Environmental status of Svalbard coastal waters: coastscapes and focal ecosystem components (SvalCoast) 143 REVIEW 6 SvalCoast

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Janne E. Søreide
University Centre in Svalbard (UNIS)

Vanessa Pitusi
UiT The Arctic University of Norway

Anna Vader
University Centre in Svalbard (UNIS)

Amanda Poste
Norwegian Institute for Water Research

Environmental status of Svalbard coastal waters: coastscapes and focal ecosystem components (SvalCoast)

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Janne E. Søreide[1], Vanessa Pitusi[1], Anna Vader[1], Børge Damsgård[1], Frank Nilsen[1], Ragnheid Skogseth[1], Amanda Poste[2], Allison Bailey[3], Kit M. Kovacs[1,3], Christian Lydersen[3], Sebastian Gerland[3], Sébastien Descamps[3], Hallvard Strøm[3], Paul E. Renaud[1,4], Guttorm Christensen[4], Maria P. Arvnes[5] Piotr Graczyk[6], Denis Moiseev[7], Rakesh Kumar Singh[8], Simon Bélanger[8], Josef Elster[9], Jacek Urbański[10], Mateusz Moskalik[11], Józef Wiktor[12], and Jan Marcin Węsławski[12]

1 University Centre in Svalbard, Longyearbyen, Norway
2 Norwegian Institute for Water Research, Tromsø, Norway
3 Norwegian Polar Institute, Fram Centre, Tromsø, Norway
4 Akvaplan-niva AS, Tromsø, Norway
5 SALT Lofoten AS, Svolvær, Norway
6 NORCE Norwegian Research Centre AS, Bergen, Norway
7 Murmansk Marine Biological Institute, Murmansk, Russia
8 University of Quebec at Rimouski, Canada
9 Centre for Polar Ecology, University of South Bohemia, České Budějovice, Czech Republic
10 GIS Centre, University of Gdańsk, Poland
11 Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland
12 Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

Corresponding author: Janne E. Søreide, Janne.Soreide@unis.no
ORCID number 0000-0002-6386-2471

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1. Introduction

Coastal waters are among the most productive regions in the Arctic (Leu et al. 2015; Smola et al. 2017; Ardyna et al. 2020). In these areas, a strong coupling exists between the sea and the land, and the shallow depths create a tight pelagic-benthic coupling (McGovern et al. 2020). These regions are also critical breeding and foraging grounds for many invertebrates, fish, bird, and marine mammal species (Dunton et al. 2012). When combined, these various groups of animals provide a valuable host of ecosystem services. Many of the Arctic marine species included in these groupings are vulnerable to anthropogenic and climate-induced stressors (Kovacs et al. 2011; Descamps et al. 2017). In Svalbard, nearshore ecosystems are being impacted directly by global warming—causing the reduction of landfast sea ice, the retreat of marine terminating (also called tidewater) glaciers, and altered wind and wave, circulation and stratification patterns)—as well as somewhat more indirectly by climate change on land (e.g. permafrost thaw, melting of glaciers, changes in precipitation and runoff) (e.g. Adakudlu et al. 2019). This has and will have a broad range of implications for physical and biogeochemical conditions in Svalbard's coastal waters, including changes in nutrient concentrations and the underwater light regime, as well as direct physical changes to coastal habitat structure (Dunton et al. 2012; McGovern et al. 2020). In turn, these changes are likely to impact the primary productivity and biodiversity of Svalbard's coastal waters (Leu et al. 2015; Descamps et al. 2017).

The loss of Arctic sea ice creates the possibility for expansion of commercial activity in Svalbard and the Arctic in general (e.g. fishing, shipping, tourism, and potentially marine mining of minerals, oil and gas exploration, etc.) (Misund et al. 2016; Stocker et al. 2020). The growth of global trade, urbanization, and travel activity create opportunities for organisms to move across previously isolated regions, thus advancing biotic homogenization and extinctions. At present, the extent of protected coastal marine ecosystems in the Arctic remains minute in comparison to the terrestrial environment (CAFF[1]). Arctic biodiversity is under growing pressure as climate change and human activities such as shipping and exploitation of natural resources increase. Government managers, industries, conservation organisations, and communities thus need access to timely and complete biodiversity status and trend data. For example, all Arctic endemic marine mammals are ice-associated, and hence, under extreme threat due to the ongoing trends in sea-ice losses (Kovacs et al. 2011). Recently a Coastal Expert Monitoring Group (CEMG) was established as part of the Circumpolar Biodiversity Monitoring Program (CBMP[2]) under the Arctic Council's Conservation of Arctic Flora and Fauna (CAFF) working group. The primary goal of the CEMG is to develop a long-term, integrated, multi-disciplinary circumpolar Arctic coastal biodiversity monitoring plan[3] 'State of Arctic Coastal Biodiversity Report' in 2023. This synopsis, which comprises an overview of Svalbard coastscapes (Rocky shore, Ice fronts etc.) and the essential focal ecosystem components (FECs) inhabiting them, will be an important contribution to this pan-Arctic synthesis from the Norwegian High Arctic.

The following three main objectives were addressed in this Svalbard synopsis:

1. Provide an overview of the extent of the different coastscapes in the Svalbard Archipelago (using the terminology of the Coastal Expert Monitoring Group in CAFF, 2019).
2. Identify the key environmental drivers (physical, chemical, biological, and anthropogenic) that influence biodiversity and ecosystem functioning in the defined coastscapes.
3. Map the status of essential Focal Ecosystem Components (FEC), defined by CAFF (2019), in these coastscapes in Svalbard, and identify gaps in current knowledge and monitoring.

1 www.caff.is
2 www.cbmp.is
3 www.caff.is/coastal

2. Overview of existing knowledge

2.1. Geographical location and climate

The Svalbard Archipelago extends from 74° to 81° N and from 10° to 35° E and is situated in the middle of the main gateway to the Arctic Ocean, halfway between mainland Norway and the North Pole. The largest island is Spitsbergen in the west, followed by Nordaustlandet in the northeast, and then Edgeøya and Barentsøya on the east side of the archipelago[4]. The distance from southern Spitsbergen to mainland Norway is approximately 680 km, with Bjørnøya, the southernmost island of Svalbard, located halfway to the mainland. Furthest to the east, in the western Barents Sea, the island Hopen is located. Long open sea expanses act as effective barriers against dispersal of organisms. Particle tracking models estimate that ocean currents can transport passive organisms over a distance of 1000 km (i.e. Lofoten, Norway to Isfjorden, Svalbard) in roughly one month (Berge et al. 2005). Strong climatic gradients over short distances characterises the Svalbard Archipelago. Warm Atlantic water impacts the southwest and northwest parts of Svalbard, whereas cold Arctic water and extensive seasonal ice cover dominate the northeast and east coasts of Svalbard. Three main climatic regions can therefore be identified for Svalbard: 1) West Svalbard with a sub-Arctic climate and very little sea-ice presence, 2) North Svalbard with a mixed Atlantic and Arctic climate exposed to the Arctic Ocean and consolidated pack ice, and 3) East Svalbard with a cold Arctic climate and extensive seasonal sea-ice formation.

2.2. Physical environment

Hydrographical observatories (moorings) in fjords in West Svalbard (Kongsfjorden and Isfjorden), operated since 2002, show an increase of 2°C over the 20-year record of observations with the strongest sea temperature increase in winter (Cottier et al. 2019). For fjords in Northeast Svalbard (Rijpfjorden), no distinct increase in sea temperatures since 2006 has been identified (Cottier et al. 2019), while in East Svalbard, continuous time series from moored observatories are lacking. The sea-ice extent and sea-ice thickness mirror the sea temperatures. In western Svalbard, sea-ice extent and thickness have been monitored in Kongsfjorden since 2003 (Gerland and Renner 2007), in Grønfjorden since 1974 (Zhuravskiy et al. 2012), and Van Mijenfjorden since 2006 (Høyland 2009; Karulina et al. 2019), and both sea-ice extent and thickness have significantly declined after 2006 (Muckenhuber et al. 2016, Pavlova et al. 2019; Gerland et al. 2020; Johansson et al. 2020). In northern Svalbard, SAR satellite products, which have been available since season 2002/03, show indications of shorter sea-ice seasons in Rijpfjorden since winter 2012/13 (Johansson et al. 2020). In eastern Svalbard (Inglefieldbukta), sea-ice monitoring has been undertaken since 2006. Data and analysis for eastern Svalbard are however too incomplete for statements about trends[5]. In southeastern Svalbard, the thickness of coastal sea ice has been monitored at Hopen since 1966 and there is a decreasing trend over the period 1966–2007 (Gerland et al. 2008). Based on SAR satellite data for the period 2005–2018 and a machine learning model, it has been possible to reconstruct landfast ice distribution from standard meteorological temperature data in the period 1973–2000[6]. From this model, fast ice with a duration of two months or longer were estimated to cover an area of 12,000 km^2 in Svalbard in the years 1973–2000, while in the years 2005–2018 this number was reduced to 8000 km^2, which was further reduced in 2014–2019 to only 6000 km^2 (Figure 1). Shallower side arms and sill fjords in Isfjorden still freeze in winter, but the sea-ice season has been reduced up to five months due to later sea-ice formation and earlier break-up (Figure 1).

4 https://toposvalbard.npolar.no/
5 For further information, contact S Gerland, NPI, Norway.
6 For further method details, contact JA Urbanski, Gdansk University, Poland.

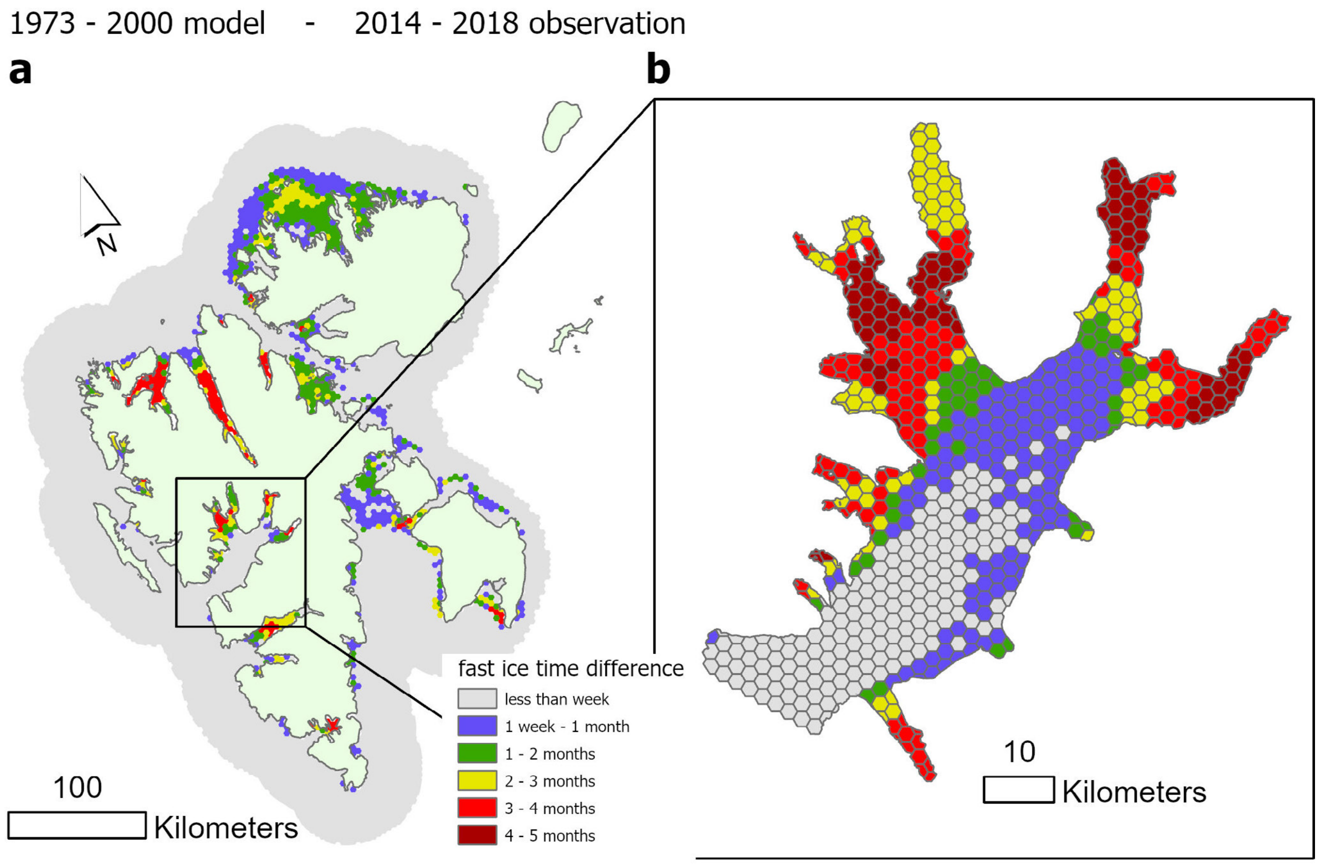

Figure 1. Reduction in land fast sea ice for the period 1973–2000 (based on model data) versus fast ice during 2014–2018 (based on observational data) in Svalbard (a) and specifically for Isfjorden (b). Model results show that fast ice coverage with a duration of two months or more has been reduced by the half over the last 30 years (from 12,000 km^2 to 6000 km^2 while the average fast ice duration has decreased between one (green) to five (dark red) months, with the most severe reduction in western Svalbard. For more details about the model results and observations, contact JA Urbanski, Gdansk University, Poland.

With reduced landfast ice and increased storm activity, coastal erosion has increased (Wojtysiak et al. 2018). As an example, between 1960 and 2011, a gravel-dominated coast in Isbjørnhamna, Hornsund experienced a significant shift from being protected by prolonged sea-ice conditions (fast ice) towards a storm-affected and rapidly changing coast. Mean shoreline erosion rates of 0.08 to 0.26 m yr^{-1} from 1960 to 1990 almost doubled to 0.13-0.45 m yr^{-1} for the years 1990 to 2011 in Isbjørnhamna (Zagórski et al. 2015). Coastal erosion, increased river runoff (Nowak et al. 2021) and increasing glacial melt is resulting in increased particle loads in coastal waters (i.e. "browning of the Arctic") which impacts the underwater light availability and thus, primary productivity (Pavlov et al. 2019). In contrast to several studies from the open sea which show that reduced sea ice leads to increased Photosynthetically Active Radiation (PAR) and increased primary production (Pabi et al. 2008; Arrigo and van Dijken 2011; Kauko et al. 2017) the counteracting effect may occur in coastal waters due to increased light attenuation by terrigenous particles (Smyth et al. 2005; McGovern et al. 2020;). Another factor affecting the penetration of PAR is the increasing cloudiness, which results in reduced PAR entering the water column (Bélanger et al. 2013). Comparison of the chlorophyll-a (Chl-a) concentration (calculated using Shanmugam et al., 2018) and SPM (calculated using Nechad et al. 2010) in a cold and relatively sea ice rich year (2008) versus a warm year with very limited seasonal sea ice (2016) in Svalbard, using MODIS-Aqua data, is shown in Figure 2. Distinct differences in productivity and turbidity between the years is seen with an overall higher primary productivity (Chl-a biomass) and particle load (turbidity) in the warmer year. However, sea-ice algae and under-ice blooms are not detectable by satellites, as a result, a significant component of the primary productivity in seasonal ice-covered regions is not accounted for in Figure 2. Field studies or other autonomous platforms are therefore needed to monitor changes in the overall primary productivity in Svalbard. Macroalgae (seaweed) and brackish water diatom colonies and other groups of eukaryotic algae and cyanobacteria (microphytobenthos) growing on intertidal mudflats (Kviderova et al. 2019, Wiktor et al. 2016) are other important primary producers in coastal regions of which we yet have much to learn since our knowledge of their productivity and ecosystem roles are fragmented and poor for the High Arctic (e.g. von Biela et al. 2016).

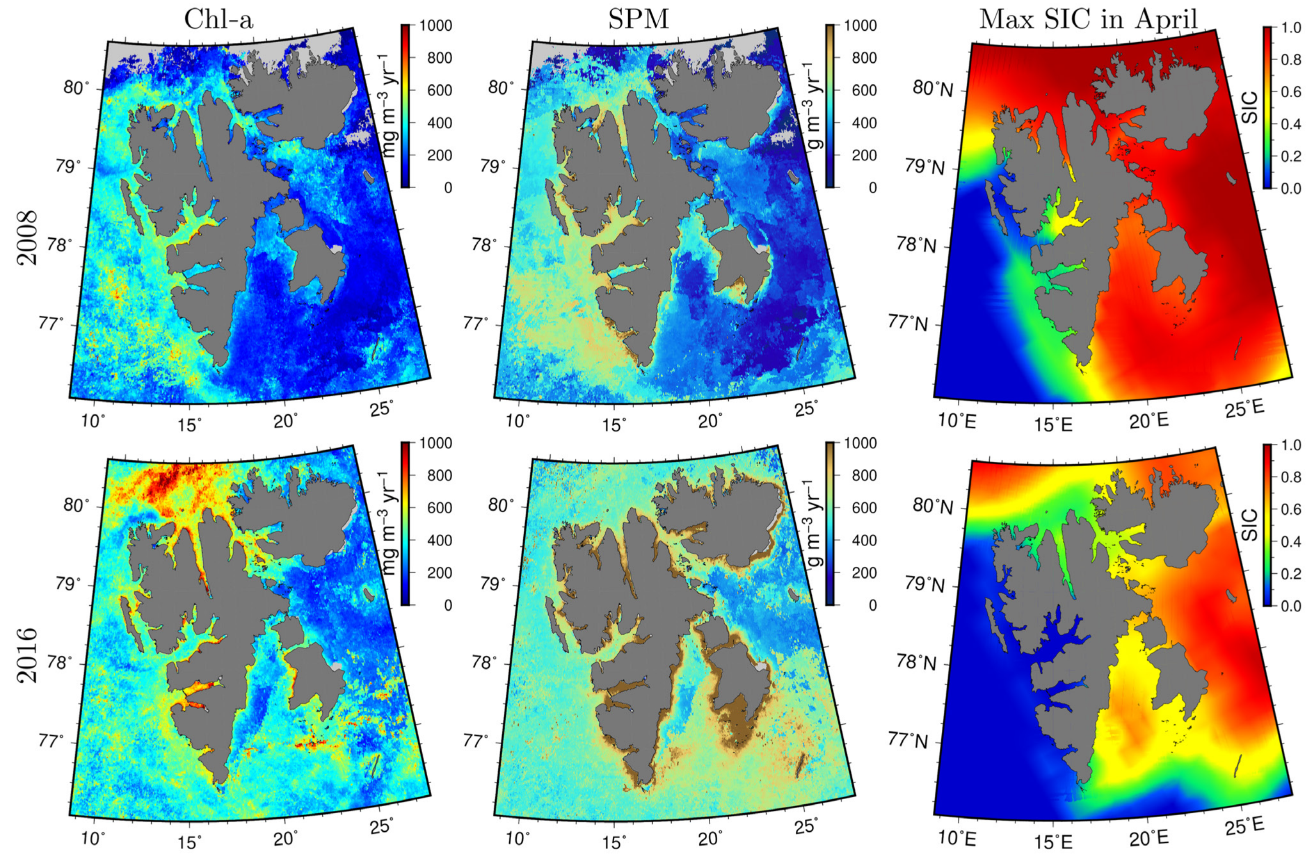

Figure 2. Spatial distribution of chlorophyll-a (Chl-a) concentration and Suspended Particulate Material (SPM) concentration integrated over the months from March to October for the year 2008 (colder year, upper panels) and 2016 (warmer year, lower panels), as well as the maximum sea-ice concentrations (April) in the two years. Sea-ice concentration (SIC) acquired from the National Snow and Ice Data Center. For more details, contact R.K. Singh and S. Belanger, UQAR, Canada.

3. Coastscapes

A pan-Arctic synthesis of coastal biodiversity is scheduled for completion in 2023 (CAFF, 2019). Seven different pan-Arctic coastscapes have been identified (see below and Appendix 3) and these coastal 'landscapes' will create the basis for comparison of characteristic coastal biota, i.e. Focal Ecosystem Components (FECs), across the Arctic. The selected FECs (Appendix 4) were chosen because they are considered to be good bio-indicators of the overall health and environmental state of the system, or simply because they are important for food security.

Since Svalbard is located in the High Arctic with marked influences from the warm West Spitsbergen Current, it is a bellwether for climate change impacts on a broader scale. Its unique mix of climatic conditions over small geographic scales makes it an ideal site to monitor the impact of climate change on Arctic marine systems. Thus, we recommend that monitoring approaches should focus on establishing the status and rate of change for the different coastscapes in all three regions in Svalbard, or at a minimum in one cold and one warm region.

Of the seven coastscapes, the most studied in Svalbard is the fjord coastscape (Figure 3; Weslawski et al. 1993; Wlodarska-Kowalczuk et al. 2012; Berge et al. 2015; Hop et al. 2019). The other six coastscapes represent the shoreline; and in Svalbard these nearshore ecosystems are understudied. However, an extensive coastal mapping project, based on aerial photos (Figure 4), was undertaken by the Norwegian Polar Institute (NPI) between 1987-1991 in order to determine the vulnerability of Svalbard coasts to a potential oil spill.

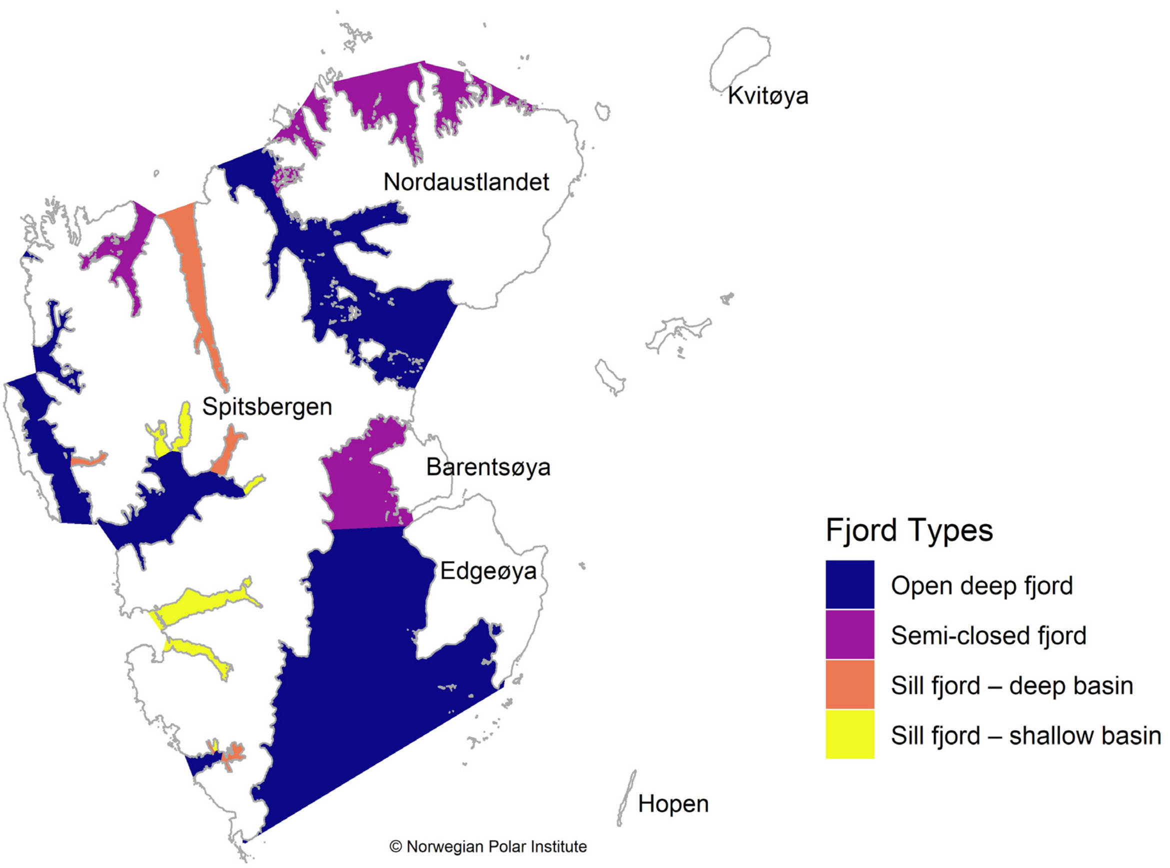

Figure 3. Svalbard fjords classified according to bathymetry and the presence or absence of a shallow sill, or threshold, which restricts the inflow of nearby oceanic water masses into the fjord. Sill fjords are further differentiated by the depth of their inner basin, with "deep" indicating a basin inside the sill deeper >120m. Semi-closed fjords were defined as fjords with an extensive, shallow shelf in front of the fjord mouth that restricts the connectivity with deep oceanic water masses.

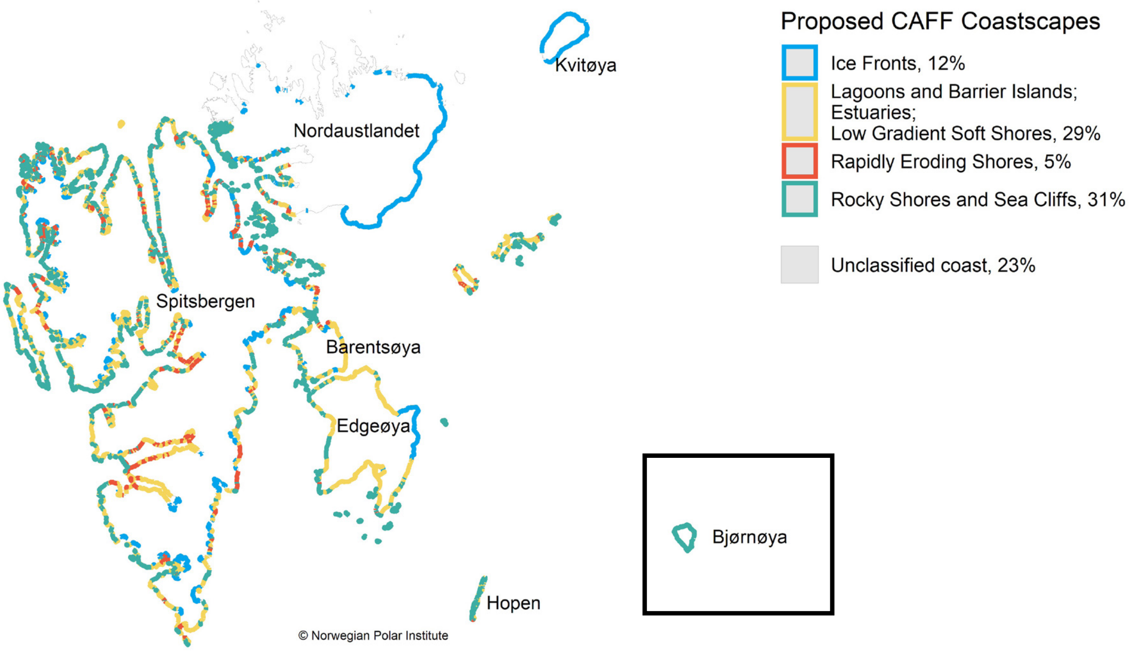

Figure 4. Geomorphological data from aerial photos (1987–1991) (unpublished data, Norwegian Polar Institute) were used to estimate the extent of coastscapes defined by CAFF (2019) in Svalbard. See Appendix 2 for the classification of geomorphology categories into coastscapes. The coastscapes low gradient soft shores, lagoons and barrier islands, and estuaries were not distinguishable based on the geomorphological data available, but see Figure 6 for more details.

NPI mapped the geomorphological characteristics of much of the Svalbard coastline, including the grain size of beach sediments (Figure 5) and special features, such as lagoons, tidal flats, and river deltas (Figure 6). While the dataset requires a final quality check and updates due to subsequent glacial retreat, it is nonetheless the most complete dataset on Svalbard coastal geomorphology today, encompassing 77% of the coastline of Svalbard at 1 km resolution (8,739 km). The yet-unmapped coastline is primarily in Nordaustlandet, but also includes some newly exposed coastline that is the result of glacial retreat since the aerial pictures were taken in the late 1980s.

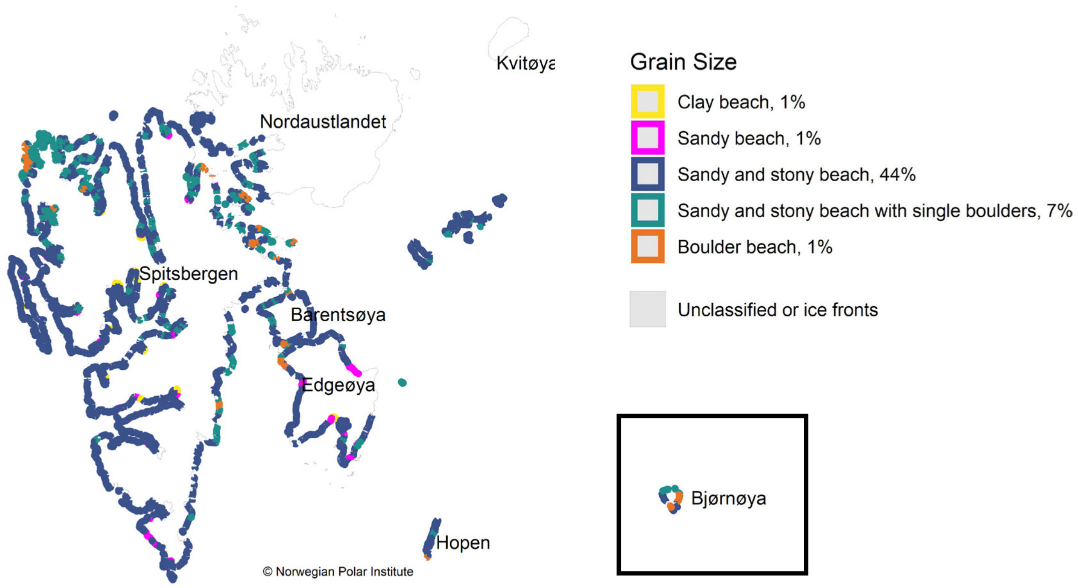

Figure 5. Coastline of Svalbard defined by sediment grain size, as classified from aerial photos (1987–1991) (unpublished data, Norwegian Polar Institute). Grey coastline indicates either unclassified coast or ice fronts. For ice fronts see also Figure 4.

Studies of biota in the intertidal zone were conducted at the same time in a collaborative project with the Institute of Oceanology Polish Academy of Sciences. They inspected, in total, 1400 km coastline by inflatable boats, targeting beaches/coastal habitats characteristic in intervals of 10 km coastline (e.g. gravel beach, sandy beach, boulder beach etc) from Isfjorden in the west to Storfjorden in the east (Weslawski et al. 1990,1997, 1999); some selected sites were revisited in 2015 and 2016 (Weslawski et al. 2018).

The geomorphological and special feature data obtained from the NPI coastal mapping project were assigned to the CAFF coastscapes as indicated in Figures 5 and 6. Certain coastscapes were more easily mapped from the geomorphological data (i.e. ice fronts, rocky shores, and sea cliffs), while other ones were less easily identifiable from geomorphology alone and will require field investigations in the future to ensure correct classification. The CAFF coastscapes 'low gradient soft shores', 'estuaries' and 'lagoons and barrier islands' are therefore currently pooled for Svalbard (Figure 4). In CAFF, there is only one fjord coastscape, but we recommend dividing it further based on bathymetry (Figure 3). From Figure 5, we see that the two most dominant shoreline coastscapes in Svalbard are rocky shore and sea cliffs (32%) and low gradient soft shores (29%), followed by not mapped (23%), ice fronts (12%) and rapidly eroding shores (4%).The environmental status for the fjord and shoreline coastscapes in Svalbard is presented briefly below, with some future perspectives and recommendations for research and monitoring.

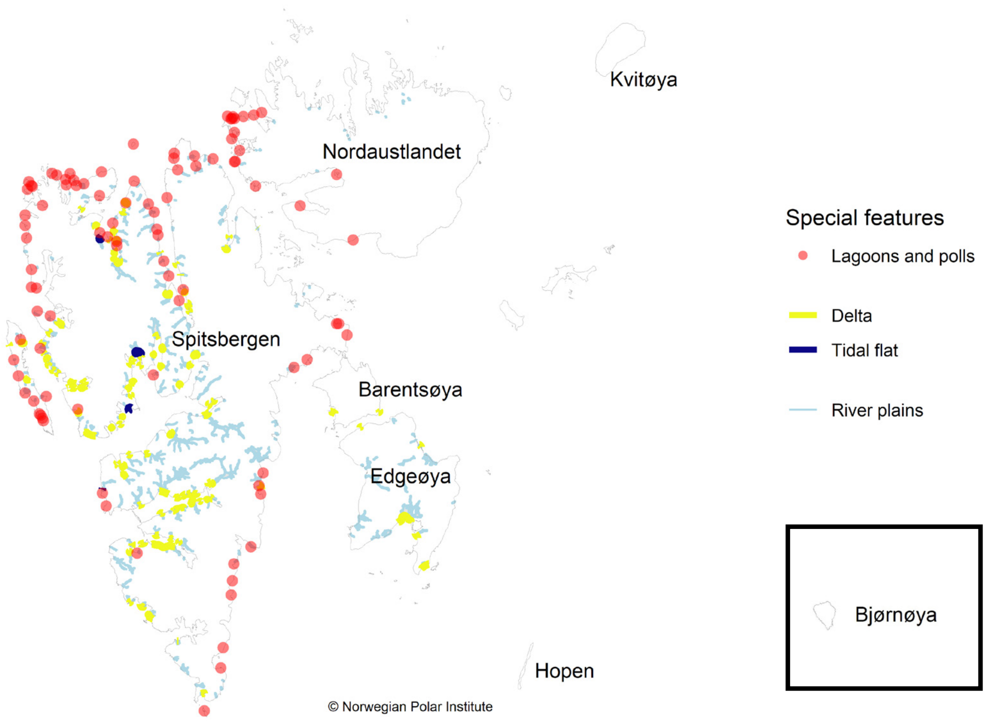

Figure 6. Lagoons and polls (= small water ponds) in Svalbard, according to the Norwegian Polar Institute report (Haug et al. 2016) with delta and tidal flats from aerial photos (1987–1991; unpublished data, Norwegian Polar Institute) and river plains (Norwegian Polar Institute mapping data, 2014).

3.1. Fjords

In Svalbard, fjords are commonly formed from drowned glacial valleys reaching depths down to 450 m, but typically they are shallower with one or more sills present. Ocean-shelf-fjord and land connectivity depend largely on the fjord's geographical location (e.g. west or east Svalbard), its bathymetry and size, and whether there are marine terminating glaciers or river deltas present. Since these factors strongly impact the fjord's biodiversity and productivity, we recommend dividing the fjord coastscape into four main types: 1) deep, open fjords, 2) semi-closed fjords, 3) shallow sill fjords (inner basin <120 m), and 4) deep sill fjords (inner basin >120 m). Deep open fjords are mainly located along west Spitsbergen (e.g. the well-studied Kongsfjorden). These are strongly influenced by warm Atlantic water and thus, harbour a more boreal community than elsewhere in Svalbard (Berge et al. 2015; Gluchowska et al. 2016; Hop et al. 2019a). These fjords are characterised by high biodiversity and productivity since they have a mixture of boreal and Arctic species and a long open water season (Hegseth et al. 2019; Hop et al. 2019a). In contrast, fjords where the advection of Atlantic water is restricted due to a shallow threshold (sill fjords) or a wide, shallow shelf (semi-closed fjords) are colder and often have seasonal ice cover. The semi-closed Rijpfjorden in Nordaustlandet and the deep sill fjord Billefjorden in inner Isfjorden, often have extensive seasonal ice cover, but can nonetheless be as similarly productive as the deep open fjords (Søreide et al. 2013).These cold relatively deep fjords tend to be dominated by a few Arctic species that are specialists, such as the copepod *Calanus glacialis* (Arnkværn et al. 2005; Søreide et al. 2008; Christensen et al. 2018; Hop et al. 2019b) and the polar cod *Boreogadus saida* (Nahrgang et al. 2014). Shallow sill fjords (e.g. Van Mijenfjorden) are generally less productive than other fjords. These are often strongly freshwater-influenced and highly turbid due to the combination of massive river runoff and restricted circulation, providing poor light conditions for primary producers. For the pelagic biota, warmer sea temperatures and less sea ice in the last few decades have resulted in a more boreal species composition in Svalbard fjords and especially in the deep open fjords in west and northwest Svalbard (e.g. Berge et al. 2014, Gluchowska et al. 2016; Hop et al. 2019a; Vithakari et al. 2018) due to massive intrusions of warm Atlantic water since 2005 (Muckenhuber et al. 2016; Cottier et al. 2019; Tverberg et al. 2019; Skogseth et al. 2020). For the benthos, a similar 'atlantification' of the community composition has been seen in western Svalbard, but in threshold fjords with glacial basins the Arctic benthic communities have largely survived, demonstrating the importance of these cold isolated habitats in the otherwise warm Atlantic influenced fjords for securing the overall biodiversity (Renaud et al. 2007, Gilg et al. 2016; Drewnik et al. 2017).

Tidewater glaciers (glaciers terminating in sea) are common in Svalbard's fjords and they are often associated with small lateral streams with deltas and estuaries. Glaciers and rivers bring melt water and sediments from land into the fjords, which typically feature species-poor soft bottom communities close to tidewater glaciers or river deltas where sedimentation rates are high (Figure 7). There tends to be a gradual increase in species richness towards the opening of such fjords (Wlodarska-Kowalczuk et al. 2012; Hop et al. 2012; Molis et al. 2019). Overall, the biodiversity of zoobenthos in Svalbard fjords is lower than in surrounding shelf seas, which is partly due to the effect of space availability and the often more stressful environment in fjords (e.g. high sedimentation, lower light availability, less mixing and sediment disturbance) (Molis et al. 2019). Among the marine zoobenthos distributed in the Barents-Greenland seas, less than 30% is found in the fjords (Wlodarska-Kowalczuk et al. 2012). High abundance of the benthic crustacean *Lepidepecreum umbo* and the mollusc *Portlandia arctica* are associated with cold Arctic conditions (Drewnik et al. 2017). A compilation of existing benthos monitoring in Svalbard is given in Appendix 5, for sampling locations and more details see Renaud and Bekkeby (2013).

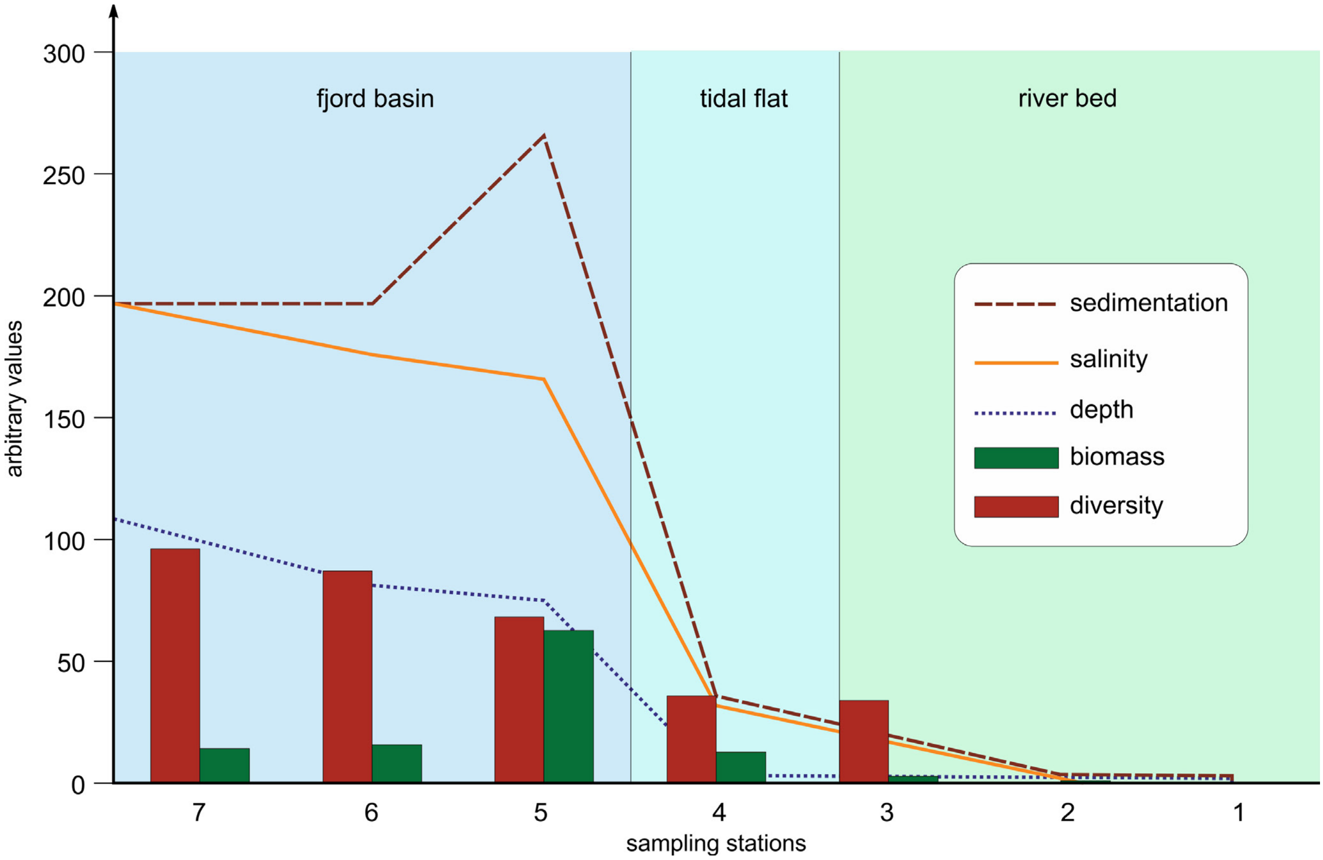

Figure 7. Biomass and diversity of zoobenthos in relation to environmental gradients across a river bed, tidal flat to fjord basin (arbitrary scale) from Weslawski et al. (1999) based on data from Adventfjorden, Spitsbergen.

Phytoplankton is regularly monitored in Svalbard, especially in fjords in western Svalbard (Hegseth et al. 2019); monthly studies are conducted in Adventfjorden year-round (Kubiszyn et al. 2017; Appendix 5). Some seasonal and time series studies also exist from Rijpfjorden (Leu et al. 2010, 2015; Hop et al. 2019b). With declining sea ice and warmer waters, the onset and magnitude of the ice algal and phytoplankton blooms are changing (Leu et al. 2015, Hegseth et al. 2019). Such distinct changes in bloom phenology are worrying since the grazers may partly miss the bloom (i.e. mismatch) with cascading impacts on higher trophic levels (Leu et al. 2011). Zooplankton abundance and community composition provide important information on the productivity and overall state of the marine fjord ecosystem (Gluchowska et al. 2016; Hop et al. 2019a). Zooplankton are important prey for many fish, seabirds, and marine mammals (Vihtakari et al. 2018) and zooplankton via seabirds fertilize the coastal tundra (Skrzypek et al. 2015). Zooplankton are not regarded as an essential FECs by CAFF in the fjord coastscapes (CAFF, 2019). However, zooplankton are an important ecosystem component in Svalbard fjords and we strongly recommend zooplankton to be monitored as an essential FEC here. In Svalbard, there is a mixture of Arctic and boreal zooplankton species. Most species are found everywhere in Svalbard, but in very different numbers depending on whether they are primarily Arctic or boreal. The relative proportion of Arctic versus boreal (Atlantic) species and vice versa provides information on the overall "fjord climate" (e.g. Leu et al. 2011; Gluchowska et al. 2016; Hop et al. 2019a;). The Arctic copepod *Calanus glacialis* and the North Atlantic *C. finmarchicus*, are regarded valid climate indicator species for respective cold and warm sea climate in Svalbard (e.g. Hop et al. 2019a). Long zooplankton time series exists from several fjords in west Svalbard Kongsfjorden since 1998 (Hop et al. 2019a); Hornsund since 1987 (Węsławski et al. 1991), and Isfjorden since 2001 (Arnkværn et al. 2005; Gluchowska et al. 2016, Christensen et al. 2018) and from northeast Svalbard (Rijpfjorden since 2003; Søreide et al. 2010; Weydmann et al. 2013, Hop et al. 2019b), while in eastern Svalbard only a few sporadic studies exist (e.g. Weslawski et al. 1997; Hirche and Kosobokova 2011).

Svalbard fjords are vital habitats for all of the Arctic endemic marine mammal species in the region, including ringed seals, bearded seals, walruses, polar bears, and white whales (Storrie et al. 2018; Bengtsson et al. 2020); the rarer whale species, bowheads, and narwhals also visit fjord environments intermittently, though they spend most of their time in recent decades in the marginal ice zone. Svalbard fjords are becoming important habitats for migratory whales since more Atlantic water comes into the fjords, which again leads to increase in the biomass of boreal fish species and krill (Berge et al. 2015; Misund et al. 2016; Vihtakari et al. 2018). Additionally, harbour seals that have previously been restricted to Prins Karls Forland furthest West, are now occupying many fjords along the west coast of Spitsbergen. Soft-bottom communities within fjords provide food for benthic foraging marine mammals, such as walruses, bearded seals, and white whales. Additionally, young seals of all species target shallow coastal waters to feed on amphipods and other available prey. Fish are important food for many marine mammals and recently a marked change in fish communities in western Svalbard has been documented (Berge et al. 2015), and a significant change in movement patterns has been detected for white whales that suggests that a change in diet has taken place, with the whales spending more time in fjords where Atlantic fish species dominate (Hamilton et al. 2019c). Sea bird diets have also changed according to the available prey species as a result of warming within the fjords (Vihtakari et al. 2018). Some species do not readily shift diet, and these species are likely to suffer negative consequences as the community changes (e.g. Hamilton et al. 2019c).Strong year classes of Atlantic cod combined with massive intrusions of warm Atlantic waters into the west-facing deep fjords have been beneficial for those feeding on them, while for most others this large cod fish is a new predator in the system; which is likely to put pressure on polar cod, a key Arctic fish species that has been a very important trophic linkage in the past (Nahrgang et al. 2014).

3.2. Low Gradient Soft Shores, Lagoons and Barrier Islands, and Estuaries

3.2.1. Low gradient shores

Low gradient shores with varying thicknesses of surficial materials over bedrock, characterised by mudflats, wetlands, and beaches are widely found in Svalbard (Figure 4). A closer look at beaches in Svalbard and their grain size (Figure 5) shows that sandy and stony beaches dominate (44%), followed by sandy and stony beaches with boulders (7%). There are only a few; clay (1%), sandy (1%) and boulder (1%) beaches identified within the archipelago. Estuaries, lagoons, and barrier islands are also naturally included in the beaches above, but these are very special ecosystem features and thus, defined as their own coastscapes by CAFF (2019). A compilation of where these unique coastscapes are located can be found in Figure 6, but for tidal flats and river deltas only old, not quality controlled data exist and thus the classification of this coastscape needs to be revisited.

3.2.2. Lagoons and Barrier Islands

Lagoons are a common feature in Svalbard (Figure 6). These highly productive ecosystems are important feeding grounds and resting sites for migratory birds and resident marine mammals. Lagoons are transitional zones between land and sea, with variable physical and chemical conditions depending on their morphology, inflow of freshwater, and degree of exchange with the open marine system (Dunton et al. 2012). These systems are extensively studied along the Alaskan Arctic coastline, which supports large populations of migratory fish and waterfowl that are essential to the culture of Iñupiat communities (Harries et al. 2018). In Svalbard, however, lagoons are poorly studied. Based on aerial photography, NPI has identified as many as 127 lagoons (Figure 6). Most of these lagoons are very shallow, and approximately two thirds of them have a visible opening to the sea. Many of these lagoons are also strongly influenced by glaciers, either terminating in the lagoon, or delivering glacial melt water to the lagoon via rivers (Haug et al. 2016). Svalbard's lagoons are important habitat for several species of birds, anadromous Arctic charr, and also for some marine mammals. In particular shallow, extensive tidal flats may be important feeding grounds for birds (Haug et al. 2016). A preliminary study in Richardlaguna (Forlandet) indicated high abundances of soft-bottom benthos, littoral amphipods, and small fish (e.g. sculpins, (McKnight 2019). In general, there are very few data available on physical and biogeochemical conditions, or the biological communities in these lagoons, and there is an urgent need for more knowledge on salinity and depth, benthic community composition and sediment properties, habitat use by higher trophic animals and mapping of coastal geology and lagoons in Svalbard (Haug et al. 2016).

3.2.3. Estuaries

River estuaries are highly dynamic environments in both space and time, where strong physical and chemical gradients play a key role in structuring biological communities. In Svalbard, a large number of rivers drain to the coast (Figure 5), many of which are glacier-fed. Some of the larger rivers have given rise to extensive braided deltas and tidal flats, which provide important habitats for seabirds, waders and other shorebirds (Haug et al. 2016). River discharge in Svalbard is highly seasonal with nearly all runoff occurring between May/June and September (Nowak et al. 2021) and most rivers freeze during the winter. These estuaries are particularly vulnerable to climate change, given that runoff in Svalbard is expected to increase dramatically, due to increases in glacial melt, melting of permafrost, and precipitation (Adakudlu et al. 2019; Hansen-Bauer et al. 2019; Nowak et al. 2021).

Biological communities in estuarine habitats need to cope with a high degree of variability in salinity, temperature, sedimentation, light, nutrient availability, and strong water currents linked to estuarine circulation patterns. Svalbard's estuaries receive large fluxes of particulate matter, leading to high light attenuation in turbid river plumes, as well as high sedimentation rates (e.g. Weslawski et al. 1999). Furthermore, given the high rate of removal of particulate matter and associated nutrients, organic matter, and terrestrially-derived contaminants (such as mercury), there is a substantial delivery of terrigenous material to estuarine sediments, with important implications for benthic communities. Soft-bottom benthic communities in these areas are thus, often low in species richness and biomass and show abrupt changes in species numbers and biomass across the tidal flats into the fjord basin (Figure 7). Taxa that are able to cope with high sedimentation rates dominate, such as the deposit feeding bivalves *Macoma* sp. and *Chaetozone* sp., as well as the motile filter-feeding bivalve *Thyasira* sp. (Włodarska-Kowalczuk et al. 2012; Pedersen-Uglestad 2019). Waders feed extensively in tidal flat areas and their numbers in Svalbard appear to be increasing. Tidal flats have the potential to harbour brackish water diatom colonies and other groups of eukaryotic algae and cyanobacteria. Such microphytobenthos communities have been found in Adventfjorden (Kvíderová et al. 2019; Wiktor et al. 2016).The phenomenon and significance of the occurrence of such autotrophic communities should be the target of future research.

Salmonids are considered an essential FECs in soft shores, lagoons, and river estuaries (CAFF, 2019). In Svalbard, there are three different species of anadromous salmonids: Arctic charr (*Salvelinus alpinus*), Atlantic salmon (*Salmo salar*) and pink salmon (*Oncorhynchus gorbuscha*). Arctic charr have a circumpolar distribution and are the world's northernmost freshwater fish and the only freshwater fish that lives and reproduces in watercourses in Svalbard. There are two main forms; a stationary form that stays in fresh water throughout its life and anadromous char which migrate into the marine environment in the summer for four to eight weeks, feeding in nearshore waters. There are probably 100–150 lakes with stationary charr, while populations of anadromous Arctic charr are found in approximately 20 lake systems in Svalbard. There is currently little knowledge about the anadromous Arctic charr migrations and habitat use in the marine environment in Svalbard. Atlantic salmon and pink salmon are relatively new species in Svalbard and most likely do not reproduce successfully within the archipelago (yet). Pink salmon is an alien species that has been monitored in Svalbard since 2015[7]. New data indicates that there is dietary overlap in nearshore areas and hence, competition between anadromous Arctic charr and pink salmon.

3.3. Rocky Shores and Sea Cliffs

The rocky shores and sea cliffs coastscape are the dominant coastscape in Svalbard (Figure 4). Waves or strong currents remove all loose material from exposed rocky shores, and the shores can be steep and reach considerable depths within a short distance from land. The rocky coast is a biologically rich environment and can include many different habitat types, such as steep rocky cliffs, platforms, rock pools, and boulder fields. Sea bird cliffs are a prominent feature within this coastscape (Figure 8). Warmer sea temperatures and less sea ice have already significantly changed the rocky shore intertidal (Weslawski et al. 2018) and sublittoral zone in Svalbard (Kortsch et al. 2012; Al-Habahbeh et al. 2020). The majority of macrophyte species and biomass is found along sheltered fjordic coastlines (Kruss et al. 2006; Bischof et al.2019; Fredriksen et al. 2019) and a five-fold increase in seaweed coverage in west Spitsbergen has been recorded

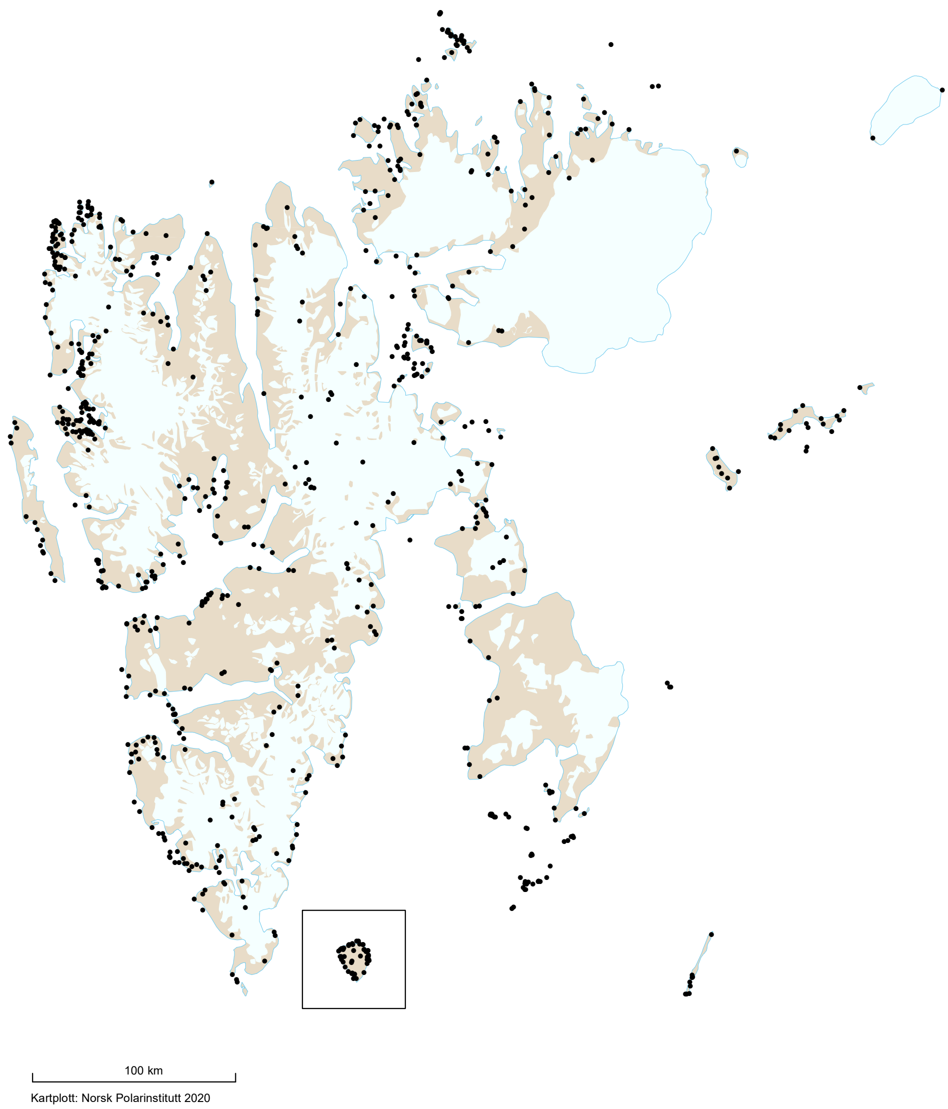

Figure 8. Seabird colonies in Svalbard (Strøm et al. 2008). The majority of the 20 species of seabirds in Svalbard hatch and raise their young close to the coast.

7 For more information contact G. Christensen, Akvaplan-via, Tromsø

since 1984 (Kortsch et al. 2012; Weslawski et al. 2018; Bischof et al. 2019). In east Svalbard, ice scouring is still restricting macroalgal establishment in the intertidal zone; it occurs primarily beyond 3 m depth in eastern Svalbard. Underwater "forests" of macroalgae are an important nursery ground for many invertebrates and fish species and facilitate a rich species diversity and assemblage. Seafloor mapping to identify suitable substrates for macroalgae may therefore be an important task to identify areas of special biological value (e.g. Bekkeby et al. 2017). Common fishes associated with kelp include several species of sculpins which is an understudied focal ecosystem component in Svalbard coastal regions. Reappearance of the blue mussel in Isfjorden in 2005, after 1000 years of absence, is one of many results of ongoing climate warming (Berge et al. 2005) and currently blue mussels are commonly spotted in the intertidal zone in Isfjorden (Leopold et al. 2018).

The kelp-barnacle (*Fucus-Balanus)* assemblages covering the rocky shoreline of western Spitsbergen, there warm Atlantic water prevent sea ice to form, is the intertidal assemblage with the highest biomass in Svalbard (Weslawski et al. 1992). In eastern Svalbard, *Balanus* spp. were not detected in the intertidal zone in the 1990s (Weslawski et al. 1992). However, with less sea-ice scouring the previously identified cut-off border for *Balanus* at Sørkapp has moved further East and North with tiny *Balanus* spp. now settling in the intertidal zone in Storfjorden[8].

3.4. Rapidly Eroding Shores

The combination of permafrost-rich, soft coastal sediments often with in-ground ice are typical for rapidly eroding shores. This is the dominant coastscape along the Beaufort Sea in Canada and Alaska, and along the coasts of the Laptev and eastern Siberian Seas in Russia (Lantuit et al. 2012). In Svalbard, this coastscape is spatially very limited (<5%). Biota is particularly scarce and the biodiversity poor in this extreme environment. All types of FEC birds (e.g. waterfowl, omnivorous, diving planktivores, surface and diving piscivores are considered essential here, in addition to phytoplankton, zooplankton, and pelagic fishes (CAFF, 2019). In Svalbard, this coastscape is poorly studied and it will probably remain little studied in the years to come since other more ecologically important coastscapes will be prioritized to study. When it comes to physical changes, these rapidly eroding shores may experience large losses of mass, as well as large collapses due to melting ground ice.

3.5. Ice Fronts

Glaciers that terminate at the sea, so-called tidewater glaciers, form a type of unique coastscape. In Svalbard, over 150 such tidewater glaciers are spread across the archipelago, with frontal areas that stretch across approximately 1000 km of Svalbard's coastline (Figure 4; Dowdeswell 1989; Blaszczyk et al. 2009). Some tidewater glaciers sit on the seafloor, while others have floating termini; the floating glaciers are particularly active, calving glacier ice into the fjords, producing large floating ice islands or icebergs of variable sizes that melt and freshening the surface waters. However, all tidewater glaciers contribute significant amounts of freshwater to the fjords, particularly during the summer melt period, when glacial rivers have their greatest outflows and calving is not restricted by the presence of landfast ice that usually forms in at least the inner parts of fjords in winter in Svalbard. The outflows from tidewater glaciers significantly impact the circulation patterns in fjords (Sundfjord et al. 2017); wind driven forcing combined with glacier river outputs cause upwelling and mixing at glacier fronts that induce seasonal productivity hotspots (Meire et al. 2016); zooplankton advected from the outer parts of the fjord towards the glacier fronts when fjord water replaces surface waters pushed offshore add to the diversity and biomass of zooplankton available in these areas (Lydersen et al. 2014). Nutrient rich sediments at tidewater glacier fronts create areas where krill and other invertebrates aggregate (Deja et al. 2019). High fish densities, particularly high concentrations of polar cod, occur in the cold water refugias created by glacier outputs, feeding on the invertebrates that occupy these waters (particularly when the fronts are deep; Szczucka et al. 2017).

8 Observation by JE Søreide, UNIS, September 2020

The presence of both large zooplankton and fish attract top predators including sea birds, seals and Arctic whales to tidewater glacier fronts (Lydersen et al. 2014; Urbanski et al. 2017). Surface-feeding seabirds including kittiwakes, fulmars, arctic terns, and glaucous gulls are the most common avian species at tidewater glacier fronts in Svalbard (Draganska-Deja et al. 2020). They occur in extremely high concentrations, intermittently, when upwelling is very pronounced, leading to prey being available at the surface. Diving predators, including seals and whales can take advantage of prey at depth and hence, are found more consistently at tidewater glacier fronts, though they also seem to specifically target plumes of subglacial discharge that appear to concentrate prey (Everett et al. 2018). Ringed and bearded seals also take advantage of the availability of glacier ice pieces, which they use as resting platforms when annually formed ice is not available (Hamilton et al. 2019b). Bearded seals have also started to give birth and nurse their young on floating glacier ice pieces, following the collapse of fast-ice formation in west coast fjords 1.5 decades ago (Kovacs et al. 2020a). In Svalbard, adult ringed seals live in close association with tidewater glacier fronts on a year-round basis, occupying small territories that encompass only one or a few glacier fronts (Figure 9; Hamilton et al. 2016a, b, 2019b). Calved glacier ice freezes into annually formed landfast ice, when fjords freeze in the fall creating areas where snow accumulates on the sea ice, which in turn creates ringed seals breeding habitat. Such areas are important spring hunting habitat for polar bears when females first emerge from dens with young cubs that cannot swim long distances (Freitas et al. 2012; Hamilton et al. 2017). White whales in Svalbard also spend most of their time at tidewater glacier fronts in Svalbard (Lydersen et al. 2001; Vacquie-Garcia et al. 2019). In a recent survey of white whales in Svalbard waters, 82% of whales seen were associated with tidewater glacier fronts (Vacquié-Garcia et al. 2020).

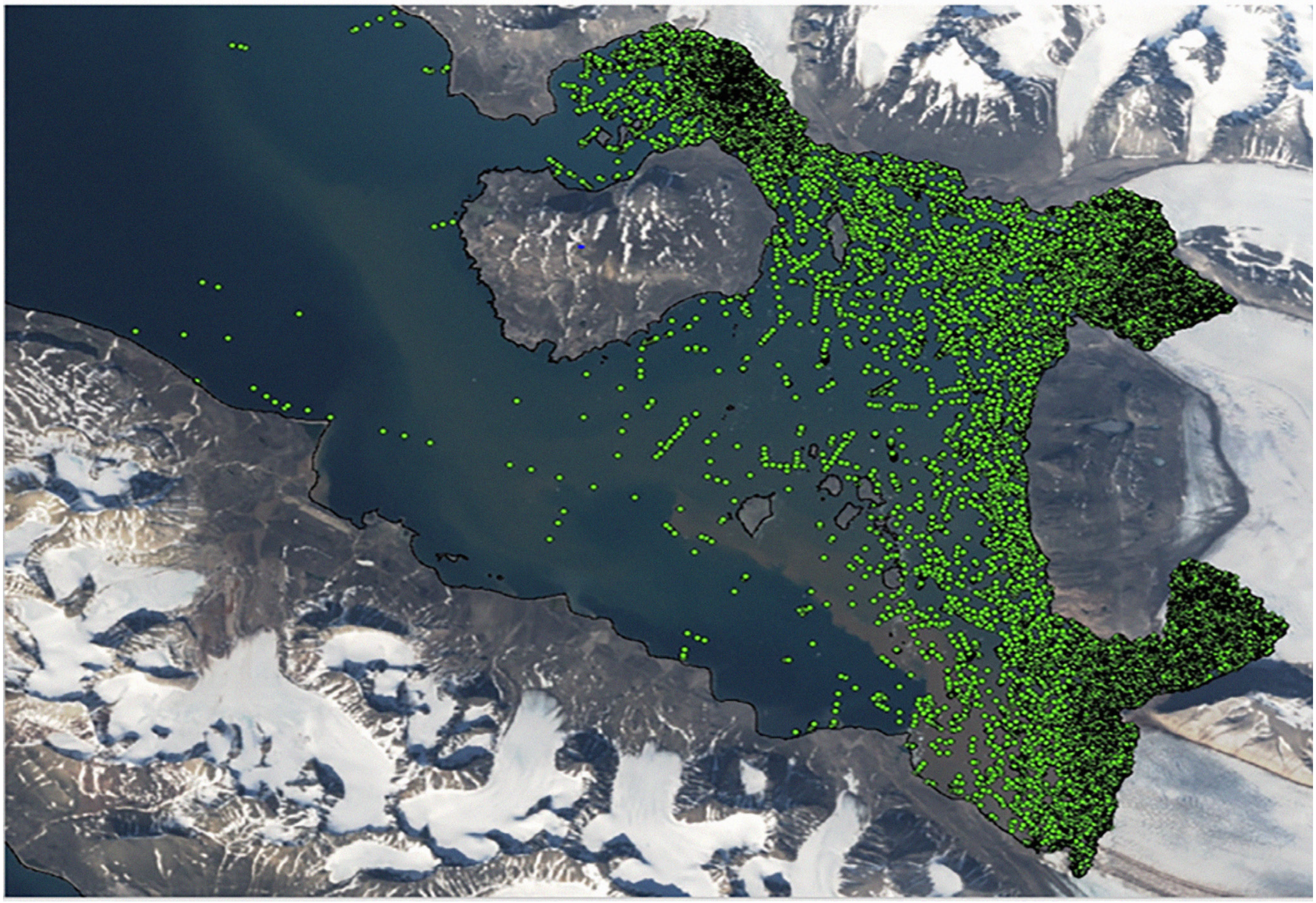

Figure 9. GPS locations (n=62,000) from six tagged ringed seals in Kongsfjorden Svalbard during 2011–2013, displaying this species' tight association with tidewater glacier fronts (ringed seal data presented in a track format in Hamilton et al. 2019b).

This important habitat for Arctic animals in Svalbard is currently threatened by global warming, with tidewater glaciers melting and withdrawing onto shore rapidly (e.g. Blaszcyk et al. 2009). These areas have received limited research attention in the past because they are highly dynamic and logistically challenging to work in. However, new robotic (underwater drone) technology will allow for rapid advances in knowledge of these important/threatened habitats (Hop et al. 2019c; Howe et al. 2019).

3.6. Seasonal Ice Edge Habitat

Most studies in the above coastscapes are conducted in summer, but all the listed coastscapes (especially those in northern and eastern Svalbard) feature sea ice in winter and spring. These seasonal sea-ice environments provide habitats that are critical for the survival of many ice dependent birds and mammals (see Ice Front coastscape; Hamilton et al. 2017; Vacquié-Garcia et al. 2017; Lone et al. 2018; Kovacs et al. 2020b; Gilg et al. 2016), and for an under-studied assemblage of biota inside the sea ice itself (Leu et al. 2010; Bluhm et al. 2018; Marquardt et al. 2018). Plants and animals living inside of sea ice are termed 'sympagic' (= living with ice). Microscopic algae specialized to grow under low light conditions in sea ice (ice algae) may start to bloom up to two months earlier than the pelagic phytoplankton spring bloom (Leu et al. 2010, 2015; Søreide et al. 2010). An unknown number of tiny larvae take advantage of this early nutritious food source after a long unproductive winter by migrating from the water column or seafloor into the mosaic of brine channels inside sea ice. Here, they can feed safely since most predators are too large and inflexible to access this brine-channel habitat. Sympagic meiofauna has barely been studied in Svalbard or elsewhere in the Arctic (Wiktor and Szymelfenig 2002) since sampling can be challenging and larval species identification is tricky. Available studies show that these small metazoans can be very numerous (>100.000 ind. m^{-2}) in the bottom 3 cm of landfast sea ice in Svalbard (Pitusi 2019) and that nematodes dominate, followed by polychaete juveniles and eggs of various species (including those of polar cod). In addition, high numbers of ciliates have been observed. Ongoing barcoding and ecological studies (Marquardt et al. 2018; Pitusi 2019; Andreasen 2019) will eventually increase our knowledge of these unique sea-ice communities and thus their broader importance in Arctic coastal ecosystems which is urgent due to the rapid decline in coastal sea ice (see above Figure 1).

4. Connections and synergies with other SESS report chapters

Coastal ecosystems in Svalbard are impacted by large scale atmospheric (Viola et al. 2019; Sipilä et al. 2020) and oceanic circulation patterns (Bensi et al.2020), pushing heat, nutrients and organisms northwards into the fjords and nearshore (Cottier et al. 2019; Edwards et al. 2020). This again impacts coastal sea-ice formation (Gerland et al. 2020) and land-to-sea interactions with earlier onset of snow melt (Killie et al. 2021), glacier melt (Schuler et al. 2020), permafrost thawing (Christiansen et al. 2021) and prolonged river runoff (Nowak et al. 2021). Further, pollution is a major threat and negative impacts of microplastics may be of special concern for Arctic coastal ecosystems (Singh et al. 2021). Autonomous observatories (Cottier et al. 2019, Hann et al. 2021) and remote sensing (Karlsen et al. 2020) will be important tools in the years to come to understand the highly dynamic and complex coastal environments.

5. Unanswered questions

The coastal areas in Svalbard are subject to substantial socio-economic impact, providing a range of ecosystem services, ranging from local recreation to large scale tourism operations, shipping and fisheries (Misund et al. 2016; Stocker et al. 2020). Increased marine activities, combined with climate change, will create new challenges for future coastal management in Svalbard. Seasonal baseline studies of key drivers, biodiversity and bio-indicators will be necessary to detect, understand, and mitigate changes in Svalbard coastscapes. Models of ecological changes are likely to be important tools for predicting future coastal change. However, the lack of baseline data and the complexity of coastal environments urge for continued and expanded monitoring to track changes and provide inputs to model development and scenario-building. Some fundamental, overarching questions are:

- Can we differentiate climate change impacts from seasonal and natural variability, when baseline data are largely lacking from the physical and biological environment?
- Do lack of species identification, or misidentification, combined with limited knowledge on species and ecosystem resilience lead to erroneous predictions regarding future climate change impacts?
- Which focal ecosystem components are the most important to monitor in the different coastscapes in Svalbard?
- What is the ecological role of the understudied unique nature types in coastal Svalbard: lagoons, river deltas/tidal flats and seasonal sea ice?
- Are the rates of environmental and ecosystem changes in the colder, poorly studied northern and eastern regions of Svalbard similar to those recorded in the warmer region of western Svalbard?

6. Recommendations for the future

There is an urgent need for more comprehensive monitoring of physical, biogeochemical, and biological parameters in coastal environments in Svalbard. Such monitoring data are vital to meet the needs of communities, industry, academia, and our national government's management of coastal ecosystems in the Arctic, as well as meeting Norway's commitments and responsibilities to international objectives, such as those outlined in the Arctic Biodiversity Assessment (CAFF, 2013) and by the Convention on Biological Diversity[9].This requires the application of multi-disciplinary studies gathering circum-Svalbard data through various observational methods ranging from satellite data to local community-based observations and measurements. These new data should be connected to and possibly adjusted according to existing monitoring programs to enable long-term databases. For this, there is a need for integrated knowledge exchange across disciplines and communication between diverse research teams in order to coordinate ongoing monitoring efforts, opportunities, and future plans. Below, some key recommendations[10]:

- Improve international coordination and cooperation to develop and maintain the infrastructure and activities required to achieve a more holistic and cost-efficient coastal observatory in Svalbard.
- Generate a list of Svalbard-specific standard coastscapes (i.e. nature types).
- Agree on a list of essential focal ecosystem components (e.g., bio-indicators) to be monitored in these coastscapes.
- Monitor environmental and ecosystem trends in both the warm and the cold regions in Svalbard.
- Adopt new methods (e.g. molecular methods)

9 https://www.cbd.int/cop/
10 See also recommendations for future research and monitoring in Appendix 6.

and technology (e.g. autonomous observatories, remote sensing) to secure cost-efficient long-term data series.

7. Data availability

Coastal environmental data from Svalbard are many and diverse, and are not found through one portal. In Appendix 5, we have compiled monitoring and long-time series data from Svalbard coastal waters relevant for this chapter. This is a work in progress. Datasets listed below will be available through the SIOS data access portal with links and contact information to where the data are stored. Some of the data sets are currently under work and not yet published, but within year 2021 they should be available and therefore they are included here. Further, we recommend a closer look at the recent established Svalbard coastal data base, where all archival taxa data observation from Svalbard from 1983 till present from Institute of Oceanology, Polish Academy of Science (IOPAN) are stored, including photos: https://adamant.iopan.pl/adamant/taxa_observations/. This is a dynamic database which will be continuously supplied with new data from also others in the future.

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- NASA Ocean Biology Distributed Active Archive Center for providing MODIS-Aqua Level-1A data.
- National Snow and Ice Data Center for distributing the sea-ice concentration data.

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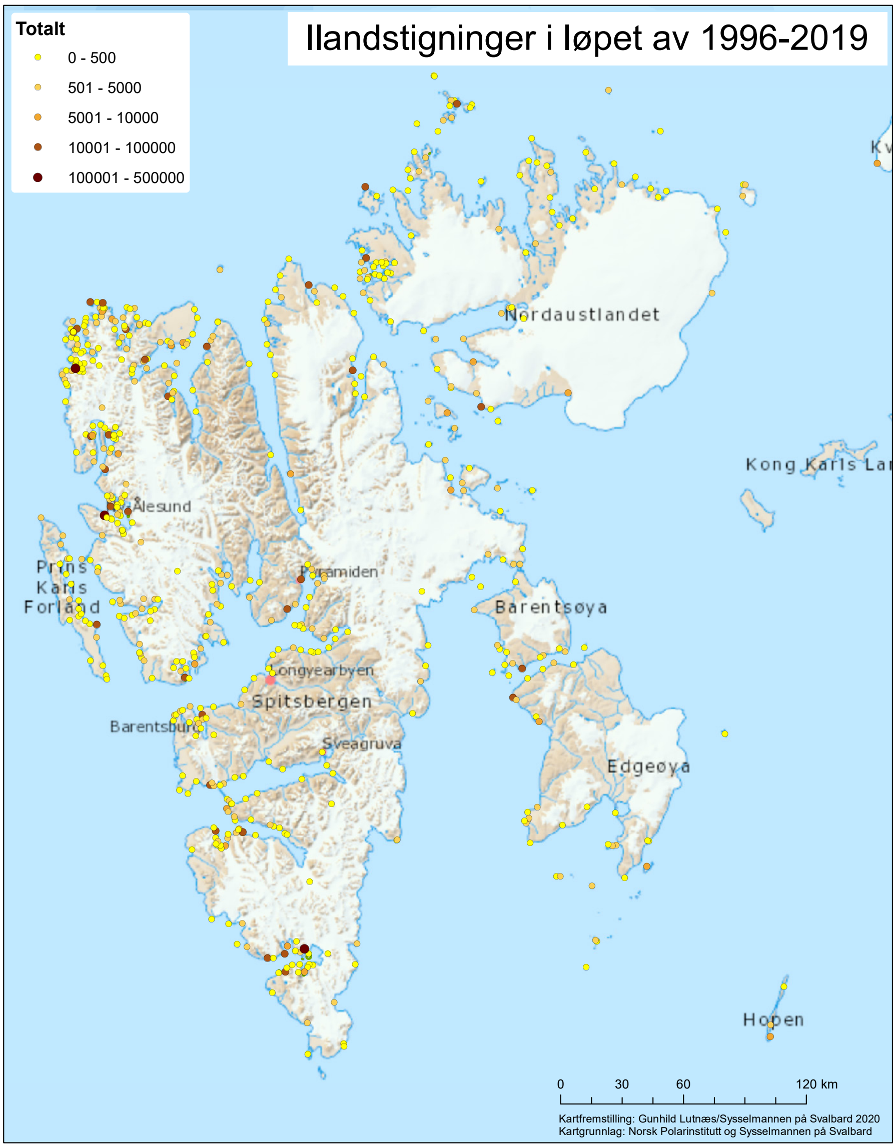
Appendix 1

Cruise tourism in Svalbard has increased the last decade especially among smaller expedition cruises that offer landings (= ‘ilandstigninger’ in Norwegian, see map, source: The Governor in Svalbard). The number of these expedition vessels (24 to 59 vessels) and passengers (10.040 to 21.000 passengers) has doubled from 2008 to 2018 (Stocker et al. 2020). Large overseas cruise ships offer primarily landings in Longyearbyen, the main settlement in Svalbard (not included in map below). The number of these overseas ships has actually decreased from 2008 to 2018 (28 to 15 ships) but the ships have become larger so the number of overseas cruise passengers has almost doubled (28.697 to 45.900 passengers; Stocker et al. 2020). West Spitsbergen is the most visited region in Svalbard. However, reduction in sea ice has opened up for more landings in northern and eastern Svalbard and allowed for an extension by starting earlier and ending later the operational season. For more detailed information see Stocker et al. 2020[11]:



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Appendix 2

Geomorphological data from aerial photos (1987–1991) (unpublished data, Norwegian Polar Institute) were used to estimate the extent of coastscapes defined by CAFF[12] in Svalbard. This table show how geomorphology and special feature classifications from NPI were assigned to the CAFF coastscapes.

CAFF Coastscapes	NPI coastal mapping for Svalbard	
	Geomorphology classifications	Special features
Rapidly Eroding Shores	Talus cones High cliff of unconsolidated material Low cliff of unconsolidated material	
Lagoons and Barrier Islands **Estuaries** **Low Gradient Soft Shores**	Barrier (beach ridge) Miscellaneous	Delta Lagoon and delta Lagoon Tidal flat
Rocky Shores and Sea Cliffs	Rocky shore Low cliff of bedrock High cliff of bedrock	
Ice Fronts	Glacier front terminating in the sea	

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Appendix 3

Coastscape description and distribution as defined by CAFF 2019[13].

COASTSCAPES	GENERAL DESCRIPTION AND DISTRIBUTION
Fjords	Long narrow inlets with steep sides and cliffs usually formed by Quaternary sub-sea level glacial erosion. They are commonly headed by tide water glaciers with associated melt water streams, and feature frequent small lateral side streams with small deltas and estuaries. Fjords are the predominant coastscape in Norway, Iceland, Greenland and the eastern Canadian Arctic.
Rapidly Eroding Shores	Coastal areas with soft shores, often containing significant ground ice, that are eroding at moderate to rapid rates to create offshore bars, spits and mudflats. Occur mostly along the southern coast of the Beaufort, East Siberian, and Laptev Sea.
Lagoons and Barrier Islands	Coasts that feature low-lying, shallow, brackish lake and wetland systems protected from the ocean by barrier bars and spits, usually connected by a relatively small stream that flows in both directions with the tide. Frequently flooded by storms that can significantly alter salinity and turbidity characteristics. Often occur with Rapidly Eroding Shore and Low Gradient Soft Shores Coastscapes that supply sediment for land building. Common in Russia, Alaska, and Canada along the Bering, Chukchi, and Beaufort Sea, and along the Iceland coasts.
Rocky shores and Sea cliffs	Low gradient to steep coasts (including sea cliffs) with exposed bedrock to the waterline that frequently include rock pools, beaches and small wetlands. Scattered throughout the Arctic and often associated with the Fjord Coastscape.
Estuaries	Estuaries develop at the mouths of most rivers where sediments are deposited. Often featuring extensive low gradient networks of wetlands, streams and brackish ponds with broad mudflats. Occur along the Arctic coast wherever rivers enter the sea; ranging from very small to very large estuaries such as the Lena, Ob, Yukon and Mackenzie.
Low Gradient Soft Shores	Low gradient coasts with varying thickness of surficial materials over bedrock, and characterised by mudflats, wetlands, and beaches. Scattered throughout the Arctic, but cover large coastal areas of the Canadian Arctic Archipelago, along the Alaskan Chukchi and Beaufort Sea, and along the Russian and Icelandic coasts.
Ice Fronts	Ice Fronts develop where glaciers reach the sea and usually produce floating ice by calving from the glacier front. They occur predominately on the east coast of Greenland, but also in the Baffin Bay area, in southern Alaska and on Svalbard, Norway. Meltwater emanating seasonally from the bottom of the glacier rises as a plum to the surface providing nutrients for lower trophic levels, and supports productive populations of surface feeding seabirds, diving seabirds and marine mammals.

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Appendix 4

List of essential Focal Ecosystem Components (FECs). The selection of FECs for each coastscape followed a stochastic dominance process based on selection criteria established by the Coastal Expert Monitoring Group (CEMG). They were assessed based on input from CEMG FEC workshops and selected scientists. For more detailed information see CAFF 2019[14]

ESSENTIAL FECS	COASTSCAPES						
	Rocky Shores	Eroding Shores	Lagoons	River Estuaries	Soft Shores	Fjords	Ice Fronts
Waterfowl		X	X	X	X	X	
Seabirds: omnivores	X	X			X		
Seabirds: diving planktivore	X	X			X		
Seabirds: surface piscivores	X	X	X	X	X		X
Seabirds: diving piscivores	X	X	X		X		
Seabirds: benthivores	X	X	X	X	X		
Subtidal flora, intertidal macroalgae	X		X	X		X	
Pinnipeds	X				X	X	X
Whales				X	X	X	X
Pelagic fishes	X	X	X			X	X
Demersal fishes	X		X	X		X	X
Salmonids			X	X	X		
Phytoplankton	X	X		X		X	X
Meso- and macro-zooplankton		X					X
Benthos	X		X	X	X	X	X
Large herbivores						X	
Coastal wetlands			X	X		X	

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Appendix 5

Data sets referred to through various publications in this chapter. The datasets are primarily ongoing monitoring and long-time series on the physical, chemical and biological environment in Svalbard coastal waters. These datasets are (or will be within 2021) available through the SIOS Data Access Portal[15]. In this metadata portal general information on the metadata and links to the data themselves are provided. The compilation of environmental coastal data from Svalbard is work in progress. The overall aim is to make relevant coastal data from Svalbard more easily available to the scientific and public community.

Dataset	Parameter	Period	Location	Metadata access (URL)	Dataset provider
Physical –chemical environment					
Hydrography	Water column temperature and salinity	1996-present	Hornsund and Kongsfjorden	Data will be available from 2021 through the IOPAN data portal http://www.iopan.gda.pl/index.html	IOPAN office@iopan.gda.pl
	Water column temperature and salinity Waves and tides	2013-present	Hornsund	Data will be available from 2021 through IG PAS Data Portal – http://dataportal.igf.edu.pl	Mateusz Moskalik (IG PAS) mmosk@igf.edu.pl
	Water column temperature and salinity	1990-present	Isfjorden	sios.metsis.met.no | Svalbard Integrated Arctic Earth Observing System (sios-svalbard.org)	Ragnheid Skogseth (UNIS) RagnheidS@UNIS.no
Fast ice cover	Percentage of fjord area	Monthly (Feb-Jun) since 2003	Inner Kongsfjorden	https://data.npolar.no/dataset/74c7b236-b94d-48c5-a665-ffcd54e8e1b7	Sebastian Gerland (NPI) sebastian.gerland@npolar.no Olga Pavlova (NPI) olga.pavlova@npolar.no
Sea ice	Time lapse photography	2015-present	Hornsund	Data will be available from 2021 through IG PAS Data Portal – http://dataportal.igf.edu.pl	Mateusz Moskalik (IG PAS) mmosk@igf.edu.pl
Sedimentology	SSC Sediment flux LOI	2015-present	Hornsund	Data will be available from 2021 through IG PAS Data Portal – http://dataportal.igf.edu.pl	Mateusz Moskalik (IG PAS) mmosk@igf.edu.pl

15 https://sios-svalbard.org/metadata_search

Biogeochemistry	Chlorophyll a (mg/m^3) Nutrients (mmol/m^3) POC/PON (µg/L)	2000-present	Kongsfjorden and adjacent shelf	https://data.npolar.no/dataset/6a4eaafa-10da-40d5-9a52-0268afbed4aa	Haakon Hop (NPI) haakon.hop@npolar.no Anette Wold (NPI) anette.wold@npolar.no
Seasonal Time Series					
Isfjord-Adventfjorden time series (IsA)	Hydrography Nutrients Phytoplankton taxonomy Chlorophyll a DNA (water) Zooplankton community	Bi-weekly to monthly data since 2011; all year	Adventfjorden (approx. 90-m depth)	In preparation for SIOS portal Data in NIRD	Anna Vader (UNIS) anna.vader@unis.no
Isfjorden Marine Observatory Svalbard (IMOS)	Hydrography Nutrients Phytoplankton taxonomy Chlorophyll a Zooplankton community	Seasonal time series since 2015 4 to 8 times per year	Isfjorden transect	In preparation for SIOS portal Data in NIRD	Janne E. Søreide (UNIS) janne.soreide@unis.no
Ecosystem monitoring in coastal waters of Svalbard "Økokyst Svalbard"	Physical parameters (temperature, salinity, oxygen) Water chemistry Phytoplankton Zooplankton Soft bottom benthic fauna Settlement plates	Monthly data; May-September 2018	Three stations in Isfjorden and Hornsund (2019-2020)	https://vannmiljo.miljodirektoratet.no/	Guttorm Christensen (Akvaplan-niva) guttorm.christensen@akvaplan.niva.no
Plankton					
Phytoplankton diversity	Abundance (cells/L)	2000-present	Kongsfjorden and adjacent shelf	https://data.npolar.no/dataset/6a4eaafa-10da-40d5-9a52-0268afbed4aa (work in progress)	Haakon Hop (NPI) haakon.hop@npolar.no Anette Wold (NPI) anette.wold@npolar.no Philipp Assmy (NPI) philipp.assmy@npolar.no
Zooplankton	Abundance (Ind/m^3)	1996-present (every July)	Kongsfjorden and adjacent shelf	https://data.npolar.no/dataset/6a4eaafa-10da-40d5-9a52-0268afbed4aa (work in progress)	Haakon Hop (NPI) haakon.hop@npolar.no Anette Wold (NPI) anette.wold@npolar.no
	Abundance (Ind/m^3)	2005; 2014-2019	Van Mijenfjorden	In preparation for SIOS portal Data in NIRD	Janne Søreide (UNIS) janne.soreide@unis.no

Dataset	Parameter	Period	Location	Metadata access (URL)	Dataset provider
Sea-ice flora and fauna					
Sympagic meiofauna	Abundance (Ind/m^2)	2014-present	Svalbard landfast ice	In preparation for SIOS portal Data in NIRD	Janne Søreide (UNIS) janne.soreide@unis.no
Benthic invertebrates					
Intertidal organisms	Flora and fauna Taxonomy Biomass Density	1981-88; 1999-2008; 2014-present	Around Svalbard	https://adamant.iopan.pl/adamant/taxa_observations/	sios.metsis.met.no | Svalbard Integrated Arctic Earth Observing System (sios-svalbard.org)
Soft bottom benthos	Sublittoral macrofauna Taxonomy Biomass Density Photography	1996-present	Hornsund and Kongsfjorden	Data will be available from 2021 through IOPAN data portal http://www.iopan.gda.pl/index.html	IOPAN office@iopan.gda.pl
Hard bottom benthos	Shallow sublittoral hard bottom fauna photography	2000-present	Isfjorden	http://www.polartimelapse.net/	IOPAN office@iopan.gda.pl
Fish					
Pelagic fish		Annually – autumn since 2010; winter since 2011; spring since 2015	Kongsfjorden, Isfjorden, Rijpfjorden and Hinlopen Strait (when sea-ice conditions allow for trawling)	In preparation for SIOS portal Data in NIRD	From UNIS, UiT and Akvaplan-niva Paul Renaud (Akvaplan-niva) paul.renaud@akvaplan.niva.no
Demersal fish		Annually – autumn since 2010; winter since 2011; spring since 2015	Kongsfjorden, Isfjorden, Rijpfjorden and Hinlopen Strait (when sea-ice conditions allow for trawling)	In preparation for SIOS portal Data in NIRD	From UNIS, UiT and Akvaplan-niva Paul Renaud (Akvaplan-niva) paul.renaud@akvaplan.niva.no

Seabirds					
Seabirds	Colony locations and total counts	1960-present	Throughout Svalbard	Historical data: https://data.npolar.no/dataset/fd4fd3aa-7249-53c9-9846-6e28c5a42587 New data upon request	Hallvard Strøm (NPI) hallvard.strom@npolar.no Sébastien Descamps (NPI) sebastien.descamps@npolar.no
	Population trends	Annual since 1987	Bjørnøya and Spitsbergen	http://www.mosj.no/en/fauna/marine/	Hallvard Strøm (NPI) hallvard.strom@npolar.no Sebastien Descamps (NPI) sebastien.descamps@npolar.no
Marine mammals					
Marine mammal distribution	Sighting records for all marine mammal species	Annual since 2002	Throughout Svalbard	Upon request	Kit Kovacs (NPI) kit.kovacs@npolar.no
Polar bear ecology	Dens and sea-ice cover Cubs per litter Cubs per female Body condition	Annually since 1979	Throughout Svalbard	http://www.mosj.no/en/fauna/marine/polar-bear.html	Jon Aars (jon.aars@polar.no)
Walrus	Population size	1980-present (every 5th year)	Throughout Svalbard	http://www.mosj.no/en/fauna/marine/walrus-population.html	Kit Kovacs (NPI) kit.kovacs@npolar.no

Appendix 6

Overview of recommendations for future monitoring/ time series rated with priority 1 to 3 (1= critical/urgent parameters; 2 = important parameters and 3 = support parameters). Climate region W = West Svalbard, E = East Svalbard, NE = Northeast Svalbard, and All = Whole Svalbard), Coastscape (see list, Appendix 3) and Focal Ecosystem Component (see list Appendix 4)

Climate region	Coastscape	FEC	Parameter	Priority (1-3)	Comment
All	Lagoons	Needs to be identified	Biodiversity, productivity, ecological role	1	No previous data
All	Estuaries, tidal flats	Phytoplankton (microphytobenthos), invertebrates and waterfowl	Biodiversity, productivity, ecological role	1	No previous data, except from Adventfjorden river delta
E/ NE	Rocky shore	Subtidal flora and intertidal macroalgae	Biodiversity, Coverage and growth (size)	1	No previous data
All	Fjords	Pelagic and demersal fish	Biodiversity, population data, biomass	1	No monitoring programme established for Svalbard fjords
All	Ice fronts, Seasonal sea, Fjords	All resident Arctic endemic marine mammals in Svalbard (only polar bears currently have marginally adequate monitoring coverage)	All relevant CAFF marine mammal FECs	1	Current monitoring is very limited and needs a major expansion for all marine mammal FECs that have been selected by CAFF
All	All vulnerable coastscapes via *in situ* measurements	Phytoplankton	Chl-a concentration, Turbidity/SPM concentration, coloured dissolved organic matter, dissolved organic carbon, PAR and primary productivity	2	Cal/Val work in progress, but still in an early phase, more research is therefore needed.
All	All vulnerable coastscapes via space borne/airborne measurements		Operation process chain to derive the parameters recorded *in situ* (listed above) and periodic calibration and validation of the algorithms.	2	
E	Fjords	Physical background data, Phytoplankton	Hydrography, turbidity, PAR, chlorophyll a	2	Autonomous observatory
All	Seasonal sea ice	Physical background data	Snow and sea-ice thickness	3	*In situ* sampling, SIMBA ice tethered buoys