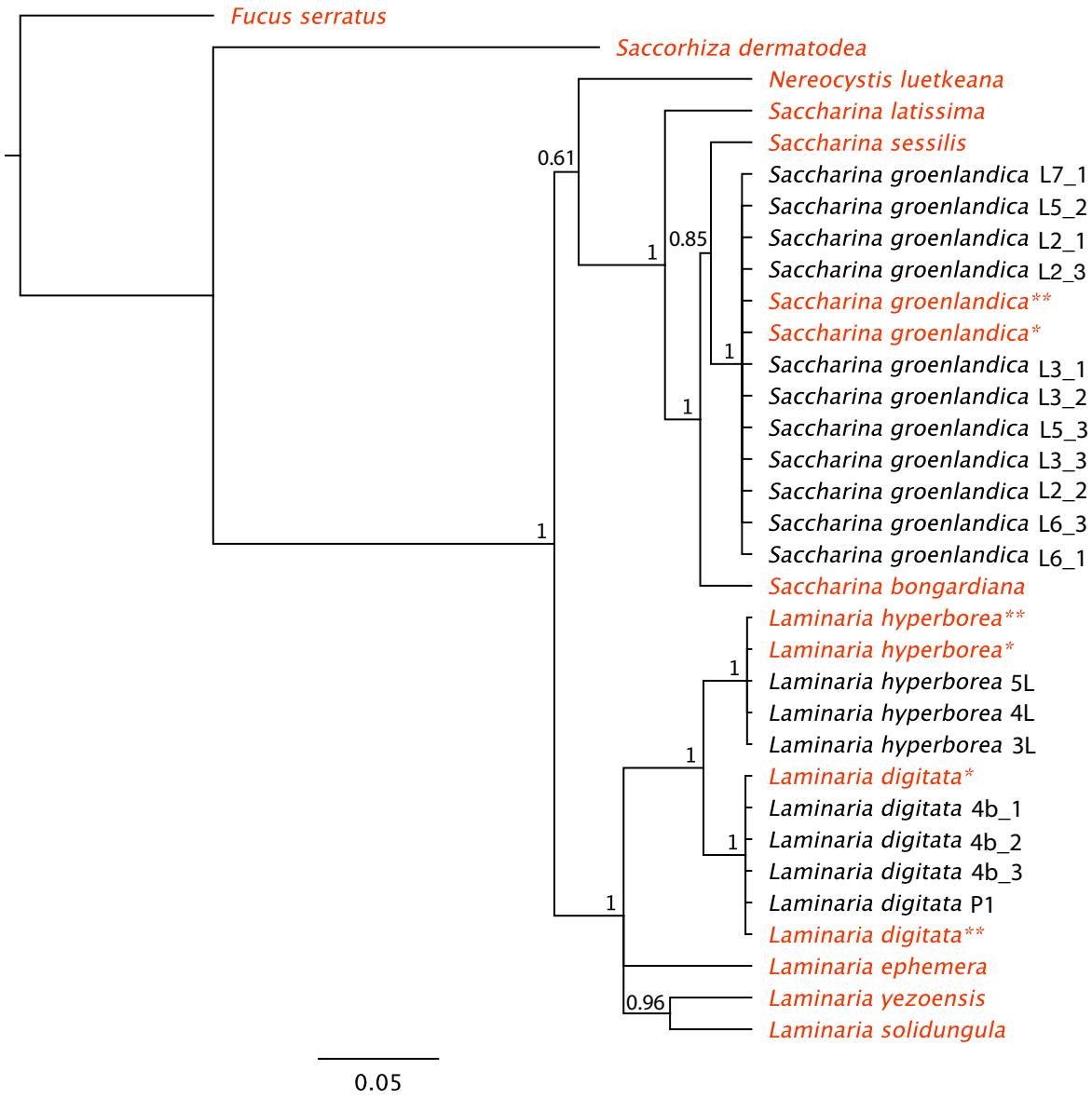


Figure 15. Bayesian posterior output tree based on the COI-gene, with *Fucus serratus* and *Saccorhiza dermatodea* as outgroups. The numbers above the lines are posterior probability values. The samples sequenced in this survey are given in black font and the species names are annotated with station and sample number. The species in red font are reference sequences retrieved from NCBI GenBank, with the top hits from the blast search annotated with * or **.

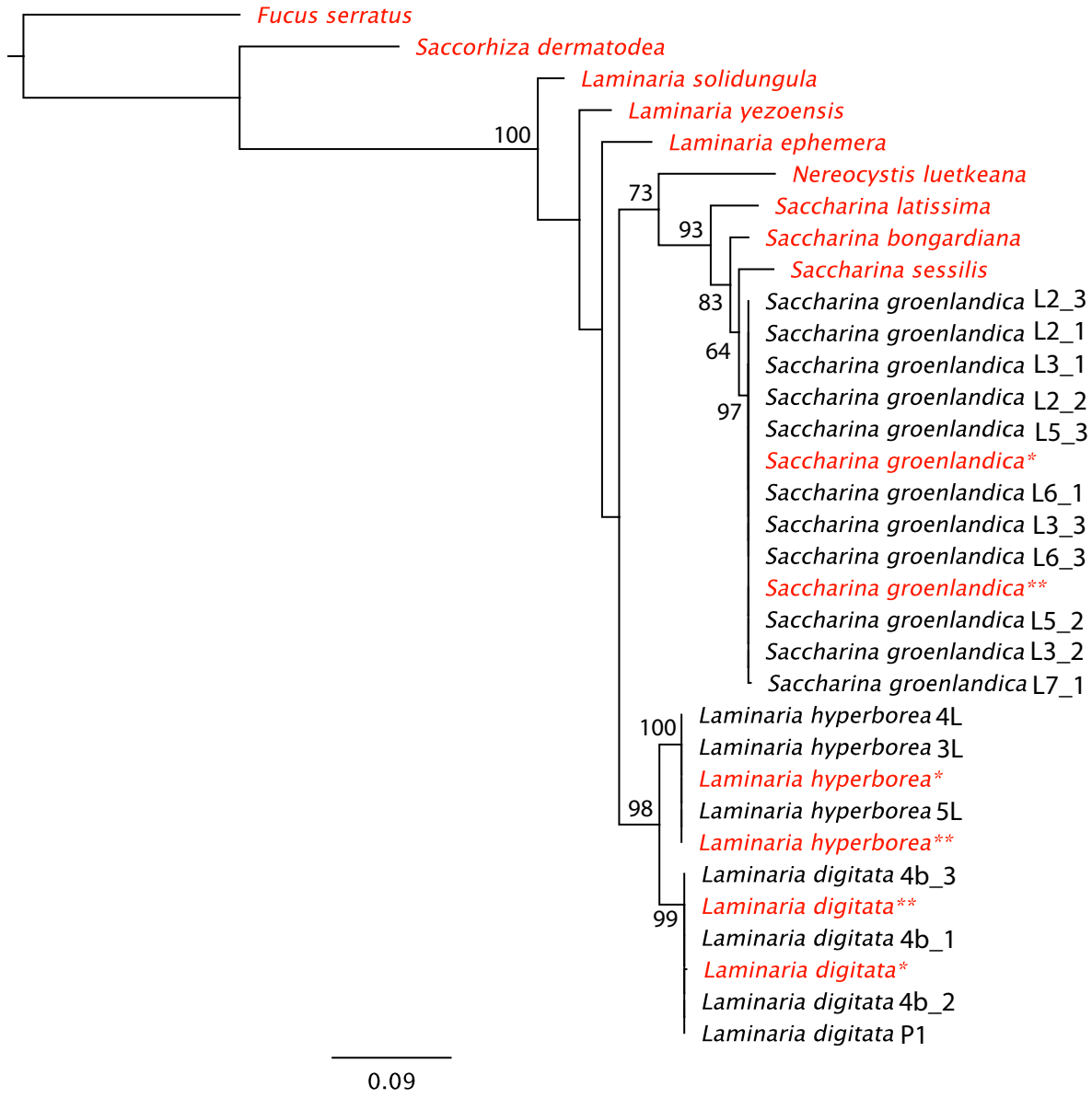


Figure 16. Maximum likelihood tree with sorted topologies based on the COI-gene. *Fucus serratus* and *Saccorhiza dermatodea* were used as outgroups. The numbers above and below the lines are bootstrap values with 1000 replications. Support values below 60% are not given in the tree. Sequenced specimens from this survey are in black font and annotated with station and sample number. The species in red font are reference sequences retrieved from NCBI's GenBank with top hits from the blast search annotated with * or **.

Locations

The digitate kelp specimens identified to *Laminaria digitata* by molecular methods were collected from one of the six sampling sites, Wijdefjorden west (L4b; Fig. 17). The digitate kelp specimens identified to *Saccharina groenlandica* were sampled from five sites: Zieglerøya (L2), Vaigattneset (L3), Kapp Kjeldsen (L5), Indre Norskøya (L6) and Revneset (L7; Fig. 17).

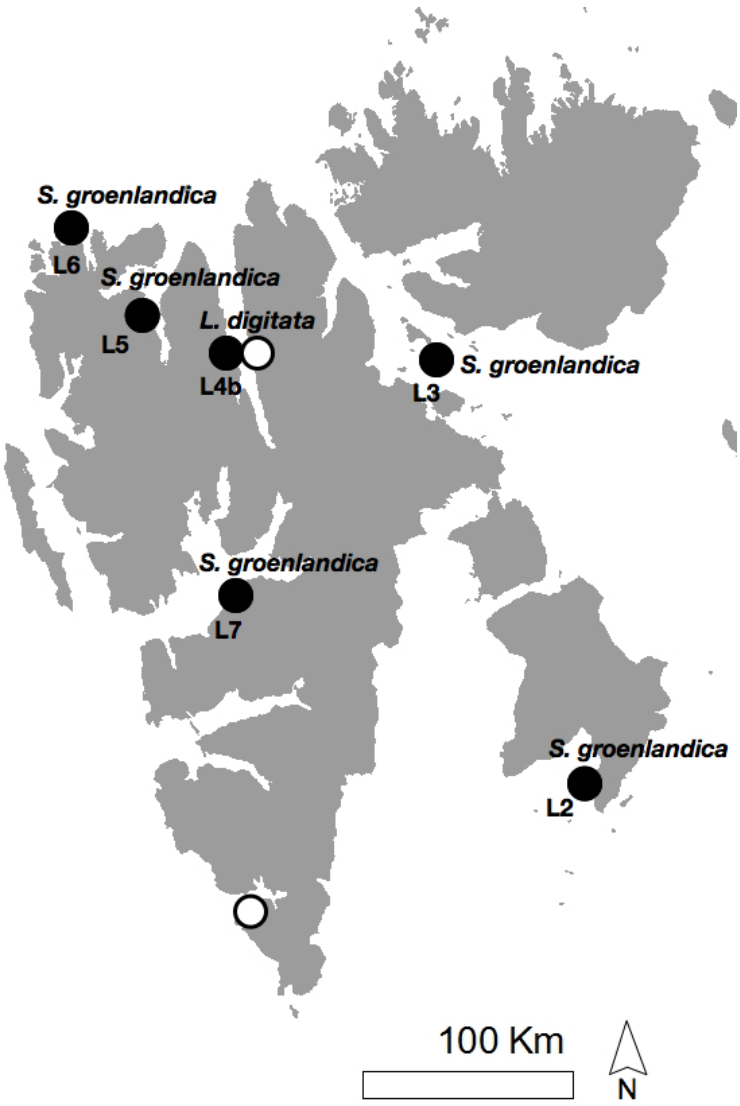


Figure 17. Map of the sampling locations of the specimens identified with the COI-gene. *Laminaria digitata* is marked with an underline and was identified from station L4b (Wijdefjorden west). *Saccharina groenlandica* was identified from stations: L2 (Zieglerøya), L3 (Vaigattneset), L5 (Kapp Kjeldsen), L6 (Indre Norskøya) and L7 (Revneset).

3.3.2 *Fucus*

Bayesian analysis

The results from the Bayesian analysis based on the mtDNA spacer region showed that the sequenced specimens (black font) could be identified to *Fucus distichus*. The sequenced specimens forms a well-supported clade, with a posterior probability of 1, with the retrieved sequences (red font) from the NCBI's GenBank (Fig. 18).

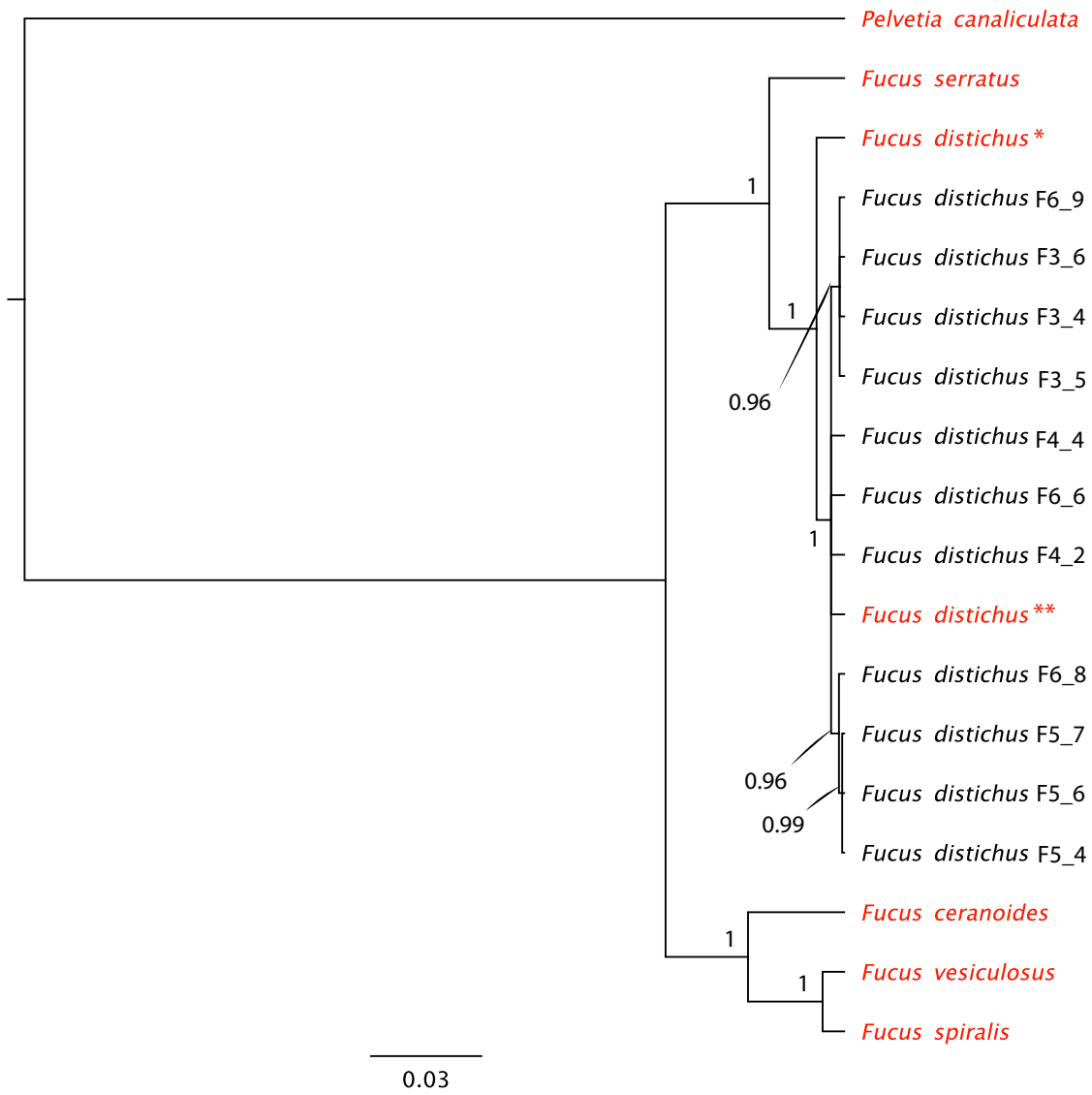


Figure 18. Bayesian posterior output tree based on the mtDNA spacer, with *Pelvetia canaliculata* as outgroup. The numbers above the lines are posterior probability values. Sequences from this survey are given in black font annotated with station and sample number while the reference sequences are in red font and the top two hits from the blast search against the NCBI genbank are annotated with * or **.

Maximum likelihood

The result from the Maximum likelihood analysis based on the mtDNA spacer region showed similar result as the Bayesian analysis. The sequenced *Fucus* specimens (black font) cluster together with the retrieved *Fucus distichus* reference sequences (red font) from NCBI's Gene Bank, with a bootstrap value of 89 (Fig. 19). The clustering within the *Fucus distichus* group is somewhat different than in the Bayesian analysis, though some similarities occur such as the grouping of *Fucus* specimens annotated with F5_4, 6, 7 (Fig. 18, 19).

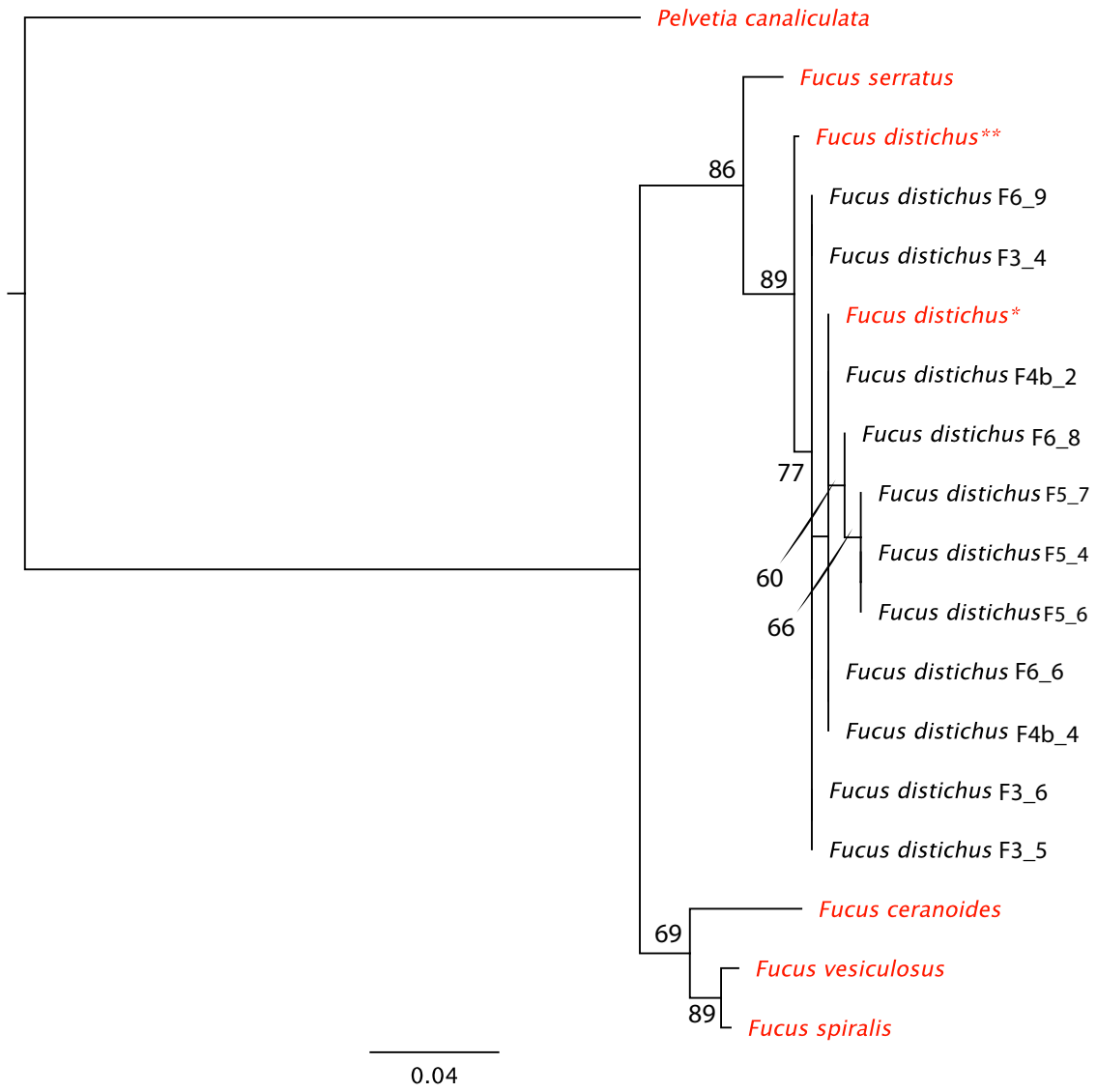


Figure 19. Maximum likelihood tree based on the mtDNA spacer, with *Pelvetia canaliculata* as outgroup. Numbers above and below the lines are bootstrap values with 1000 replications. Support values below 50 are not plotted in the tree. Sequences from this survey are in black font and annotated with station and sample number. Reference sequences retrieved from NCBI genbank are in red font, and the top two hits in the blast search is annotated with * or **.

Locations

The sequenced specimens of *Fucus* were sampled from six sites: Zieglerøya (F2), Vaigattneset (F3), Wijdefjorden west (F4b), Kapp Kjeldsen (F5), Indre Norskøya (F6) and Revneset (F7). They were all identified to *Fucus distichus* (Fig. 20).

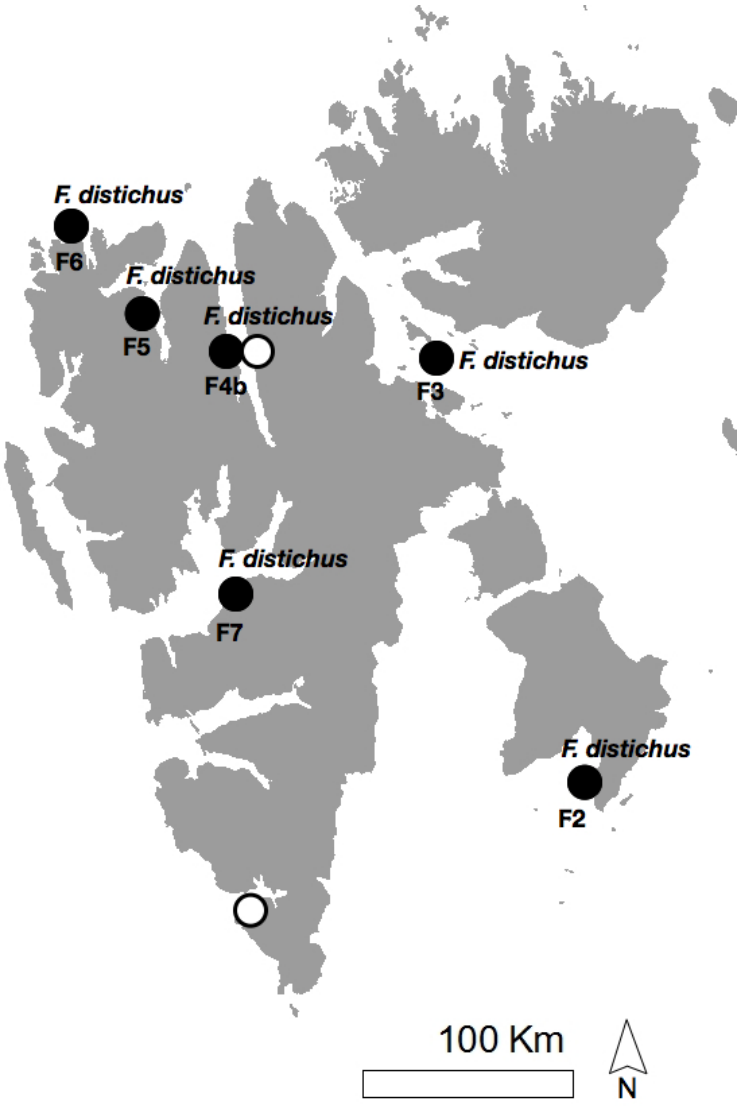


Figure 20. Map of the locations to the *Fucus distichus* samples that were identified with molecular methods. *Ceramium virgatum* was only found at the station Kapp Kjeldsen (F/C5). All the *Fucus* samples were identified to *Fucus distichus.*

3.3.3 Ceramium

Bayesian analysis

Specimens of *Ceramium* were identified to *Ceramium virgatum* in the Bayesian analysis based on the rubisco spacer region (Fig. 21). The sequenced specimens (black font) and the reference sequence retrieved from NCBI's GenBank (red font) formed a well supported clade with a posterior probability of 1 (Fig. 21).

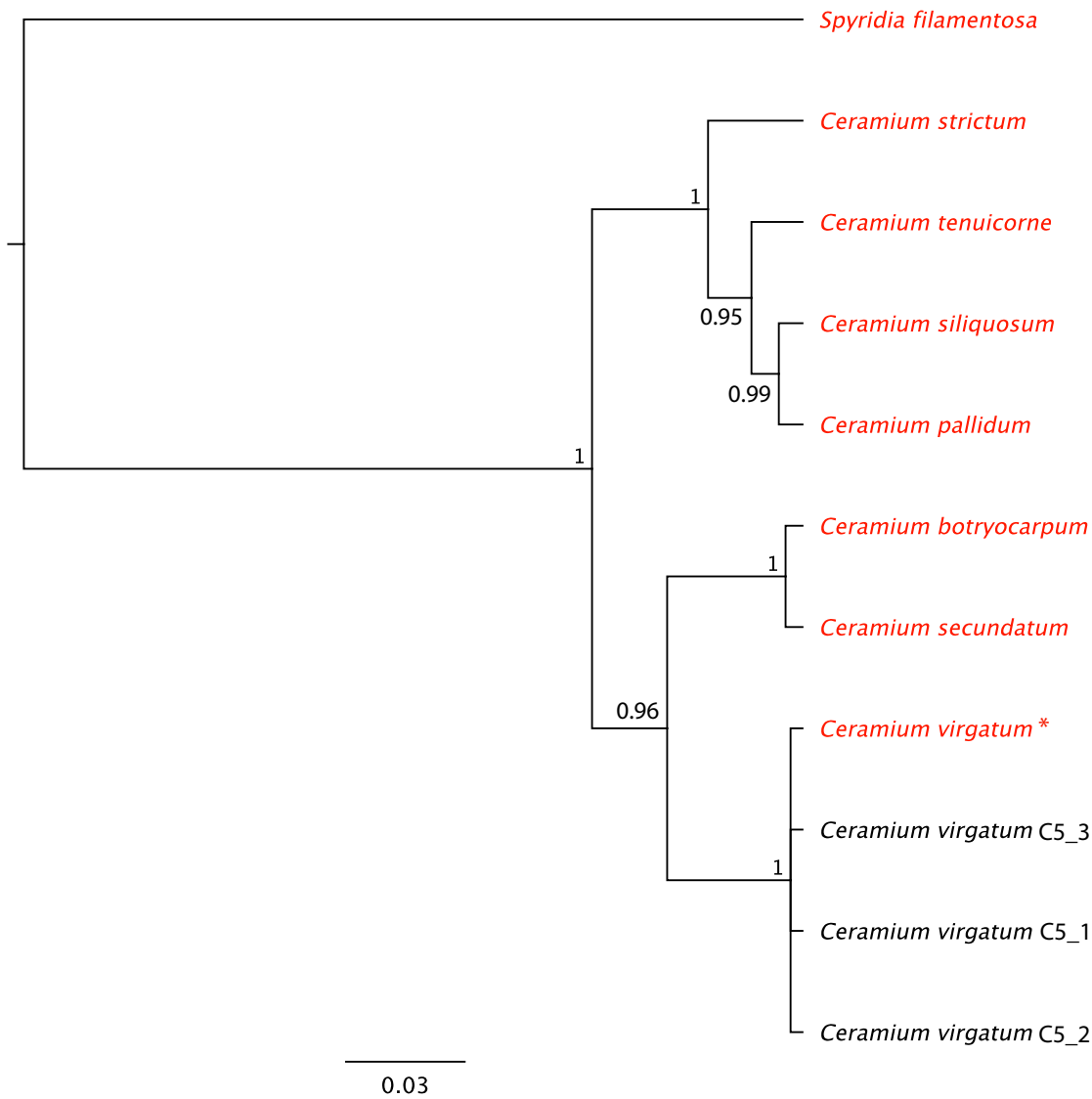


Figure 21. Bayesian posterior output tree based on the rubisco spacer region, with *Spyridia filamentosa* as outgroup. The number above and below the lines are posterior probability values. Sampled sequences in this survey are in black font and reference sequences from the NCBI genbank are in red font. The best hit in the blast search against the NCBI genbank is annotated with *.

Maximum likelihood

The maximum likelihood analysis also resulted in a supported group, with a bootstrap value of 95, consisting of the sequenced specimens (black font) and the reference sequence of *Ceramium virgatum* (red font) retrieved from the NCBI's GenBank. The result supports the species identification of the specimens to *C. virgatum* (Fig. 22).

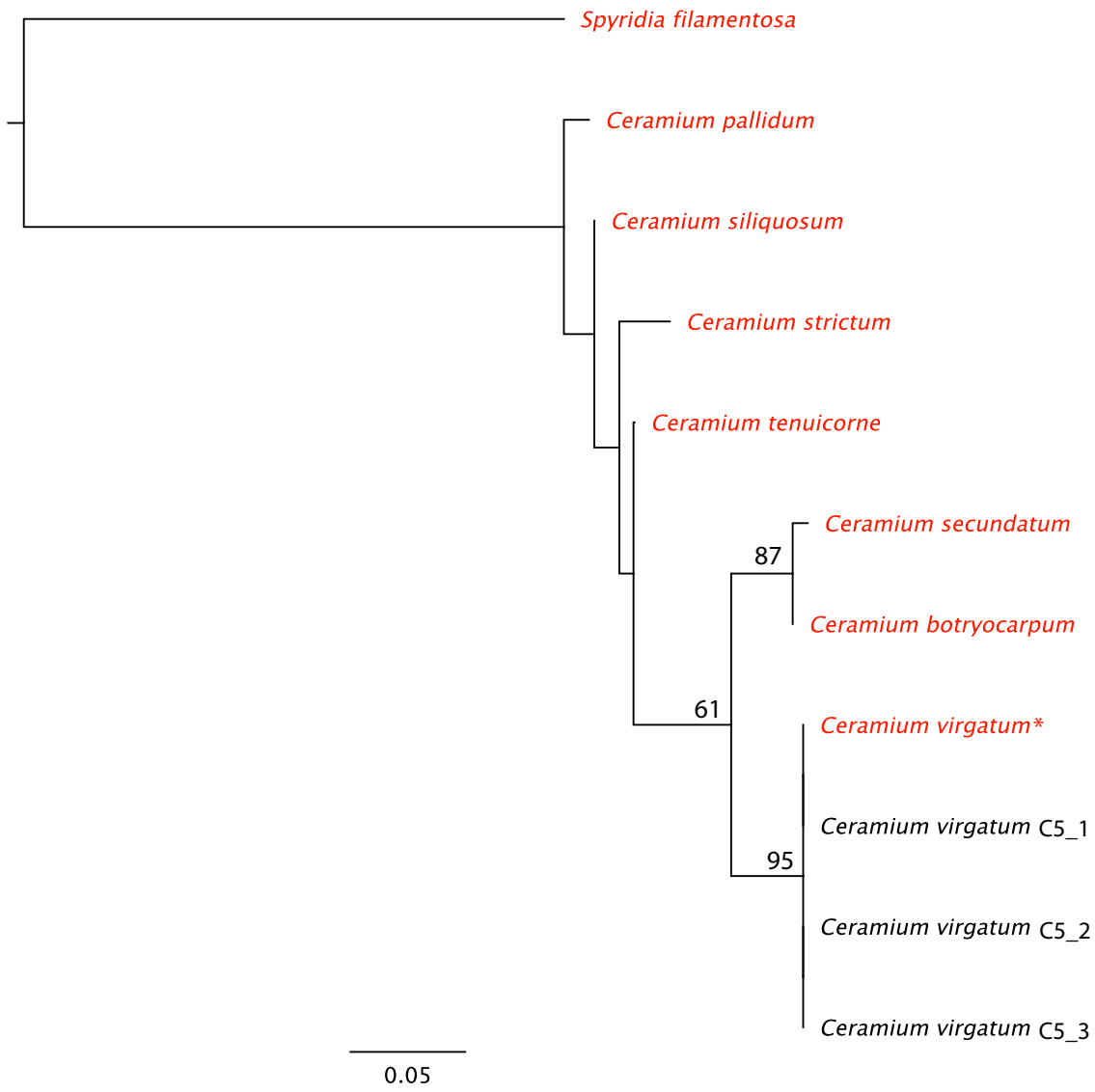


Figure 22. Maximum likelihood tree based on the rubisco spacer region, with *Spyridia filamentosa* as outgroup. The values above the line are bootstrap values with 1000 replications. Values below 50 are not included in the tree. Sequenced specimens from this survey are in black font, while the reference sequences retrieved from NCBI genbank are in red font. The best blast hit of the sequences against the NCBI gene bank is annotated with *.

Location

Ceramium virgatum was identified from one station, Kapp Kjeldsen (C5), using the rubisco spacer region (Fig. 23).

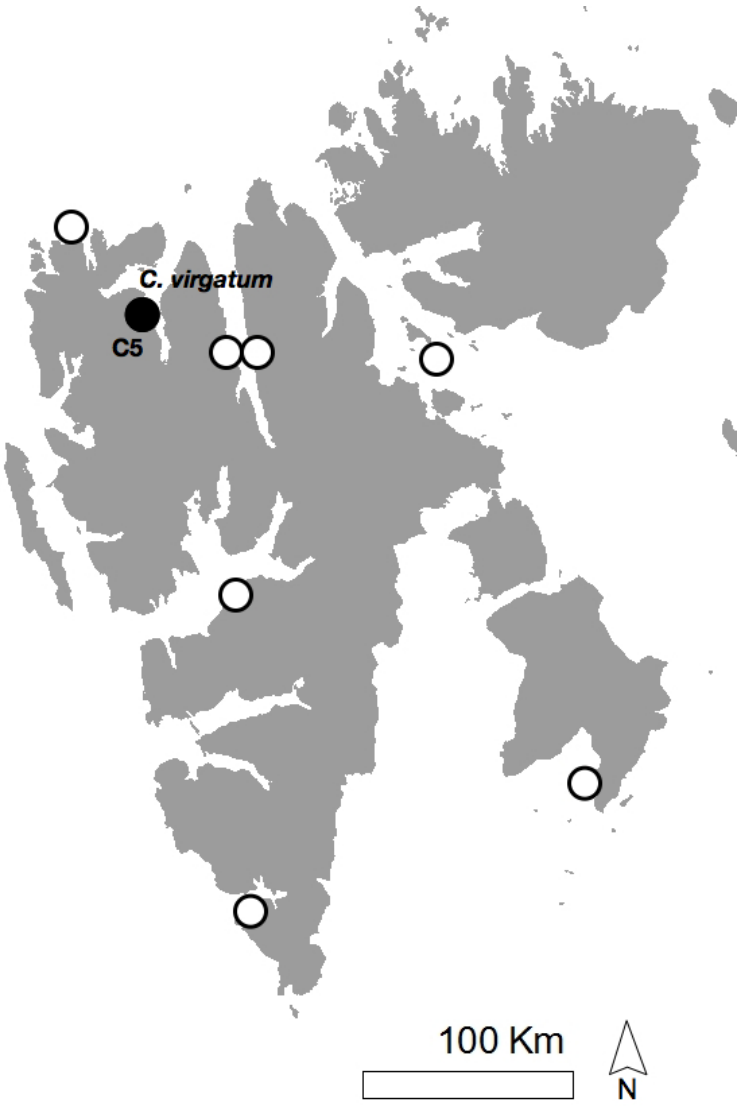


Figure 23. Map showing the location at which the sequenced *Ceramium* specimens were sampled.

4. Discussion

This survey will be discussed with a focus on a) Macroalgal research in the Arctic b) Macroalgal research in Svalbard c) Environmental conditions d) Results from the phylogenetic analyses e) Troubleshooting and future prospective, and f) Conclusions.

In this study a total of 53 taxa were identified including 12 chlorophytes, 25 phaeophytes, 15 rhodophytes and 1 xanthophyte (excluding unidentified specimens). A higher number of brown algal species were recorded relative to red and green algae (Fig. 12). Brown algal species are thought to be more abundant in cold water, and the higher number of brown algal species was therefore expected (Graham et al. 2009). Also a relatively high number of green algae were expected as sampling was conducted in the littoral and upper sublittoral zone. Green algae have a higher abundance in this zone because they are very tolerant to varying environmental conditions such as fluctuating salinity, and may be the first algae to colonize ice scoured areas (Lüning 1990; Hop et al. 2012). Red algae are often found in the understory vegetation and in deeper waters, and if the entire sublittoral was included a higher number of red algae than recorded in the present study could be expected (Gómez et al. 2009; Hop et al. 2012). The number of taxa identified from each of the eight sites did not differ much. However, site 4a (Wijdefjorden east) stood out with only seven recorded taxa (discussed below). Five taxa were present at all eight sites: *Acrosiphonia arcta, Ulothrix flacca, Fucus distichus, Pylaiella littoralis* and *Pylaiella varia*. In addition, *Desmarestia aculeata, Alaria esculenta, Saccharina latissima* and *Rhodomela confervoides* were present at seven sites (Appendix III). Only two species identified in this survey, *Laminaria solidungula* and *Saundersella simplex*, do not occur along the Norwegian coast.

4.1 Macroalgal research in the Arctic

In this section I want to compare my study area to other islands in the Arctic region in terms of the number of species recorded. The Arctic may be defined in several ways, however the definition based on the 0°C February seawater isotherm was adopted in this study (Lünning 1990). The algal flora of the Arctic is relatively poorly investigated compared to lower latitudes because of its inaccessibility and difficult sampling conditions (Fredriksen et al. 2014). Novaya Zemlya is located further east in the Arctic (Fig 1) and there are recorded 123

macroalgal species from this archipelago (Taylor 1954). The eastern side of Novaya Zemlya borders the Kara Sea, which is influenced by large river outflows. The fresh water discharge reduces the salinity in the Kara Sea and also increases turbidity affecting the algal flora (Lein and Lein 1998). Northeast of Svalbard is Franz Josef Land (Fig 1). Vinogradova and Schoschina (1993) have recorded 63 species from this archipelago (cited in Lein and Lein 1998). As Franz Josef Land is situated far north, with the northern part covered by permanent ice, these investigations record the northern distribution limit of macroalgal species. Compared to Novaya Zemlya and Franz Josef Land, Svalbard may be regarded as having a richer macroalgal flora. This may be explaind by the different environmental conditions. However, Kjellmann (1877b) performed investigations on the algal vegetation on the west and north coast of Novaya Zemlya and described his findings as "Spitsbergen's flora" (see Lein and Lein 1998). Because Novaya Zemlya and Franz Josef Land are relatively unexplored, we might expect an increase in the number of species with further investigations. Pedersen (2011) describes approximately 200 species from Greenland (west of Svalbard) and recognizes the southwestern side as the most well developed area with respect to algal vegetation, with a gradual reduction in species richness northwards. The reason for this is related to the gradual change in environmental factors northwards with respect to both ice and light conditions (Pedersen 2011). The Southern part of Greenland is situated south of the polar circle, thus the gradual change in the light conditions. Also, the marine environment has different characteristics on the west and east coast of Greenland mainly due to the ocean currents (Cottier et al. 2010). From Svalbard currently 194 species are recorded (Fredriksen et al. in prep). The intertidal zone of Svalbard has been characterized as similar to that of western Greenland and Baffin Island, Canada (Weslawski et al. 1993). However, the flora in southwestern Greenland is of a more temperate character than Svalbard by occurrence of cold temperate-species (e.g. *Ascophyllum nodosum, Cladophora rupestris*, and *Membranoptera alata*), which are not present in Svalbard (Lüning 1990; Weslawski et al. 1993).

4.2 Macroalgal research in Svalbard

The present study was conducted within a predefined ten-day cruise around Svalbard. The cruise program gave the opportunity to access eight sites, including a few sites from areas which had been investigated previously. Kjellmann (1875a, 1875b, 1877a) performed surveys on the north, west and east coast of Svalbard. These surveys give records of macroalgal species from Mosselbay, Tommelpynten (Duym Point), Norskøyane and Isfjorden among

others. Although Kjellmann (1875a, 1875b, 1877a) sampled many sites around the coast of Svalbard, none of these are in close proximity to the sampling sites in the present study, with the exception of Indre Norskøya. Hornsund, Isfjorden and Kongsfjorden are the most thoroughly investigated fjords of Svalbard (e.g. Weslawski et al. 2010; Fredriksen and Kile 2012; Fredriksen et al. 2014). Relevant comparisons for the present study are the surveys performed in Isfjorden and Hornsund, as this study included sampling sites in these fjords. A comparison of species in the present with previous studies should be treated with caution (Appendix IV-VI). There are clear differences between the surveys in relation to the number of sampling sites, the sampling depth and sampling methods. In addition, a difference in number of species may also be partly explained by the precision in species identification.

4.2.1 Hornsund

31 taxa were identified from Arkeologvika in Hornsund in the littoral and upper sublittoral zone (Fig. 13). Florczyk and Latala (1989) performed investigations on the macroalgal flora in the littoral zone at 66 stations in the Hornsund fjord in 1981. Three additional sites were sampled in 1983, which also included samples from deeper waters (Florczyk and Latala 1989). The survey identified a total of 48 macroalgal taxa in the littoral and sublittoral zone (Appendix IV). The number of identified taxa is reduced to 44 due to nomenclatural revisions (Guiry and Guiry 2014). Compared to the present study, 10 taxa were not registered by Florczyk and Latala (1989; Appendix IV). From the 69 sampling sites, Florczyk and Latala (1989) described 25 taxa not observed in the present study. Because more species are expected if the sublittoral is included, the discrepancy may be connected to the deeper water samples and also the higher number of sampling sites. Florczyk and Latala (1989) included six sampling sites (47, 48, 49, 53, 60 and 66) that are relatively close to Arkeologvika. From these sites only 12 different taxa from the littoral zone were described, which is relatively low compared to the number of species found in the present study.

In 1988 Weslawski et al. (1993) sampled 128 sites in South Spitsbergen National Park (SSNP), including Hornsund. From the study they identified a total of 18 macroalgal taxa (Appendix IV). However, the paper does not give a Hornsund specific species list, rather the results are compiled from the 128 sampling sites in the SSNP. Twenty years later, Weslawski et al. (2010) revisited several of the sampling sites in Hornsund and Sorkappland. They registered 14 different macroalgal taxa (Appendix IV). Even though Weslawski et al. (1993,

2010) sampled a larger area, 18 taxa were described in the present study that were not recorded in the previous studies (Appendix IV). This discrepancy could be explained by the difference in sampling depths. Weslawski et al. (1993, 2010) only included samples from the littoral zone, excluding the kelp species and associated flora. However, the discrepancy could also reflect the importance of precision in species identification. Although the studies performed by Weslawski et al. (1993, 2010) were conducted in a larger area than Hornsund, it is included in this discussion because it is interesting to consider the number of species Weslawski et al. (1993, 2010) identified from such a large area in south Spitsbergen.

The most recent investigation in Hornsund concerning the macroalgal flora was performed by Tatarek et al. (2012). One of their sampling sites, Höyferpynten, is located in the outer part of the bay Arkeologvika, and the comparison will therefore be conducted with the result from this sampling site. Unlike the present survey, Tatarek et al. (2012) sampled from 3-40 m depth, excluding the littoral zone. Their study recorded 13 taxa from Höyferpynten (Tatarek et al. 2012). Tatarek et al. (2012) identified five species not recorded in the present study. They were: *Halosiphon tomentosus, Laminaria solidungula, Dumontia contorta, Odonthalia dentata and Ptilota gunneri*. The discrepancy is probably a result of the different sampling depths. The species not observed in this study are quite large and should be easy to recognize if present. Due to the sampling methods used in this study, species growing in deeper water would not have been sampled. A total of 23 more taxa were registered from Arkeologvika compared to Höyferpynten. Although this is a higher number of taxa, many of the species not recognized by Tatarek et al. (2012) are small filamentous algae often connected to the littoral zone and can indicate that their study focused on the larger species.

In the present study 8 taxa (*Monostroma grevillei, Ulvaria splendens, Pogotrichum filiforme, Pylaiella varia, Halothrix lumbricalis, Stictyosiphon tortilis, Haplospora globosa* and *Porphyra* sp.) were recorded in Hornsund for the first time, and one (*Halothrix lumbricalis*) is new for Svalbard. In addition, encrusting calcareous algae not formerly recorded in Hornsund were observed in Arkeologvika.

4.2.2 East and north coast

Previous research in the South East National Reserve, including Edgeøya, has been performed by Weslawski et al. (1993). They identified only three algal species (*Ulva*

compressa, *Pylaiella littoralis* and *Fucus distichus*), thus 24 algal taxa described in the present study have not previously been recorded from Zieglerøya (Edgeøya).

There are no previous surveys of macroalgal flora from Sofiaøya, Wijdefjorden (west and east), and Kapp Kjeldsen. A much higher number of algae were identified at Wijdefjorden west (4b) compared the east side of the fjord (4a). The difference in number of species may be explained by different sampling methods. Wijdefjorden east was only sampled by hand picking on a small skerry 5 m from a beach dominated by small stones and gravel, while Wijdefjorden west, consisting of solid rock, was also sampled by snorkeling and by using a throwable rake. This may also explain why there are no red algal species identified from site 4a, and 7 red algal species identified from site 4b (Fig 13). The difference in number of recorded species may also be due to local variations within the fjord and varying degree of ice scouring. Generally, the circulation in the northern hemisphere fjords is deflected to the right in the direction of the outflow (Svendsen et al. 2002, Cottier et al. 2010). The east side of Wijdefjorden may thus be exposed to higher water turbidity and sea ice. However, the importance of the rotational effect is dependent on the width and stratification of the fjord (Cottier et al. 2010), and no such estimation has been made in Wijdefjorden. All the taxa identified from site 4a, were also found at 4b. The taxa described from Sofiaøya, Wijdefjorden (west and east), and Kapp Kjeldsen have all previously been recorded in Svalbard. However, this study is the first survey at these four sites and may contribute to valid information of the distribution of algal species in Svalbard.

4.2.3 Indre Norskøya

In the present study, 34 taxa were recorded from Indre Norskøya (Fig. 13). Kjellmann (1875b, 1877a) registered 50 different taxa of macroalgae from Fair Haven and the surrounding islands, including Norskøyane. Kjellmann (1875a) sampled by dredging, which would have included the sublittoral zone. The higher number of species recorded in the previous studies may thus be a result of different sampling methods. In addition, Kjelmann (1875b, 1877a) examined a larger area than the present study, which also may explain the higher number of species recorded. 17 species recorded in my study are new for Fair Haven and the surrounding islands, and one of these is new for Svalbard (*Halothrix lumbricalis*). 69 algal taxa are now recorded from this area.

4.2.4. Isfjorden

Previous studies in Isfjorden include the work of Svendsen (1959) and Fredriksen and Kile (2012). In the present study, 28 macroalgal taxa were recorded from Revneset in Isfjorden. Svendsen (1959) registered a total of 59 macroalgal taxa from the supralittoral, littoral and sublittoral zone. Fredriksen and Kile (2012) registered a total of 83 different taxa of macroalgae, 81 from the sublittoral and 39 from the littoral zone. The higher number of taxa described from the sublittoral zone compared to the littoral zone by Fredriksen and Kile (2012) indicates that more taxa could be expected when the sublittoral is included. Furthermore, the sampling in this survey was carried out in the inner part of the fjord, while Svendsen (1959) and Fredriksen and Kile (2012) sampled in the outermost part of the fjord, at Kapp Linné and in Ymerbukta. Fjord systems have environmental gradients from the outer part and inwards with respect to wave exposure, salinity and turbidity (Jorde and Klavestad 1963; Hop et al. 2002; Husa et al. 2014). The outer part of Isfjorden may be more influenced by Atlantic water. As one moves into the fjord a higher influence of fresh water and higher turbidity is expected (Hop et al. 2002; Fredriksen et al. in press). At the time of sampling the turbidity at Revneset was high. We might therefore expect a decline in abundance and change in species composition towards the inner part of the fjord (Jorde and Klavestad 1963 in Husa et al. 2014; Hop et al. 2002). All the species described in the present study were previously recorded in Isfjorden. The species *Saccharina groenlandica* and *Ulvaria splendens* were not recorded by Svendsen (1959) and Fredriksen and Kile (2012). However, *Saccharina groenlandica* has previously been recorded in Isfjorden in a study performed during a UNIS bachelor coarse (Devor et al. 2012; see section 4.5.1), and *Ulvaria splendens* was recognized by Fredriksen et al. (in press). Today a total of 104 macroalgal taxa have been recorded in Isfjorden (Fredriksen et al. in press).

4. 3 Environmental conditions

4.3.1 Ice scouring

The littoral zone has often been regarded as supporting little life in Svalbard due to the influence of sea-ice (Weslawski et al. 1993, 2010; Fredriksen and Kile 2012, Fredriksen et al. 2014). In sea ice areas the littoral zone is, with regard to macroalgae, mainly composed of annual and pseudoannual filamentous green and brown algae, while perennial species are restricted to greater depths (Svendsen 1959; Ellis and Wilce 1961; Wulff et al. 2009; Hop et al 2012). The difference in ice conditions between the west and east coast of Spitsbergen

(Fig. 3) has led to the impression that the west coast has a richer algal flora in the littoral zone than the east coast (Weslawski et al. 1993). The results from my study support the impression that areas exposed to ice scouring have little algal growth in the littoral zone. At ice scoured sites only filamentous algae in cracks on the cliffs were found (Fig. 24: A). There were two sites with rich algal vegetation in the littoral zone mainly composed of *Fucus* assemblages (Fig. 24: B). These sites were located far south (site 1) and far north (site 6) on the west coast of Spitsbergen. The pattern from the cluster analysis of sites based on the species composition (present/absent) may be explained by exposure to ice scouring. Five sites (2, 3, 4b, 5 and 7) were grouped in one cluster in the dendrogram. The ice chart shows that sites 2, 3, 4b and 5 were covered by fast ice during the winter prior to sampling, and this was consistent with the visual judgment of sampling sites during sampling. The two west coast sites (1 and 6) form another cluster and sites 1 and 6 were similar in terms of having rich algal vegetation in the littoral zone. However, they were less than 50% similar with respect to species composition (Fig. 14), probably due to a large difference in latitude. Site 6 (northernmost site) was exposed to open water the year of sampling, which was consistent with the observation of algal vegetation in the littoral zone. The ice free condition is probably related to the West Spitsbergen Current transporting warmer water far north. Sites 1 and 7 were exposed to open and very open drift ice respectively, the year of sampling. Site 1 had a well-developed algal flora in the littoral zone, while site 7 had a poorer flora and appeared to be ice scoured. The difference in algal vegetation between these sites may be due to local variations within the fjords and more turbid water from run-off in Isfjorden (site 7). In

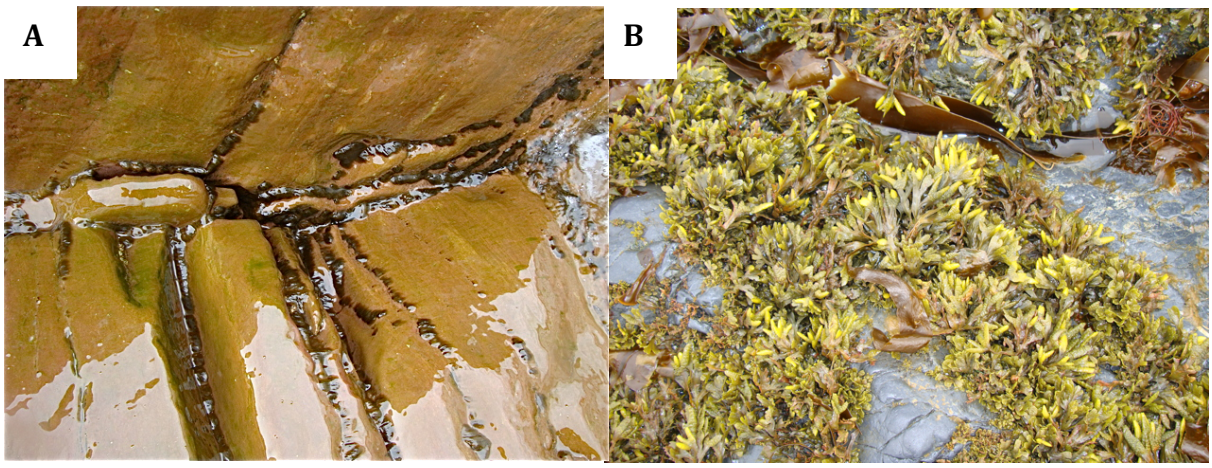


Figure 24. A: Image from sampling site 5, which was object to ice scouring the year of sampling. There were only filamentous green and brown algae growing in cracks in the littoral zone. B: Image from sampling site 1 showing rich algal vegetation in the littoral zone.

addition, site 7 was located in the inner part in Isfjorden, while Arkeologvika was located in the outer part in Hornsund.

4.3.2 Run-off from land

Run-off from land is high during the summer months due to melting of snow and ice (Svendsen et al. 2002; Nowak and Hodson 2013). The water may therefore be very turbid, which reduces light penetration into the water column (Hop et al. 2002; Wiencke et al. 2007). Run-off influences the algal vegetation in several ways: lower depth limit (not examined in this study), salinity and particles (sedimentation). Run-off may affect species composition through decreased salinity and increased turbidity in the littoral and upper sublittoral zone (Svendsen 1959; Hop et al. 2002; Svendsen et al. 2002). The macroalgal species in areas with fluctuating salinity due to a seasonal supply of freshwater must be able to tolerate osmotic stress (Lüning 1990; Hop et al. 2002). Measurements of irradiance, turbidity and salinity were not conducted and the assessment of the conditions (turbidity) at the sampling sites was therefore based on visual judgment. Sites 5 and 7 were exposed to high water turbidity at the time of sampling. Based on the assumption that turbid water indicates fresh water input, both decreased salinity and increased turbidity have influenced the species composition at sites 5 and 7. This may be the reason why these two fjord stations showed high similarity in species composition. The sites with relatively low water turbidity (at the time of sampling) formed two clusters in the analysis (sites 2 and 3; sites 1 and 6). The two clusters are relatively different in terms of species composition based on the cluster analysis, which may be related to the different ice conditions.

4.3.3 Substratum

The diversity of algal species is also dependent on substrate (Hop et al. 2002) thus we might therefore expect a difference in species composition related to this factor. However, the sampling sites in this study were partly chosen based on occurrence of hard substratum such as cliffs and boulders, and therefore substratum is not a random factor in this study. Although two sites were mainly composed of boulders (sites 2 and 3) and formed one cluster. Although some patterns can be seen in the data obtained, this interpretation should be treated with caution since the sampling was purely qualitative.

4.3.4 Other interactions

Biological interactions between species and herbivory by snails and sea urchins have not been included in this study. Such interactions may also influence the algal distribution significantly (Hop et al. 2002; Norderhaug and Christie 2009; Fredriksen et al. in press). New littoral species like *Mytilus* will compete for space and may alter the macroalgal vegetation in the littoral zone dependent on their abundance (Hurd et al. 2014). Slope and bearing may influence the macroalgae vegetation. The sites in Svalbard were in relatively open areas and this was not regarded as a factor influencing qualitative species composition.

4.4 Changes in climate

The changes in climate are predicted to cause alterations in the algal vegetation with respect to species distribution and composition (Müller et al. 2009; Bartsch et al. 2012; Kortsch et al. 2012). Increased temperature, as predicted by IPCC, will cause increased melting and thus elevated suspension of particles in the sea. This will likely reduce the lower depth limit and also the biodiversity of macroalgal species (Bartsch et al. 2012). The temperature increase will also cause a decrease in the duration and extend of sea ice and thus a reduction in ice scouring leading to improved conditions for algal growth in the littoral zone. We might therefore expect an increased distribution of macroalgal species, including perennials, into areas previously subject to ice scouring (Weslawski et al 2010; Bartsch et al. 2012; Fredriksen et al. 2014). The upward shift of macroalgal species into the littoral zone may be counteracted by high levels of ultraviolet B radiation in the littoral zone compared to the sublittoral (Bartsch et al. 2012 and references therein). Responses to climate change have been reported from studies in Svalbard. Kortsch et al. (2012) registered an increase in the macroalgal cover in Kongsfjorden and Smeerenburgfjord. They related this to the increased temperature that, besides higher temperature, resulted in an extended period of ice-free days and a longer light season for the macroalgal vegetation in ice covered waters. Records of increased macroalgal diversity in the littoral zone in Kongsfjorden (Spitsbergen, Svalbard) have been associated with increased temperature and a reduction in ice scouring (Fredriksen et al. 2014). Additional indications of a changing environment have been related to the reappearance of the blue mussel (*Mytilus edulis* L.) in Svalbard after 1000 years of absence (Berge et al. 2005). Berge et al. (2005) concluded that the increased transport of Atlantic Water, favorable wind conditions and elevated sea surface temperature affected the settlement of blue mussels in Isfjorden. Furthermore, observations of cold-temperate,

temperate and subtropical krill species in Kongsfjorden have been taken as an indication of increased influence of Atlantic water in Kongsfjorden (Buchholz et al. 2012). The above-mentioned studies predict that if the observed trends of warmer sea surface temperature continue, we might expect establishment of temperate macroalge species into the Arctic. However, Svalbard is part of a larger system where climate induced changes to oceanic circulation patterns could result in altered supply pathways and thus unpredictable responses in community composition.

4.5 Phylogenetic analyses

4.5.1 Digitate kelp

The phenotypically plastic species *Saccharina groenlandica* has been morphologically associated with both *Laminaria digitata* and *Saccharina latissima*. *Saccharina groenlandica* is previously known from northern areas such as Arctic Canada (McDevit and Saunders 2010), East Greenland (Lund 1959) and North America (e.g. Labrador; Taylor 1957) (Guiry and Guiry 2014). The original description of this species was done by Rosenvinge (1893) on a specimen from Greenland. However, Pedersen (2011) assigned all digitate kelp species from Greenland to *Laminaria nigripes*. Previous studies in Svalbard have recorded two species of digitate kelp: *Laminaria digitata* and *Laminaria nigripes* (e.g. Kjellmann 1883; Vinogradova 1995b; Svendsen 1959; Fredriksen and Kile 2012). Whether *L. nigripes* should be regarded as a valid species or in fact be included in *S. groenlandica* needs to be confirmed.

The phylogenetic analysis based on the COI gene assigned the digitate kelp specimens to either *Saccharina groenlandica* or *Laminaria digitata*. *Laminaria digitata* was only identified from one site (4b, Wijdefjorden west), while *Saccaharina groenlandica* was identified from five sites (2, Zieglerøya; 3, Vaigattneset; 5, Kapp Kjeldsen; 6, Indre Norskøya and 7, Revneset; Fig. 17). Molecular studies regarding digitate kelp in Svalbard have been performed by Lund (2014). She identified all the specimens collected from Kapp Mitra (North-West Spitsbergen), Smeerenburgfjorden (North-West Spitsbergen) and Gyldénøyane (Nordaustlandet) to *Saccharina groenlandica* based on the COI gene. In addition, unpublished records of *Saccharina groenlandica,* based on the COI gene, were also done during a UNIS bachelor course AB202 (Devor at al. 2012) from Hinlopen and Isfjorden. From Kongsfjorden (North-West Spitsbergen), both *Laminaria digitata* and *Saccharina groenlandica* were present in their samples (Devor at al. 2012). More studies are needed to

elucidate the geographical distribution of these kelp species in Svalbard waters and in the Arctic in general. However, the results indicate that *Saccharina groenlandica* is more abundant in Svalbard than *Laminaria digitata.*

4.5.2 *Fucus*

Fucus species are common members of the intertidal marine flora in the North Pacific and North Atlantic (Kucera and Saunders 2008). Some *Fucus* species are easily distinguishable, such as *Fucus serratus*. However, due to a high degree of phenotypic plasticity many *Fucus* species are difficult to identify based on morphological characters. Coyer at al. (2006) have concluded that *Fucus distichus* and *Fucus evanescens* are conspecific based on the mitochondrial DNA spacer. Kucera and Saunders (2008) also support this in their study on *Fucus* species utilizing the COI gene. However, both *Fucus disticus* and *Fucus evanescens* are still regarded as taxonomically valid species by Guiry and Guiry (2014). These two species have previously been separated by size and width of the thallus and by distribution. *Fucus distichus* are thought to inhabit the upper littoral zone and *Fucus evanescens* the lower littoral and the upper sublittoral zone (Jaasund 1965; Kucera and Saunders 2008; Pedersen 2011). In the present study all fucoid specimens collected were identified to one species, *Fucus distichus*, supporting the result from Coyer et al. (2006) and Kucera and Saunders (2008; Fig. 18; Fig. 19).

4.5.3 *Ceramium*

The red algal genus *Ceramium* includes cosmopolitan species that is known to cause taxonomic difficulties due to a high degree of plasticity in morphological characters (Skage et al. 2005, Maggs et al. 2002). Two species are previously recorded from Svalbard; *Ceramium circinatum* and *Ceramium virgatum* (Vinogradova 1995a; Hansen and Jenneborg 1996). *Ceramium* specimens were sampled from one site (5, Kapp Kjeldsen) and were all identified to *Ceramium virgatum* by using the rubisco spacer region.

4.6 Troubleshooting and further prospective

4.6.1 Macroalgal investigations

The sampling methods used in this study enabled the collection of macroalgal species in the littoral and the sublittoral zone. However, the sites with high water turbidity were difficult to sample by snorkeling and we did not obtain the same overview here as in the sites with low water turbidity. Due to the sampling methods, the data obtained are entirely qualitative. Thus, the absence of a species in these data sets does not mean that it necessarily is absent in nature. Measurements of salinity and temperature are lacking from the survey and this could have provided valuable information. Because this project was part of a pre-planned cruise program with a focus on terrestrial biology, the locations sampled were dependent on the other research groups on the expedition.

Some taxa are in need of a taxonomic evaluation. Difficulties with morphological identification are related to lack of diagnostic characters to distinguish between species. Issues with taxonomical confusion make comparisons to previous investigations challenging. Small green algae such as species within the genera *Ulothrix, Acrosiphonia* and *Urospora* are challenging to identify by morphological characters due to partly overlapping characters and the fact that the literature may not correspond in the species descriptions. Similar problems are also related to species of brown and red algae. Species within the genera *Fucus, Laminaria* and *Saccharina* may be difficult to identify due to a high degree of phenotypic plasticity. Also, the genus *Alaria* may cause problems. For instance, *Alaria pylaii* is suspected to be a form, variety or ecotype of *A. esculenta* (Lüning 1990, Kraan et al. 2001, Lane et al. 2007), but is still a valid species according to Guiry and Guiry (2014). The genera *Ceramium* and *Rhodomela* include species that have a varying morphology and the distinction between some species is uncertain. New insights into green, brown and red algal species are needed, using both morphological and molecular characters.

4.6.2 Phylogenetic analyses

The phylogenetic analyses were done using sequences downloaded from NCBI's GenBank. A weakness of the GenBank is that there is no quality control on the sequences submitted. This means that the sequences in GenBank may be wrongly identified. The reference sequences used in the phylogenetic tree of the kelp species were submitted to GenBank by

McDevit and Saunders, known for their work with kelp. I also included specimens given to me by Tove Gabrielsen, which were identified *in situ* as *Laminaria hyperborea* and *Laminaria digitata* from the Norwegian mainland. The authors submitting the reference sequences used in the phylogenetic analysis for *Fucus* were less known to me. However, a misidentified species may be revealed in the phylogeny. The reference sequences used in the phylogenetic analysis of *Ceramium* were submitted to GenBank by Gabrielsen, Brochmann and Rueness, or Skage, Gabrielsen and Rueness known to have done a lot of work with species within the genus.

The identification of *Fucus distichus* was ensured by DNA barcoding from six of eight sites. From site 1 and 4a, the species identification is based on morphological traits only. Tissue samples of the digitate kelp specimens from site 1 are lacking. This is unfortunate as there are no records of molecular studies of kelp specimens in southwest Spitsbergen, and could therefore have provided valuable information regarding the geographical distribution of kelp species in Svalbard. The use of mucilage ducts to identify species like *Laminaria digitata, Saccharina groenlandica* and *Saccharina latissima* is debated (Chapman 1975; McDevit and Saunders 2010). However, it would have been interesting to examine this character in an attempt to separate the species based on this morphological trait. Unfortunately, tissue samples were only taken for molecular analysis and this character could therefore not be examined. *Saccharina groenlandica* has also been described with morphology similar to that of *Saccharina latissima* (McDevit and Saunders 2010). It would have been interesting to sequence the specimens with *Saccharina latissima* morphology. It would also be interesting to study how environmental factors, such as wave exposure and ice conditions affect the morphology of kelp species in the Arctic. The distribution of kelp species in the Arctic needs to be elucidated using molecular tools in combination with morphological characters.

4.7 Conclusions

This study has identified 53 macroalgal species in the littoral and upper sublittoral zone at eight sites located around Svalbard. Highest number of species was found at the northernmost site (6) with 34 species (17:6:10:1= Phaeophyceae:Rhodophyta:Chlorophyta:Xantophyceae). Four locations had not been investigated previously, thus this thesis publishes the first records of macroalgal species at these locations. One of the species recorded, *Halothrix lumbricalis* (Ectocarpales, Phaeophyceae), is new for Svalbard. *Halothrix lumbricalis* was recorded at site 1 Arkeologvika and site 6 Indre Norskøya at the west coast of Svalbard. In addition, the study indicated that *Saccharina groenlandica* is more abundant than *Laminaria digitata* in Svalbard. All fucoid specimens were identified to *Fucus disticus* and the *Ceramium* specimens were identified to *Ceramium virgatum*. Changes in macroalgal distribution have been documented and considering the observed and predicted global climatic changes continued monitoring of macroalgal flora is important to include in future research.

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Appendix I

E.Z.N.A.® Cycle Pure Kit Centrifugation Protocol

E.Z.N.A.® Cycle Pure Kit Centrifugation Protocol

E.Z.N.A.® Cycle Pure Kit - Centrifugation Protocol Materials and Equipment to be Supplied by User:

- Microcentrifuge capable of at least 13,000 x *g*
- Nuclease-free 1.5 mL microcentrifuge tubes
- 100% ethanol
- Optional: Sterile deionized water or TE Buffer
- For Fragments < 200 BP, 100% Isopropanol

Before Starting:

• Prepare DNA Wash Buffer according to the "Preparing Reagents" section on Page 4.

1. Perform agarose gel/ethidium bromide electrophoresis to analyze PCR product.
2. Determine the volume of your PCR reaction.
3. Transfer the sample into a clean 1.5 mL microcentrifuge tube.
4. Add 4-5 volumes CP Buffer. For PCR products smaller than 200 bp, add 5 volumes CP Buffer and 0.4 V 100 % Isopropanol

   Note: Volume refers to the size of your PCR reaction. For example, if your PCR reaction is 100 µL and is smaller than 200 bp, you would use 500 µL CP Buffer abd 40 µL Isopropanol.

5. Vortex to mix thoroughly. Briefly centrifuge to collect any drops from the inside of the lid.
6. Insert a HiBind® DNA Mini Column into a 2 mL Collection Tube (provided).
7. Add the sample from Step 5 to the HiBind® DNA Mini Column.
8. Centrifuge at maximum speed (≥13,000 x *g*) for 1 minute at room temperature.

E.Z.N.A.® Cycle Pure Kit Centrifugation Protocol

9. Discard the filtrate and reuse collection tube.
10. Add 700 µL DNA Wash Buffer.
11. Centrifuge at maximum speed for 1 minute.

    Note: DNA Wash Buffer must be diluted with ethanol before use. Please see the Preparing Reagents section on Page 4 for instructions.

12. Discard the filtrate and reuse collection tube.
13. Repeat Steps 10-12 for a second DNA Wash Buffer wash step.
14. Centrifuge the empty HiBind® DNA Mini Column at maximum speed for 2 minutes to dry the column.

    Note: This step is critical for removal of trace ethanol that may interfere with

downstream applications.

15. Transfer the HiBind® DNA Mini Column into a clean 1.5 mL microcentrifuge tube (not provided).
16. Add 30-50 µL Elution Buffer, TE Buffer, or sterile deionized water directly to the center of column matrix.
17. Let sit at room temperature for 2 minutes.
18. Centrifuge at maximum speed for 1 minute.

    Note: This represents approximately 80-90% of bound DNA. An optional second elution will yield any residual DNA, though at a lower concentration.

19. Store DNA at -20°C.

Appendix II

Table 1. Reference sequences downloaded from Genbank. Region: cytochrome oxidase subunit 1 (COI) gene, partial cds; mitochondrial

Saccorhiza dermatodea voucher GWS007139	GI:211906747	FJ409212.1
Saccharina sessilis voucher GWS003208	GI:211906739	FJ409208.1
Saccharina latissima voucher GWS007538	GI:262179708	GU097832.1
** Saccharina groenlandica voucher GWS005291	GI:262179522	GU097739.1
* Saccharina groenlandica voucher GWS005377	GI:262179524	GU097740.1
Saccharina bongardiana voucher Lbong2	GI:262179504	GU097730.1
Nereocystis luetkeana voucher GWS003400	GI:262179490	GU097723.1
Laminaria yezoensis voucher GWS004941	GI:211906657	FJ409167.1
Laminaria solidungula voucher GWS005335	GI:211906655	FJ409166.1
** Laminaria hyperborea voucher GWS009235	GI:211906633	FJ409155.1
* Laminaria hyperborea voucher GWS009234	GI:211906635	FJ409156.1
Laminaria ephemera voucher GWS011013	GI:262179456	GU097706.1
** Laminaria digitata voucher GWS007680	GI:211906621	FJ409149.1
* Laminaria digitata voucher GWS005604	GI:262179446	GU097701.1
Fucus serratus voucher GWS002293	GI:183397516	EU646716.1

Table 2. Reference sequences downloaded from Genbank. Region: 23S ribosomal RNA gene, partial sequence; 23S ribosomal RNA-trnK intergenic spacer gene, complete sequence; and tRNA-Lys gene, partial sequence; mitochondrial

Pelvetia canaliculata isolate C31	GI:530723383	KC143810.1
Fucus vesiculosus haplotype h14	GI:284926985	GQ385125.1
Fucus spiralis haplotype h8	GI:284926979	GQ385119.1
Fucus serratus isolate CCFs22	GI:336454335	HQ316129.1
** Fucus evanescens isolate CCFe24	GI:336454342	HQ316136.1
Fucus evanescens isolate CCFe13	GI:336454345	HQ316139.1
Fucus ceranoides haplotype B11	GI:371491826	JN084387.1

Table 3. Reference sequences downloaded from Genebank. Region: Ribulose-1,5-bisphosphate carboxylase/oxygenase large subunit (rbcL) and ribulose-1,5-bisphosphate carboxylase/oxygenase small subunit (rbcS) genes, partial cds; chloroplast genes for chloroplast products.

Ceramium botryocarpum	GI:37955452	AY254306.1
Ceramium pallidum	GI:37955443	AY254303.1
Ceramium secundatum clone Cse	GI:29378614	AF543815.1
Ceramium siliquosum clone Csi.1	GI:29378593	AF543808.1
Ceramium strictum clone Csp4.2	GI:29378602	AF543811.1
Ceramium tenuicorne	GI:37955431	AY254299.1
Ceramium virgatum	GI:37955446	AY254304.1
Spyridia filamentosa	GI:37955506	AY255476.1

Appendix III

Table 1. Taxonomic overview of the species recorded in the present study at the eight sites.

	Site 1	Site 2	Site 3	Site 4a	Site 4b	Site 5	Site 6	Site 7
Chlorophyta								
Ulvophyceae								
Cladophorales								
Cladophoraceae								
Chaetomorpha melagonium (F. Weber & Mohr) Kützing	X	X	X		X		X	
Ulotrichales								
Ulotrichaceae								
Acrosiphonia arcta (Dillwyn) Gain	X	X	X	X	X	X	X	X
Acrosiphonia sonderi (Kützing) Kornmann	X						X	
Spongomorpha aeruginosa (Linnaeus) Hoek							X	
Ulothrix flacca (Dillwyn) Thuret	X	X	X	X	X	X	X	X
Ulothrix speciosa (Carmichael) Kützing							X	
Urospora penicilliformis (Roth) Areschoug	X					X	X	X
Urospora wormskioldii (Mertens ex Hornemann) Rosenvinge	X							
Gomontiaceae								
Monostroma grevillei (Thuret) Wittrock	X						X	
Ulvales								
Kornmanniaceae								
Blidingia minima (Nägel ex Kützing) Kylin							X	
Ulvaceae								
Ulva prolifera O.F. Müller	X	X					X	
Ulvaria splendens (Ruprecht) Vinogradova	X	X			X			X
Unidentified green algae			X					
Ochrophyta								
Phaeophyceae								
Desmarestiales								
Desmarestiaceae								
Desmarestia aculeata (Linnaeus) J.V. Lamouroux	X	X	X	X	X	X		X
Ectocarpales								
Acinetosporaceae								
Pogotrichum filiforme Reinke	X							

	Site 1	Site 2	Site 3	Site 4a	Site 4b	Site 5	Site 6	Site 7
Pylaiella littoralis (Linnaeus) Kjellmann	X	X	X	X	X	X	X	X
Pylaiella varia Kjellmann	X	X	X	X	X	X	X	X
Chordariaceae								
Chordaria flagelliformis (O.F. Müller) C. Agardh	X	X			X	X	X	X
Climacosorus mediterraneus Sauvageau						X		X
Dictyosiphon foeniculaceus (Hudson) Greville	X				X	X	X	
Elachista fucicola (Velley) Areschoug	X	X	X		X		X	X
Halothrix lumbricalis (Kützing) Reinke	X						X	
Litosiphon laminariae (Lyngbye) Harvey						X	X	
cf. *Myrionema* sp. Greville		X					X	
Saundersella simplex (De A. Saunders) Kylin							X	X
Stictyosiphon tortilis (Gobi) Reinke	X					X		X
Ectocarpaceae								
Ectocarpus fasciculatus Harvey		X			X	X	X	X
Ectocarpus siliculosus (Dillwyn) Lyngbye		X				X		
Fucales								
Fucaceae								
Fucus distichus Linnaeus	X	X	X	X	X	X	X	X
Laminariales								
Alariaceae								
Alaria esculenta (Linnaeus) Greville	X	X	X		X	X	X	X
Laminariaceae								
Laminaria digitata (Hudson) J.V. Lamouroux					X			
Laminaria solidungula J. Agardh			X		X		X	
Saccharina groenlandica (Rosenvinge) C.E. Lane, C. Mayes, Druehl and G.W. Saunders		X	X			X	X	X
Saccharina latissima (Linnaeus) C.E. Lane, C. Mayes, Druehl and G.W. Saunders	X	X	X		X	X	X	X
Saccharina groenlandica/Laminaria digitata	X							
Sphacelariales								
Sphacelariaceae								
Sphacelaria sp.	X							
Battersia arctica (Harvey) Draisma, Prud'homme and H. Kawai		X	X		X	X		
Chaetopteris plumosa (Lyngbye) Kützing		X	X		X	X	X	X
Tilopteridales								

	Site 1	Site 2	Site 3	Site 4a	Site 4b	Site 5	Site 6	Site 7
Phyllariaceae								
Saccorhiza dermatodea (Bachelot de la Pylaie) J. Agardh	X	X			X			X
Tilopteridaceae								
Haplospora globosa Kjellmann	X	X				X	X	X
Unidentified brown algae		X				X		
Unidentified epiphytes		X	X	X		X	X	X
Xanthophyceae								
Vaucheriales								
Vaucheriaceae								
Vaucheria sp. A.P. de Candolle		X	X	X	X		X	
Rhodophyta								
Bangiophyceae								
Bangiales								
Bangiaceae								
Porphyra sp.	X							
Florideophyceae								
Acrochaetiales								
Acrochaetiacea								
Acrochaetium sp. Nägeli					X			
Rhodochorton purpureum (Lightfoot) Rosenvinge			X			X	X	X
Ceramiales								
Ceramiaceae								
Ceramium virgatum Roth						X		
Delesseriaceae								
Phycodrys rubens (Linnaeus) Batters	X					X		X
Rhodomelaceae								
Odonthalia dentata (Linnaeus) Lyngbye						X		X
Polysiphonia arctica J. Agardh		X	X			X		X
Polysiphonia stricta (Dillwyn) Greville					X			
Rhodomela confervoides (Hudson) P.C. Silva	X	X	X		X	X	X	X
Wrangeliaceae								
Ptilota serrata Kützing					X	X	X	X
Gigartinales								
Kallymeniaceae								
Euthora cristata (C. Agardh) J. Agardh	X							

	Site 1	Site 2	Site 3	Site 4a	Site 4b	Site 5	Site 6	Site 7
Hildenbrandiales								
Hildenbrandiaceae								
Hildenbrandia rubra (Sommerfelt) Meneghini							X	
Palmariales								
Palmariaceae								
Devaleraea ramentacea (Linnaeus) Guiry	X	X	X		X		X	X
Palmaria palmata (Linnaeus) Weber and Mohr		X	X		X	X		X
Calcearous crusts	X		X		X		X	

Appendix IV

Table 1. Macroalgal species recorded in Hornsund by Florczyk and Latala (1989), South Spitsbergen National park (SPNP) by Weslawski et al. (1993), Hornsund and Sorkappland by Weslawski et al. (1993, 2010), Höyferpynten by Tatarek et al. (2012) and Arkeologvika in the present study (Moy). The names listed in the column Taxa follow the nomenclature of Guiry and Guiry (2014). If species in the previous studies are recorded under synonyms to these currently accepted names they are listed in the column synonyms.

Taxa	Synonyms	Florczyk and Latala (1989) (Hornsund)	Weslawski et al. (1993) (SPNP)	Weslawski et al. (2010) (Hornsund and Sorkappland)	Tatarek et al. (2012) (Höyferpynten, Hornsund)	Moy
Chlorophyta						
Uvlophyceae						
Cladophorales						
Cladophoraceae						
Chaetomorpha melagonium (F. Weber & Mohr) Kützing		X				X
Ulotrichales						
Ulothrichaceae						
Acrosiphonia arcta (Dillwyn) Gain		X	X			X
Acrosiphonia duriuscula (Ruprecht) Yendo		X	X			
Acrosiphonia flagellata Kjellman				X		
Acrosiphonia sonderi (Kützing) Kornmann					X	X
Ulothrix flacca (Dillwyn) Thuret	*Ulothrix pseudoflacca* Wille	X	X			X
Ulothrix implexa (Kützing) Kützing		X	X			
Urospora elongata (Rosenvinge) Hagem		X	X			
Urospora penicilliformis (Roth) Areschoug		X	X			X
Urospora wormskioldii (Mertens ex Hornemann) Rosenvinge		X	X	X		X
Gomontiaceae						
Monostroma grevillei (Thuret) Wittrock						X
Ulvales						
Kornmanniaceae						
Blidingia minima (Nägel ex Kützing)		X				

Taxa	Synonyms	Florczyk and Latala (1989) (Hornsund)	Weslawski et al. (1993) (SPNP)	Weslawski et al. (2010) (Hornsund and Sorkappland)	Tatarek et al. (2012) (Höyferpynten, Hornsund)	Moy
Kylin						
Ulvaceae						
Ulva compressa Linnaeus	*Enteromorpha compressa* (Linnaeus) Nees		X			
Ulva lactuca Linnaeus				X		
Ulva prolifera O.F. Müller	*Enteromorpha prolifera* (O.F.Müller) J.Agardh	X				X
Ulvaria obscura (Kützing) P.Gayral ex C.Bliding		X				
Ulvaria splendens (Ruprecht) Vinogradova						X
Ulvellaceae						
Ulvella scutata (Reinke) R.Nielsen, C.J.O'Kelly & B.Wysor	*Pringsheimiella scutata* (Reinke) Marchewianka	X				
Ocrophyta						
Phaeophyceae						
Desmarestiales						
Desmarestiaceae						
Desmarestia aculeata (Linnaeus) J.V. Lamouroux		X	X	X		X
Ectocarpales						
Acinetosporaceae						
Pogotrichum filiforme Reinke						X
Pylaiella littoralis (Linnaeus) Kjellmann		X	X	X		X
Pylaiella varia Kjellmann						X
Chordariaceae						
Chordaria flagelliformis (O.F. Müller) C. Agardh		X	X	X		X
Dictyosiphon foeniculaceus (Hudson) Greville		X	X	X	X	X
Elachista fucicola (Velley) Areschoug		X	X	X		X
Halothrix lumbricalis (Kützing) Reinke						X
Isthmoplea sphaerophora (Carmichael) Gobi				X		
Stictyosiphon tortilis						X

Taxa	Synonyms	Florczyk and Latala (1989) (Hornsund)	Weslawski et al. (1993) (SPNP)	Weslawski et al. (2010) (Hornsund and Sorkappland)	Tatarek et al. (2012) (Höyferpynten, Hornsund)	Moy
(Gobi) Reinke						
Ectocarpaceae						
Ectocarpus siliculosus (Dillwyn) Lyngbye		X	X			
Scytosiphonaceae						
Petalonia zosterifolia (Reinke) Kuntze	*Ilea zosterifolia* (Reinke) Norstedt	X	X			
Scytosiphon lomentaria (Lyngbye) Link				X		
Fucales						
Fucaceae						
Fucus distichus Linnaeus		X	X	X		X
Laminariales						
Alariaceae						
Alaria esculenta (Linnaeus) Greville	*Alaria grandifolia* J.Agardh	X			X	X
Alaria pylaiei (Bory de Saint-Vincent) Greville	*Alaria membranacea* J.Agardh	X				
Laminariaceae						
Laminaria digitata (Hudson) J.V. Lamouroux	*Laminaria cucullata* f. *typica* (Kjellmann) A. Zinova	X			X	
Laminaria solidungula J. Agardh		X			X	
Saccharina latissima (Linnaeus) C.E. Lane, C. Mayes, Druehl and G.W. Saunders	*Laminaria saccharina* (Linnaeus) J.V.Lamouroux	X			X	X
L. digitata/S. groenlandica						X
Sphacelariales						
Sphacelariaceae						X
Battersia arctica (Harvey) Draisma, Prud'homme and H. Kawai	*Sphacelaria arctica* Harvey	X				
Chaetopteris plumosa (Lyngbye) Kützing	*Sphacelaria plumosa* Lyngbye	X		X		
Tilopteridales						
Halosiphonaceae						
Halosiphon tomentosus (Lyngbye) Jaasund	*Chorda tomentosa* Lyngbye	X	X		X	

Taxa	Synonyms	Florczyk and Latala (1989) (Hornsund)	Weslawski et al. (1993) (SPNP)	Weslawski et al. (2010) (Hornsund and Sorkappland)	Tatarek et al. (2012) (Höyferpynten, Hornsund)	Moy
Phyllariaceae						
Saccorhiza dermatodea (Bachelot de la Pylaie) J. Agardh	*Phyllaria lorea* (Bory de Saint-Vincent) Kjellman	X			X	X
Tilopteridaceae						
Haplospora globosa Kjellmann						X
Rhodophyta						
Bangiophyceae						
Bangiales						
Bangiaceae						
Porphyra sp						X
Florideophyceae						
Ceramiales						
Delesseriaceae						
Membranoptera alata (Hudson) Stackhouse		X				
Pantoneura fabriciana (Lyngbye) M.J.Wynne	*Pantoneura baerii* (Ruprecht) Kylin	X				
Phycodrys rubens (Linnaeus) Batters		X			X	X
Rhodomelaceae						
Odonthalia dentata (Linnaeus) Lyngbye		X			X	
Polysiphonia arctica J. Agardh		X				
Polysiphonia fucoides (Hudson) Greville	*Polysiphonia nigrescens* (Hudson) Greville ex Harvey	X				
Polysiphonia stricta (Dillwyn) Greville	*Polysiphonia urceolata* (Lightfoot ex Dillwyn) Greville	X				
Rhodomela confervoides (Hudson) P.C. Silva	*Rhodomela subfusca* (Woodward) C.Agardh	X				X
Rhodomela lycopodioides (Linnaeus) C.Agardh		X		X		
Wrangeliaceae						
Ptilota gunneri P.C.Silva, Maggs & L.M.Irvine in Maggs & Hommersand	*Ptilota plumosa* C.Agardh	X			X	
Corallinales						

Taxa	Synonyms	Florczyk and Latala (1989) (Hornsund)	Weslawski et al. (1993) (SPNP)	Weslawski et al. (2010) (Hornsund and Sorkappland)	Tatarek et al. (2012) (Höyferpynten, Hornsund)	Moy
Hapalidiaceae						X
Gigartinales						
Cystocloniaceae						
Fimbrifolium dichotomum (Lepechin) G.I.Hansen	*Rhodophyllis dichotoma* (Lepechin) Gobi	X				
Dumontiaceae						
Dumontia contorta (S.G.Gmelin) Ruprecht	*Dumontia incrassata* (O.F.Müller) J.V.Lamouroux	X	X		X	
Kallymeniaceae						
Euthora cristata (C. Agardh) J. Agardh	*Callophyllis cristata* (C.Agardh) Kützing	X			X	X
Palmariales						
Meiodiscaceae						
Meiodiscus spetsbergensis (Kjellman) G.W.Saunders & McLachlan	*Rhodochorton spetsbergense* (Kjellman) Kjellman	X				
Palmariaceae						
Devaleraea ramentacea (Linnaeus) Guiry	- *Halosaccion arcticum* A.D.Zinova - *Halosaccion ramentaceum* (Linnaeus) J.Agardh -*Halosaccion ramentaceum* f. *robustum* Kjellman	X		X		X
Palmaria palmata (Linnaeus) Weber and Mohr		X				

Appendix V

Table 1. Species recorded from Fair Haven and the surrounding islands by Kjellmann (1875a,1877a) and species recorded in the present study (Moy) from Indre Norskøya. The names listed in the column Taxa follow the nomenclature of Guiry and Guiry (2014). If species in the previous studies are recorded under synonyms to these currently accepted names they are listed in the column synonyms.

Taxa	Synonyms	Kjellmann (1875a, 1877a)	Moy
Chlorophyta			
Ulvophyceae			
Cladophorales			
Cladophoraceae			
Not listed in Guiry and Guiry (2015)	*Chaetomorpha maritima**	X	
Chaetomorpha melagonium (F. Weber & Mohr) Kützing	*Conferva melagonium* F.Weber & Mohr	X	X
Cladophora hutchinsiae (Dillwyn) Kützing	*Cladophora diffusa* Harvey	X	
Rhizoclonium riparium (Roth) Harvey		X	
Ulotrichales			
Ulotrichaceae			
Acrosiphonia arcta (Dillwyn) Gain	*Cladophora arcta* (Dillwyn) Kützing	X	X
Acrosiphonia sonderi (Kützing) Kornmann			X
Spongomorpha aeruginosa (Linnaeus) Hoek			X
Ulothrix discifera Kjellman		X	
Ulothrix flacca (Dillwyn) Thuret			X
Ulothrix speciosa (Carmichael) Kützing			X
Urospora penicilliformis (Roth) Areschoug		X	X
Gomontiaceae			
Monostroma grevillei (Thuret) Wittrock			X
Monostroma lubricum Kjellman		X	
Ulvales			
Kornmanniaceae			
Blidingia minima (Nägel ex Kützing) Kylin			X
Ulvaceae			
Ulva compressa Linnaeus	*Enteromorpha intestinalis* f. *compressa* (L) Le Jol.	X	
Ulva lactuca Linnaeus	*Ulva crassa* Kjellman	X	
Ulva prolifera O.F. Müller			X
Ulvaria obscura (Kützing) P.Gayral ex C.Bliding	*Monostroma blyttii* (Areschoug) Wittrock	X	
Ulvaria splendens (Ruprecht) Vinogradova	*Monostroma fuscum* Wittrock	X	
Ochrophyta			
Phaeophyceae			
Desmarestiales			
Desmarestiaceae			
Desmarestia aculeata (Linnaeus) J.V. Lamouroux		X	
Desmarestia viridis (O.F.Müller) J.V.Lamouroux		X	
Ectocarpales			
Acinetosporaceae			

Taxa	Synonyms	Kjellmann (1875a, 1877a)	Moy
Pylaiella littoralis (Linnaeus) Kjellmann		X	X
Pylaiella varia Kjellmann			X
Chordariaceae			
Chordaria flagelliformis (O.F. Müller) C. Agardh			X
Chordaria chordaeformis (Kjellman) H.Kawai & S.-H.Kim in S.-H.Kim & Kawai	*Chordaria flagelliformis* f. *subsimplex* Kjellmann, *Chordaria flagelliformis* f. f. *ramusculifera* Kjellmann	X	
Delamarea attenuata (Kjellman) Rosenvinge	*Dictyosiphon chordaria* f. *simpliciusculus* Areschoug	X	
Dictyosiphon foeniculaceus (Hudson) Greville	*Dictyosiphon hippuroides* (Lyngbye) Kützing	X	X
Elachista fucicola (Velley) Areschoug		X	X
Halothrix lumbricalis (Kützing) Reinke			X
Litosiphon laminariae (Lyngbye) Harvey			X
cf. *Myrionema* sp. Greville			X
Saundersella simplex (De A. Saunders) Kylin			X
Stictyosiphon subarticulatus (Areschoug) Hauck	*Phloeospora subarticulata* Areschoug	X	
Ectocarpaceae			
Ectocarpus fasciculatus Harvey			X
Fucales			
Fucaceae			
Fucus distichus Linnaeus		X	X
Laminariales			
Alariaceae			
Alaria esculenta (Linnaeus) Greville			X
Chordaceae			
Chorda filum (Linnaeus) Stackhouse			
Laminariaceae			
Laminaria digitata (Hudson) J.V. Lamouroux		X	
Laminaria solidungula J. Agardh		X	X
Saccharina groenlandica (Rosenvinge) C.E. Lane, C. Mayes, Druehl and G.W. Saunders			X
Saccharina latissima (Linnaeus) C.E. Lane, C. Mayes, Druehl and G.W. Saunders	*Laminaria agardhii* Kjellman	X	X
Sphacelariales			
Lithodermataceae			
Lithoderma fatiscens Areschoug		X	
Sphacelariaceae			
Battersia arctica (Harvey) Draisma, Prud'homme and H. Kawai	*Sphacelaria arctica* Harvey	X	
Chaetopteris plumosa (Lyngbye) Kützing		X	X
Tilopteridales			
Phyllariaceae			
Saccorhiza dermatodea (Bachelot de la Pylaie) J. Agardh		X	
Tilopteridaceae			
Haplospora globosa Kjellmann			X
Rhodophyta			

Taxa	Synonyms	Kjellmann (1875a, 1877a)	Moy
Bangiophyceae			
Bangiales			
Bangiaceae			
Wildemania miniata (C.Agardh) Foslie	*Porphyra miniata* (C.Agardh) C.Agardh	X	
Florideophyceae			
Acrochaetiales			
Acrochaetiacea			
Acrochaetium sp. Nägeli (1858)			
Grania efflorescens (J.Agardh) Kylin	*Chantransia efflorescens* (J.Agardh) Kjellman	X	
Rhodochorton purpureum (Lightfoot) Rosenvinge	*Thamnidium rothii* (Turton) Thuret	X	
Ceramiales			
Ceramiaceae			
Pterothamnion plumula (J.Ellis) Nägeli in Nägeli & Cramer	*Antithamnion plumula* (J.Ellis) Thuret	X	
Corallinales			
Corallinaceae			X
Lithophyllum fasciculatum (Lamarck) Foslie	*Lithothamnion fasciculatum* (Lamarck) Areschoug	X	
Delesseriaceae			
Pantoneura fabriciana (Lyngbye) M.J.Wynne	*Delesseria baeri* Ruprecht	X	
Phycodrys rubens (Linnaeus) Batters	*Delesseria sinuosa* J.V.Lamouroux	X	
Rhodomelaceae			
Odonthalia dentata (Linnaeus) Lyngbye		X	
Polysiphonia arctica J. Agardh		X	X
Rhodomela confervoides (Hudson) P.C. Silva			X
Rhodomela lycopodioides (Linnaeus) C.Agardh	*Rhodomela lycopodioides* f. *cladostephus* (J.Agardh) Kjellman	X	
Rhodomela tenuissima (Ruprecht) Kjellman		X	
Rhodymeniales			
Rhodymeniaceae			
Sparlingia pertusa (Postels & Ruprecht) G.W.Saunders, I.M.Strachan & Kraft	*Rhodymenia pertusa* (Postels & Ruprecht) J.Agardh	X	
Wrangeliaceae			
Ptilota serrata Kützing		X	
Ptilota gunneri P.C.Silva, Maggs & L.M.Irvine in Maggs & Hommersand	*Ptilota plumosa* C.Agardh	X	
Gigartinales			
Cystocloniaceae			
Fimbrifolium dichotomum (Lepechin) G.I.Hansen	*Rhodophyllis veprecula* J.Agardh	X	
Kallymeniaceae			
Euthora cristata (C. Agardh) J. Agardh		X	
Phyllophoraceae			
Coccotylus truncatus (Pallas) M.J.Wynne & J.N.Heine	*Phyllophora interrupta* (Greville) J.Agardh	X	
Hildenbrandiales			
Hildenbrandiaceae			
Hildenbrandia rubra (Sommerfelt) Meneghini	*Hildenbrandia rosea* Kützing	X	
Palmariales			
Meiodiscaceae			

Taxa	Synonyms	Kjellmann (1875a, 1877a)	Moy
Meiodiscus spetsbergensis (Kjellman) G.W.Saunders & McLachlan	- *Thamnidium penicilliforme* (Kjellman) Kjellman - *Thamnidium spetsbergense* Kjellman	X	
Palmariaceae			
Devaleraea ramentacea (Linnaeus) Guiry	*Halosaccion ramentaceum* (Linnaeus) J.Agardh	X	X
Palmaria palmata (Linnaeus) Weber and Mohr	*Rhodymenia palmata* (Linnaeus) Greville	X	X

Appendix VI

Table 1. Species registered by Svendsen (1959), Fredriksen and Kile (2012) and the present study (Moy) in Isfjorden. The names listed in the column Taxa follow the nomenclature of Guiry and Guiry (2014). If species in the previous studies are recorded under synonyms to these currently accepted names they are listed in the column synonyms.

Taxa	Synonyms	Per Svendsen (1959)	Fredriksen and Kile (2012)	Moy
Chlorophyta				
Ulvophyceae				
Cladophorales				
Cladophoraceae				
Chaetomorpha melagonium (F. Weber & Mohr) Kützing		X	X	
Chaetomorpha linum (O.F.Müller) Kützing			X	
Cladophora spp.		X	X	
Rhizoclonium riparium (Roth) Harvey		X	X	
Ulotrichales				
Ulotrichaceae				
Acrosiphonia arcta (Dillwyn) Gain			X	X
Pseudothrix groenlandica (J.Agardh) Hanic & S.C.Lindstrom	*Capsosiphon groenlandicus* (J.Agardh) K.L.Vinogradova		X	
Spongomorpha sp.		X		
Spongomorpha aeruginosa (Linnaeus) Hoek			X	
Ulothrix flacca (Dillwyn) Thuret	*Ulothrix* cf. *pseudoflacca* Wille	X	X	X
Ulothrix cf. *implexa* (Kützing) Kützing			X	
Ulothrix cf. *subflaccida* Wille			X	
Urospora penicilliformis (Roth) Areschoug		X		X
Gomontiaceae				
Monostroma spp.		X		
Ulvales				
Kornmanniaceae				
Blidingia minima (Nägel ex Kützing) Kylin			X	
Kornmannia leptoderma (Kjellman) Bliding			X	
Ulvaceae				
Ulva sp.	*Enteromorpha* sp.	X		
Ulva compressa Linnaeus	*Enteromorpha compressa* (Linnaeus) Nees	X		
Ulva prolifera O.F. Müller			X	
Ulvaria splendens (Ruprecht) Vinogradova				X
Ulvellaceae				
Epicladia flustrae Reinke	*Acrochaete flustrae* (Reinke) O'Kelly in Gabrielson, Widdowson & Lindstrom		X	
Ulvella sp.	*Acrochaete* sp.		X	
Ochrophyta				
Phaeophyceae				
Desmarestiales				
Desmarestiaceae				

Taxa	Synonyms	Per Svendsen (1959)	Fredriksen and Kile (2012)	Moy
Desmarestia aculeata (Linnaeus) J.V. Lamouroux		X	X	X
Desmarestia viridis (O.F.Müller) J.V.Lamouroux		X	X	
Ectocarpales				
Acinetosporaceae				
Pogotrichum filiforme Reinke			X	
Pylaiella littoralis (Linnaeus) Kjellmann		X	X	X
Pylaiella varia Kjellmann		X	X	X
Chordariaceae				
Asperococcus sp.		X		
Chordaria chordaeformis (Kjellman) H.Kawai & S.-H.Kim in S.-H.Kim & Kawai			X	
Chordaria flagelliformis (O.F. Müller) C. Agardh		X	X	X
Climacosorus mediterraneus Sauvageau			X	X
Delamarea attenuata (Kjellman) Rosenvinge		X	X	
Dictyosiphon chordaria Areschoug		X	X	
Dictyosiphon foeniculaceus (Hudson) Greville	*Dictyosiphon* cf. *corymbosus* Kjellman	X	X	
Elachista fucicola (Velley) Areschoug		X	X	X
Eudesme virescens (Carmichael ex Berkeley) J.Agardh			X	
Isthmoplea sphaerophora (Carmichael) Gobi		X	X	
Leptonematella fasciculata (Reinke) P.C.Silva			X	
Litosiphon laminariae (Lyngbye) Harvey			X	
Myrionema corunnae			X	
Omphalophyllum ulvaceum Rosenvinge			X	
Phaeostroma pustulosum Kuckuck			X	
Punctaria cf. *plantaginea* (Roth) Greville			X	
Punctaria tenuissima (C.Agardh) Greville			X	
Saundersella simplex (De A. Saunders) Kylin			X	X
Stictyosiphon tortilis (Gobi) Reinke			X	X
Ectocarpaceae				
Ectocarpus spp.		X		
Ectocarpus fasciculatus Harvey			X	X
Ectocarpus siliculosus (Dillwyn) Lyngbye	*Ectocarpus confervoides* Le jolis	X	X	
Scytosiphonaceae				
Petalonia fascia (O.F.Müller) Kuntze			X	
Petalonia zosterifolia (Reinke) Kuntze			X	
Scytosiphon sp.		X		
Scytosiphon lomentaria (Lyngbye)			X	
Stragularia clavata (Harvey)			X	

Taxa	Synonyms	Per Svendsen (1959)	Fredriksen and Kile (2012)	Moy
G.Hamel				
Fucales				
Fucaceae				
Fucus distichus Linnaeus		X	X	X
(*Fucus evanescens*)			(X)	
Ishigeales				
Petrodermataceae				
Petroderma maculiforme (Wollny) Kuckuck			X	
Laminariales				
Alariaceae				
Alaria sp**.**		X		
Alaria esculenta (Linnaeus) Greville	*Alaria grandifolia* J.Agardh	X	X	X
Chordaceae				
Chorda filum (Linnaeus) Stackhouse		X	X	
Mesogloia vermiculata (Smith) S.F.Gray		X		
Laminariaceae				
Laminaria digitata (Hudson) J.V. Lamouroux		X	X	
Laminaria solidungula J. Agardh		X	X	
Saccharina groenlandica (Rosenvinge) C.E. Lane, C. Mayes, Druehl and G.W. Saunders				X
Saccharina latissima (Linnaeus) C.E. Lane, C. Mayes, Druehl and G.W. Saunders	*Laminaria saccharina* (Linnaeus) J.V.Lamouroux	X	X	X
Ralfsiales				
Ralfsiaceae				
Ralfsia sp.		X		
Sphacelariales				
Lithodermataceae				
Lithoderma sp.		X		
Sphacelariaceae				
Battersia arctica (Harvey) Draisma, Prud'homme and H. Kawai	*Sphacelaria arctica* Harvey		X	
Chaetopteris plumosa (Lyngbye) Kützing	*Sphacelaria plumosa* Lyngbye	X	X	X
Sphacelaria sp.		X		
Stypocaulaceae				
Protohalopteris radicans (Dillwyn) Draisma, Prud'homme & H.Kawai	*Sphacelaria radicans* (Dillwyn) C.Agardh		X	
Tilopteridales				
Halosiphonaceae				
Halosiphon tomentosus (Lyngbye) Jaasund	*Chorda tomentosa* Lyngbye	X	X	
Phyllariaceae				
Saccorhiza dermatodea (Bachelot de la Pylaie) J. Agardh	*Phyllaria dermatodea* (Bachelot de la Pylaie) Gobi	X	X	X
Tilopteridaceae				
Haplospora globosa Kjellmann		X	X	X
Xanthophyceae				
Vaucheriales				
Vaucheriaceae				
Vaucheria sp. A.P. de Candolle			X	

Taxa	Synonyms	Per Svendsen (1959)	Fredriksen and Kile (2012)	Moy
Rhodophyta				
Bangiophyceae				
Bangiales				
Bangiaceae				
Wildemania amplissima (Kjellman) Foslie	*Porphyra amplissima* (Kjellman) Setchell & Hus		X	
Wildemania miniata (C.Agardh) Foslie	*Porphyra miniata* (C.Agardh) C.Agardh	X		
Florideophyceae				
Acrochaetiales				
Acrochaetiacea				
Audouinella spp.			X	
Rhodochorton purpureum (Lightfoot) Rosenvinge	*Rhodochorton rothii* (Turton) Nägeli	X	X	X
Ceramiales				
Ceramiaceae				
Antithamnionella floccosa (O.F.Müller) Whittick			X	
Ceramium sp.		X	X	
Pterothamnion plumula (J.Ellis) Nägeli in Nägeli & Cramer				
Scagelothamnion pusillum (Ruprecht) Athanasiadis	*Antithamnion boreale* (Gobi) Kjellman	X	X	
Delesseriaceae				
Pantoneura fabriciana (Lyngbye) M.J.Wynne	*Pantoneura baerii* (Ruprecht) Kylin	X		
Phycodrys rubens (Linnaeus) Batters		X	X	X
Rhodomelaceae				
Odonthalia dentata (Linnaeus) Lyngbye		X	X	X
Polysiphonia arctica J. Agardh		X	X	X
Polysiphonia fucoides (Hudson) Greville			X	
Polysiphonia stricta (Dillwyn) Greville			X	
Rhodomela confervoides (Hudson) P.C. Silva			X	X
Rhodomela lycopodioides (Linnaeus) C.Agardh		X		
Corallinales				
Corallinaceae			X	
Hapalidiaceae				
Lithothamnion sp.		X		
Gigartinales				
Phyllophoraceae				
Coccotylus truncatus (Pallas) M.J.Wynne & J.N.Heine	*Phyllophora brodiei* (Turner) Endlicher	X		
Rhodymeniales				
Wrangeliaceae				
Ptilota gunneri P.C.Silva, Maggs & L.M.Irvine in Maggs & Hommersand	*Ptilota plumosa* C.Agardh	X	X	
Ptilota serrata Kützing	*Ptilota pectinata* (Gunnerus) Kjellman	X	X	X
Gigartinales				
Cystocloniaceae				

Taxa	Synonyms	Per Svendsen (1959)	Fredriksen and Kile (2012)	Moy
Fimbrifolium dichotomum (Lepechin) G.I.Hansen	*Rhodophyllis dichotoma* (Lepechin) Gobi	X		
Dumontiaceae				
Dilsea carnosa (Schmidel) Kuntze	*Dilsea edulis* Stackhouse	X		
Dilsea socialis (Postels & Ruprecht) Perestenko	*Dilsea integra* (Kjellman) Rosenvinge	X		
Kallymeniaceae				
Euthora cristata (C. Agardh) J. Agardh		X	X	
Hildenbrandiales				
Hildenbrandiaceae				
Hildenbrandia rubra (Sommerfelt) Meneghini	*Hildenbrandia prototypus* Nardo	X	X	
Palmariales				
Meiodiscaceae				
Meiodiscus spetsbergensis (Kjellman) G.W.Saunders & McLachlan			X	
Rubrointrusa membranacea (Magnus) S.L.Clayden & G.W.Saunders	- *Rhodochorton membranaceum* (Magnus) Hauck - *Colaconema membranaceum* (Magnus) Woelkerling	X	X	
Palmariaceae				
Devaleraea ramentacea (Linnaeus) Guiry	*Halosaccion ramentaceum* (Linnaeus) J.Agardh	X	X	X
Palmaria palmata (Linnaeus) Weber and Mohr	*Rhodymenia palmata* (Linnaeus) Greville	X	X	X
Rhodophysemataceae				
Cf. *Rhodophysema* sp.			X	
Rhodophysema kjellmanii G.W. Saunders & Clayden	*Halosacciocolax kjellmanii* S.Lund		X	
Red fleshy crusts			X	

Appendix VII

Permanent slides

1 *Acrosiphonia arcta*
2 *Acrosiphonia sonderi*
3 *Spongomorpha aeruginosa*
4 *Ulothrix flacca*
5 *Ulothrix speciosa*
6 *Urospora penicilliformis*
7 *Urospora penicilliformis*
8 *Urospora wormskioldii*
9 *Monostroma grevillei* (basal part)
10 *Monostroma grevillei* (apical part)
11 *Blidingia minima*
12 *Ulva prolifera*
13 *Ulva prolifera* (section)
14 *Ulvaria splendens*
15 *Ulvaria splendens* (section)
16 unid. green algae
17 *Desmarestia aculeata*
18 *Desmarestia aculeata* (section)
19 *Pogotrichum filiforme*
20 *Pylaiella littoralis*
21 *Pylaiella varia*
22 *Chordaria flagelliformis*
23 *Chordaria flagelliformis* (section)
24 *Climacosorus mediterraneus*
25 *Dictyosiphon foeniculaceus*
26 *Dictyosiphon foeniculaceus* (section)
27 *Elachista fucicola*
28 *Halothrix lumbricalis*
29 *Litosiphon laminariae*
30 *Litosiphon laminariae* (section)
31 cf. *Myrionema* sp.
32 *Saundersella simplex*
33 *Saundersella simplex* (squashed)
34 *Stictyosiphon tortilis*
35 *Stictyosiphon tortilis* (section)
36 *Ectocarpus fasciculatus*
37 *Ectocarpus siliculosus*
38 *Fucus distichus*
39 *Fucus distichus* (caeostomata)
40 *Laminaria solidungula*
41 *Sphacelaria* sp.
42 *Battersia arctica*
43 *Battersia arctica*
44 *Chaetopteris plumosa*
45 *Chaetopteris plumosa*
46 *Haplospora globosa* (gametophyte)
47 *Haplospora globosa* (sporophyte)
48 Unid. brown algae
49 Unid. brown algae
50 Unid. brown algae (section)
51 *Vaucheria* sp
52 *Acrochaetium* sp
53 *Rhodochorton purpureum*
54 *Ceramium virgatum*
55 *Phycodrys rubens*
56 *Phycodrys rubens*
57 *Odonthalia dentata*
58 *Polysiphonia arctica*
59 *Polysiphonia arctica* (section)
60 *Polysiphonia stricta*
61 *Rhodomela confervoides*
62 *Rhodomela confervoides*
63 *Rhodomela confervoides* (section)
64 *Ptilota serrata*
65 *Ptilota serrata*
66 *Devaleraea ramentacea*
67 *Devaleraea ramentacea* (section)
68 *Palmaria palmata*
69 *Palmaria palmata* (section)
70 unid. epiphyte
71 unid. epiphyte
72 unid. epiphyte
73 unid. epiphyte
74
75
76
77
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80

Herbarium specimens

1 *Chaetomorpha melagonium*
2 *Ulvaria splendens*
3 *Desmarestia aculeata*
4 *Fucus distichus*
5 *Alaria esculenta*
6 *Laminaria solidungula*
7 *Saccharina groenlandica*
8 *Saccharina latissima*
9 *Chaetopteris plumosa*
10 *Saccorhiza dermatodea*
11 *Porphyra* sp.
12 *Ceramium virgatum*
13 *Phycodrys rubens*
14 *Odonthalia dentata*
15 *Rhodomela confervoides*
16 *Ptilota serrata*
17 *Euthora cristata*
18 *Devaleraea ramentacea*
19 *Palmaria palmata*