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Rapid Assessment of Circum-Arctic Ecosystem Resilience (RACER)

THE WEST GREENLAND SHELF

WWF Report

Ilulissat Icefjord, West Greenland. Photo: Eva Garde

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Report
Rapid Assessment of Circum-Arctic Ecosystem Resilience (RACER). The West Greenland Shelf.

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Ilulissat Ice Fjord. Photo by Eva Garde.

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TABLE OF CONTENT

RAPID ASSESSMENT OF CIRCUMARCTIC ECOSYSTEM RESILIENCE

WWF'S RAPID ASSESSMENT OF CIRCUMARCTIC ECOSYSTEM RESILIENCE (RACER) presents a new tool for identifying and mapping places of conservation importance throughout the Arctic.

Recognizing that conservation efforts targeting the vulnerability of arctic habitats and species are not keeping pace with accelerating climate change, RACER instead locates sources of ecological strength. RACER finds places that generate what scientists call ecosystem resilience to fortify the wider ecological regions in which these places are found. RACER then looks ahead to whether these wellsprings of resilience will persist in a climate-altered future.

The RACER method has two parts. The first part maps the current location of land or sea features (such as mountains, wetlands, polynyas, river deltas, etc.) that are home to exceptional growth of vegetation and animals (productivity) and varieties of living things and habitats (diversity). These key features are especially productive and diverse because the characteristics that make them up (e.g., the terrain of mountains or the outflow at river mouths) act as drivers of ecological vitality. The exceptional vitality of these key features–in the places where they are currently found–is what makes them local sources of resilience for the ecosystems and ecosystem services of their wider regions (ecoregions). The second part of RACER tests whether these key features will continue to provide region-wide resilience despite predicted climate-related changes to temperature, rain, snowfall, sea ice, and other environmental factors important to living systems. Changes to these climate variables affect the drivers of ecological vitality (which depend on these variables) at key features. RACER uses forecast changes to these climate variables to predict the future vitality of key features and the likely persistence of ecosystem resilience for arctic ecoregions through the remainder of this century.

RACER's new method focuses conservation and management attention on the importance of minimizing environmental disturbance to places that are–and will be for the remainder of this century – sources of ecosystem resilience in the Arctic. In particular, RACER's ecosystem-based approach equips resource managers and conservationists with new targets for their efforts–managing not just our impact on species and habitats but on the combinations of geographical, climatic, and ecological characteristics that drive ecosystem functioning in the Far North. Identifying the sources of resilience for region-wide arctic ecosystems and nurturing them into the future may be the best hope for the survival of the Arctic's unique identity—including its habitats, plants, animals and the ecological services that northern people and cultures depend upon.

Source: Christie, P. and Sommerkorn, M. 2012. RACER: Rapid Assessment of Circum-Arctic Ecosystem Resilience, 2nd ed. Ottawa, Canada: WWF Global Arctic Program. 72 pp.

FOREWORD

The Greenland nature, wildlife and human way of life are unique to the Arctic regions. The nature in these remote regions is as grand and harsh as it is delicate and vulnerable – vulnerable to changes and to disturbances. The Arctic wildlife is exceptional and so well adapted to the cold and icy elements of this part of the world that changes in the environment can have severe impacts, in worst case fatal, on the populations living here. Also the traditional way that people have lived for centuries in the Arctic is threatened by climate change and new developing industries. The nature and wildlife of the Arctic deserve to be safeguarded into a future of change, so that all of our children's children also can enjoy the rare wonders of the Arctic.

This report puts focus on marine West Greenland, a region we call the West Greenland Shelf ecoregion. This ecoregion is biologically rich and diverse, and stretches all along the West Greenland coast from the southern Cape Farewell to the northern Melville Bay in the high Arctic. The region is inhabited by a wide variety of species including endemic Arctic species as well as annually migrating species from southern regions. The Greenlandic people, inhabiting the region, are economically as well as culturally dependent on the living resources harvested along the coast. The Greenland economy is currently completely reliant on the income from industrial fisheries, primarily the shrimp fishery. The traditionally hunted species are e.g. seal, walrus, narwhal and polar bear as well as a range of sea birds, and this hunt contributes significantly to the income of the many families living in small and larger settlements along the coast line. Today, Greenland is facing new developments as changes in the climate allows for new industrial activities, e.g. mineral and oil- and gas exploration and exploitation. Often these activities take place in areas essential for the Arctic wildlife and/or areas used for fishing and hunting, potentially creating conflicts of interests.

This report points at six areas along the West Greenland coast that are exceptional productive and diverse as well as they are resilient to climatic changes. As such they contribute significantly to the long-term functioning of the Greenland marine ecosystem, the wildlife living here and the people depending on the resources it provides. We therefore hope with this report to put focus on these six valuable marine areas in West Greenland and that the results will be used in constructive conservation discussions and decisions in Greenland. Relevant issues to discuss include:

- Minimization of environmental disturbances and risk of pollution in the designated areas in those essential periods of the year when humans hunt and fish, and animal breed, forage, and migrate.
- Introduction of long-term management plans for each of the designated areas that take into account threats against the ecosystems, e.g. human disturbance, pollution, habitat degradation, unsustainable use of the living resources, and invasive species.
- Long-term, sustainable management based on traditional knowledge and biological advice of those unique Arctic species that uses the designated areas throughout or part of the year, e.g.

by introducing sanctuaries for species of special importance for the Greenlandic ecosystems and culture like the polar bear, narwhal, walrus and thick-billed murre.

- Introduction of zones without any oil- and gas activities within the designated areas. Such zones will protect the ecosystems, animal species and as such the livelihoods of hunters and fishermen.

Gitte Seeberg, CEO WWF Denmark

ENGLISH ABSTRACT

The West Greenland Shelf ecoregion stretches along the approximately 2000 km of coast line from Cape Farewell (59°N) in southern Greenland to the northern Melville Bay (75°N) in the north. It extends 40-250 km out into the sea, and lines up with Baffin Bay, Davis Strait and the Labrador Sea. Depth ranges from a few meters up to about 2000 meters at the edge of the shelf. The West Greenland Shelf ecoregion encompasses a number of significant fishing banks, including the Store Hellefiske Bank and Fyllas Bank, as well as some of the world's most productive glaciers including the fastest glacier brook in the world, Sermeq Kujalleq (Jakobshavn Glacier) situated within the Disko Bay area. Formation of sea ice in the fall and the spring break-up are central physical conditions that define the northern part of the ecoregion, where sea ice is present for large periods of the year. The southern part of the ecoregion from Maniitsoq and south generally has open water all year around. The West Greenland Shelf ecoregion is characterized by low biodiversity compared to non-Arctic regions but with often numerous and dense animal populations, from the small in size but ecologically very important copepods to some of the largest creatures on earth, the bowhead whales.

For millennia people have inhabited the region where they have lived off the living resources; fish, seabirds and marine mammals. Today, the Greenland economy is almost exclusively dependent on the income from industrial fisheries, but interest for mineral and oil- and gas exploration and exploitation are growing and activities in these fields are becoming increasingly more active.

This rapid assessment of ecosystem resilience in the West Greenland shelf ecoregion has used analysis of satellite remote sensing data, relevant scientific literature and reports, and expert evaluation to designate marine key features where productivity and diversity are exceptional. Based on our results, six key features have been designated: 1. Upernavik Coastal Zone; 2. Disko Bay; 3. Store Hellefiske Bank; 4. The Søndre Isortoq Plume; 5. The Fyllas Bank area; and 6. The Southwest Greenland Shelf and Banks. Subsequently WWF has, based on data from General Circulation Models and together with experts into Arctic biology and ecology, evaluated that the likelihood that these six key features will continue to contribute to region-wide resilience despite climatic changes is medium or high for them all depending on the area.

The results of this report are intended to inform discussions about the best management approaches to safeguard the exceptional productivity and diversity of the designated areas to better fortify the resilience inherent in the larger ecosystem.

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RESUMÈ

Den Vestgrønlandske kontinentalsokkel økoregion (the West Greenland Shelf ecoregion) strækker sig cirka 2000 km langs den vestgrønlandske kystlinje fra Kap Farvel i syd (59° N) til Melvillebugten i nord (75° N). Den spænder 40-250 km ud i havet, og flugter med Baffin Bugten, Davis Strædet og Labradorhavet. Dybden varierer fra nogle få meter op til omkring 2000 meter på kanten af kontinentalsoklen. Området omfatter en række vigtige fiskebanker, herunder Store Hellefiske Banke og Fyllas Banke, samt nogle af verdens mest produktive gletsjere, blandt andet den hurtigst producerende gletsjer i verden Sermeq Kujalleq (Jakobshavn Isbræ) beliggende i Diskobugten. Dannelsen af havis i efteråret og havisens opbrud om foråret er centrale fysiske forhold, der definerer den nordlige del af denne økoregion, hvor havis er til stede i store dele af året, mens den sydlige del, fra Maniitsoq og sydpå, generelt har åbent vand hele året rundt. Hele området er karakteriseret ved en lav biodiversitet, set i forhold til ikke-arktiske områder, men til gengæld findes her mange store og talrige dyrebestande, fra de små i kropsstørrelse men økologisk meget vigtige vandlopper til nogle af de største skabninger på jorden, grønlandshvalerne.

I årtusinder har folk levet her og ernæret sig af de levende ressourcer; fisk, havfugle og havpattedyr. I dag er Grønlands økonomi afhængig af indtægterne fra fiskeriet af især rejer, men interessen for mineraludvinding og olie- og gas efterforskning og udnyttelse er stigende, og aktiviteter indenfor disse områder er øgende.

I denne rapport er der anvendt analyser af satellitdata, relevant videnskabelig litteratur og rapporter, og ekspertvurderinger til udpegelsen af bevaringsværdige marine områder indenfor Den Vestgrønlandske Kontinentalsokkel økoregion, hvor produktivitet og diversitet er ekstraordinær. Baseret på vores resultater, er seks områder blevet udpeget: 1. Upernavik kystnære zone; 2. Diskobugten; 3. Store Hellefiske Banke; 4. Søndre Isortoq fjordmunding; 5. Fyllas Banke området; og 6. Sydvest Grønlands sokkel og banker. Efterfølgende har WWF, baseret på data fra klimamodeller og sammen med eksperter indenfor arktisk biologi og økologi, vurderet at sandsynligheden for, at netop disse seks områder vil fortsætte med at bidrage til hele regionens modstandsdygtighed, trods klimaændringerne, er medium eller høj for dem alle, afhængigt af området.

Resultaterne af denne rapport kan bruges som grundlag for diskussioner om forvaltning til bevarelse af de udpegede områders enestående produktivitet og mangfoldighed, for på den måde at beskytte det vestgrønlandske marine økosystem ud i fremtiden.

A MARINE STUDY: THE WEST GREENLAND SHELF

THE WEST GREENLAND SHELF is a biologically rich and diverse ecoregion stretching along the West coast of Greenland. The region is inhabited by a wide variety of Arctic species, and has been the home for successive waves of human habitation for millennia living off the natural resources. The results of RACER's assessment of this important ecoregion are presented in this report.

The West Greenland Shelf ecoregion stretches along the approximately 2000 km (measured in a straight line) of coast line from Cape Farewell (59°N) in southern Greenland to the northern Melville Bay (75°N) in the north of Greenland (Fig. 1, Appendix 1). It extends 40-250 km out into the sea, and lines up with Baffin Bay, Davis Strait and the Labrador Sea. Depth ranges from a few meters up to about 2000 meters at the edge of the shelf (Fig. 2). North of the ecoregion lies the North Water polynia which is an essential area utilized by a variety of marine species as well as man. The West Greenland Shelf ecoregion encompasses a number of significant fishing banks, including the Store Hellefiske Bank and Fyllas Bank, where high water velocity creates strong upwelling that in turn provide nutrients for sustained high primary productivity in these relatively shallow areas (Merkel et al. 2012). The ecoregion also holds one of the world's most productive glaciers and the fastest glacier brook in the world, Sermeq Kujalleq (Jakobshavn Glacier) situated within the Disko Bay area. Formation of sea ice in the fall and the spring break-up are central physical conditions that define the northern part of the ecoregion, where sea ice is present for large periods of the year (Box 1). The southern part of the ecoregion from Maniitsoq and south generally has open water all year around. Several fjords along the extended coastline lead melting water and nutrient rich sediments from the inland ice sheet to the coastal waters.

The West Greenland Shelf ecoregion is characterized by low biodiversity compared to non-Arctic regions but with often numerous and dense animal populations. The most significant ecological event is the spring bloom of planktonic algae (phytoplankton) – the primary producers in the food web. These are grazed upon by zooplankton, including the copepods Calanus, representing one of the key species groups in the marine ecosystem (Appendix 2) (Merkel et al. 2012). The two Arctic species *Calanus hyperboreus* and *Calanus glacialis* are adapted to the cold waters of the Arctic regions while a third species, *Calanus finmarchicus*, is a northatlantic species adapted to warmer temperatures. The two former species contain large amounts of fat which are important for the species higher in the food web feeding on Calanus (Grenvald et al. 2012). Benthic macrofauna species consume a significant proportion of the available production and, in turn, are an important food source for fish, seabirds and mammals. Shrimps (*Pandalus borealis*), Greenland halibut (*Reinhardtius hippoglossoides*), redfish (*Sebastes spp.*) and Atlantic cod (*Gadus morhua*) are economically important species in Greenland whereas e.g. the sandeel (*Ammodytes ssp.*) and capelin (*Mallotus villosus*) are important prey species for other fish, sea birds and marine mammals. Millions of sea birds are found in the region – among others are thick-billed murre (*Uria lomvia*), common eider (*Somateria mollissima*), king eider (*Somateria spectabilis*) and little auks (*Alle alle*). Also large marine mammals thrive in the region: Polar bear (*Ursus maritimus*), walrus (*Odebenus rosmarus rosmarus*), true seals (Phocidae spp.), and a number of cetacean species migrate to the region each spring to feed and mate, e.g. fin whale (*Balaenoptera physalus*), minke whale (*Balaenoptera acutorostrata*), and humpback whale (*Megaptera novaeangliae*). Three whale species are endemic to the Arctic and subarctic regions. These are the Arctic whales: the bowhead whale (*Balaena mysticetus*), the narwhal (*Monodon monoceros*), and the beluga whale (*Delphinapterus leucas*) (Appendix 2).

For millennia people, the most recent being Inuit, have inhabited the region where they have maintained a living despite the often harsh living conditions. The sea has provided them with fish, marine mammals and sea birds, and on land they have hunted the large ungulates reindeer and musk oxen as well as smaller mammals and birds. Today, the Greenland economy is almost exclusively dependent on the income from industrial fisheries, primarily the shrimp fishery, but in recent years increased interest for mineral and oil- and gas exploration have been seen. These new industries have become increasingly more active and licenses for mining exploitation and development are emerging.

The new and large-scale industries and accelerating climate-related impacts on the environment as well as on human societies add urgency to the need for a strategic and forward-looking approach to resource development and fish and wild life management. RACER's assessment provides conservation targets to encourage resilience in the West Greenland Shelf ecoregion and to help this unique and ecologically important Arctic area respond and adapt to rapid change.

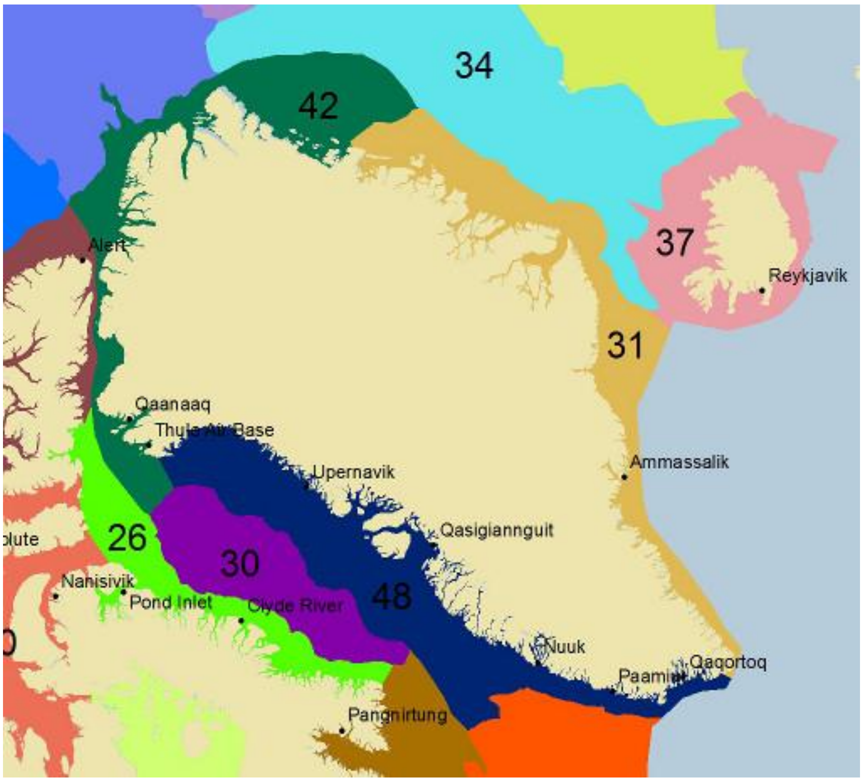

Fig. 1. Marine Arctic ecoregions. The dark blue area is marine ecoregion M48 – the West Greenland Shelf. Source: WWF, adapted from Spalding et al. 2007.

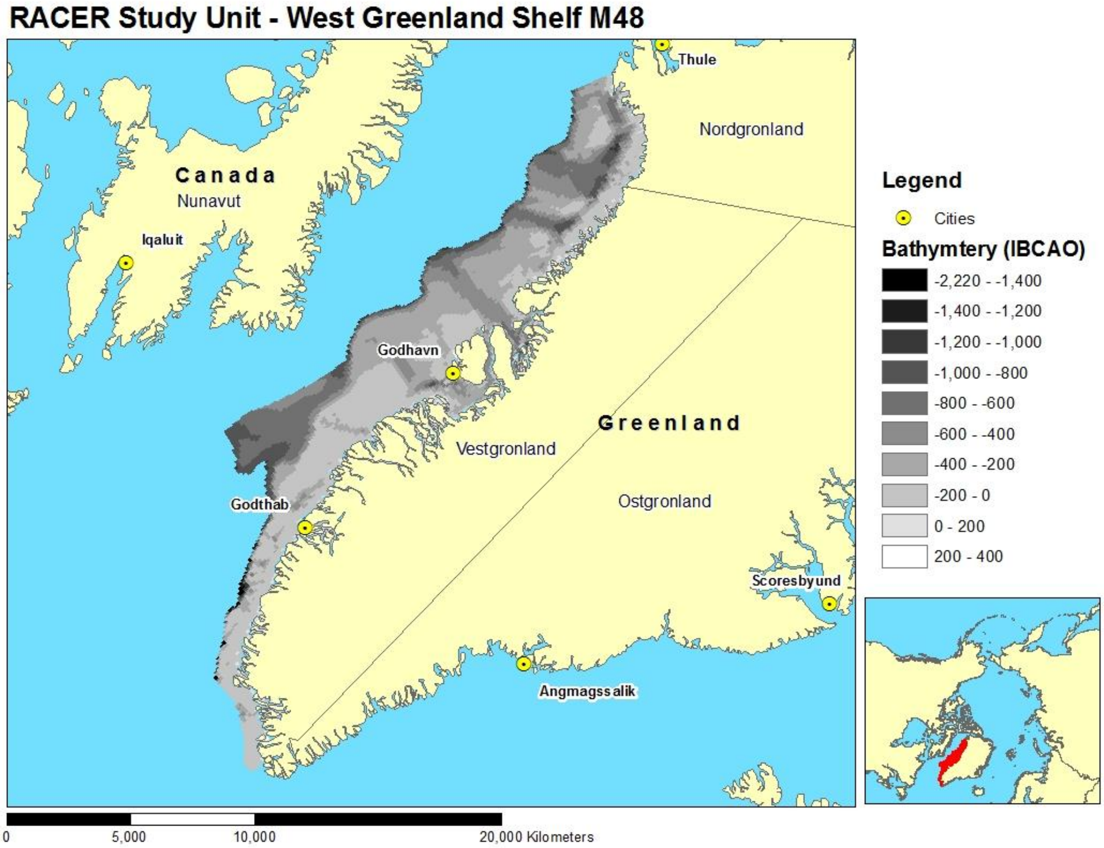

Fig. 2. Bathymetry of the West Greenland Shelf ecoregion.

Box 1.

Sea ice and icebergs at the West Greenland Shelf.

The West Greenland Shelf ecoregion is dominated by four types of sea ice: the West ice, Storisen (the East Greenland pack ice), fast ice, and icebergs.

The West ice consists of first year drift ice that forms west of the ecoregion in Baffin Bay and the Davis Strait. The ice builds up during November and December, and in January it encloses the entire coast of Western Greenland from around 68°N and northwards. The West ice reaches maximum thickness in late March. In the Disko bay area, the sea ice is approximately 75 cm at maximum thickness, whereas maximum thickness is reached at approximately 130-180 cm in Melville Bay at the northern part of the ecoregion. In spring the West ice starts to break up, starting in the south of the region and continues northwards. The West Greenland Shelf area is usually ice-free by late July-August. The area from 62-67°N is usually ice-free during winter caused by the warm water from the West Greenland Current.

Storisen (the East Greenland pack ice) consists mainly of multi-year drift ice, often more than 3 meters in thickness, and is transported with the East Greenland Current from the Arctic Ocean to southwest Greenland.

Fast ice is formed by freezing sea water or when drift ice freeze to an edge like the coast or a bank. The fast ice begins to build up from the inner parts of the fjord systems in October-November.

Icebergs are calved by the multiple coastal glaciers, which are fed by the Greenland Ice Cap found in western Greenland. The most productive west coast glaciers are Sermeq Kujalleq (Jakobshavn Glacier) near Ilulissat in the Disko Bay, as well as several large glaciers further north in the Ummannaq og Upernavik districts. In general, icebergs are found at the West Greenland Shelf ecoregion from 60-72° N, though lesser iceberg concentration near Sisimiut (Merkel et al. 2012).

KEY FEATURES IMPORTANT FOR RESILIENCE

This rapid assessment of ecosystem resilience in the West Greenland shelf ecoregion involves analysis of satellite remote sensing data (Tremblay et al. 2011, Appendix 3), relevant scientific literature and reports, and expert evaluation (RACER workshop, January 2014). Six marine key features within the West Greenland Shelf ecoregion have been identified and located as places of current and future conservation importance.

The six key features described in this report were identified by evidence suggesting exceptional productivity (Fig. 3, Appendix 4) and diversity during specific times of the year when plankton is most abundant and wildlife and Inuit hunters and fishermen tend to congregate in these areas. This ecological vitality is used to infer the importance of these features as sources of ecological resilience for the wider ecoregion. The resulting map of key features (Fig. 4) is intended to inform discussions about the best management approaches to safeguard the exceptional productivity and/or diversity of these places (and the drivers responsible for them) to better fortify the resilience inherent in the larger ecosystem.

The second part of RACER evaluates the likelihood that key features will continue to contribute to region-wide resilience when 21st century climate change affects the drivers at work in these ecologically vital places. The main drivers behind the exceptional productivity and/or diversity of the ecoregion's key features are described in Table 1. Drivers susceptible to the impacts of climate change, such as sea surface temperature, sea ice, and salinity, figure prominently in the ecological performance of key features. But climate-impervious drivers, such as seabed terrain responsible for nutrient-rich upwelling, are also important. These drivers will provide an important focus for future conservation efforts.

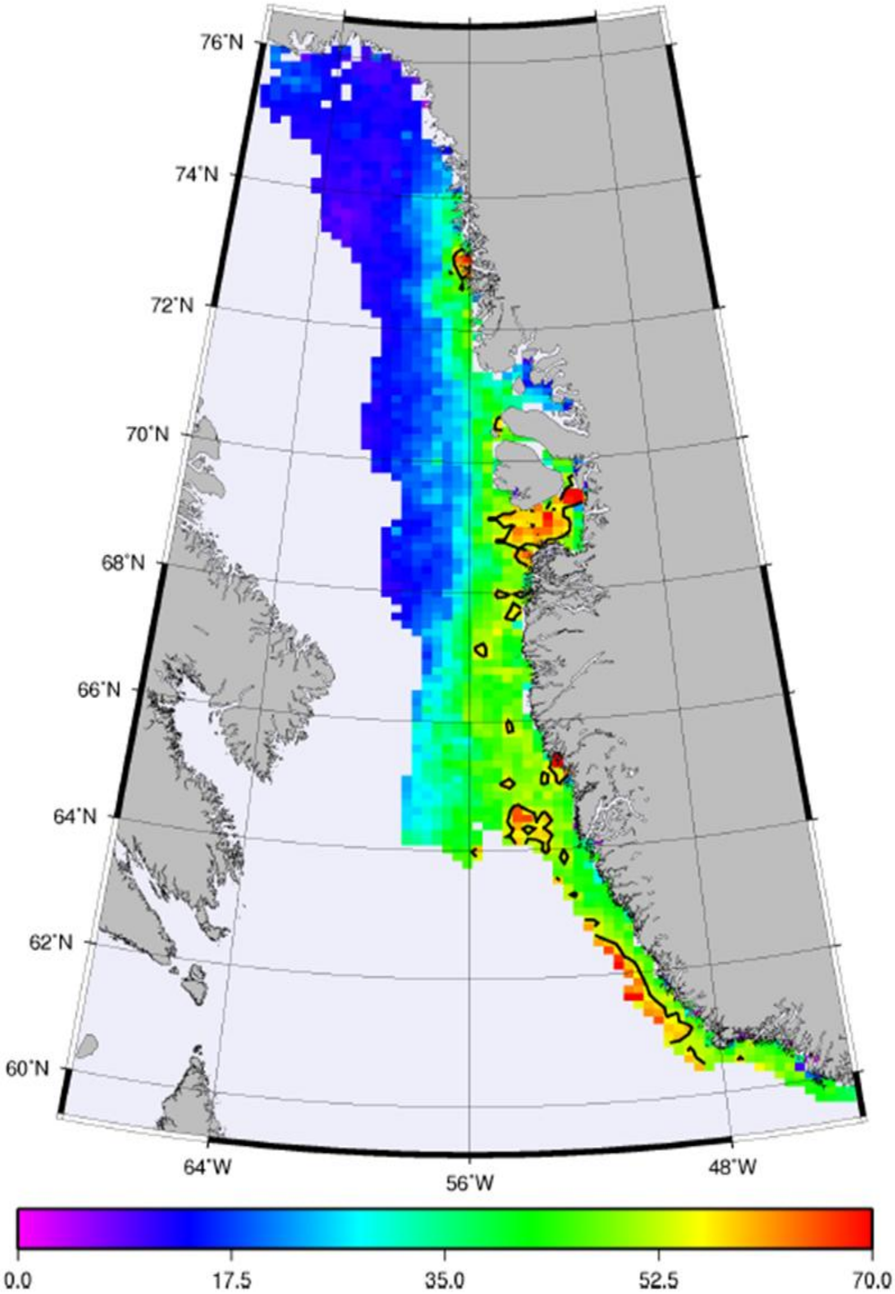

Fig. 3. Primary production rates (g C m^{-2} y^{-1}) of the West Greenland Shelf. Contour lines indicate the 10% most productive pixels based on the 90th percentile analysis (ACTUS inc. & WWF, 2011: Rapid assessment of the marine primary productivity trends in the Arctic Ocean and its surrounding seas). Based on data collected over a thirteen-year period from 1998-2011.

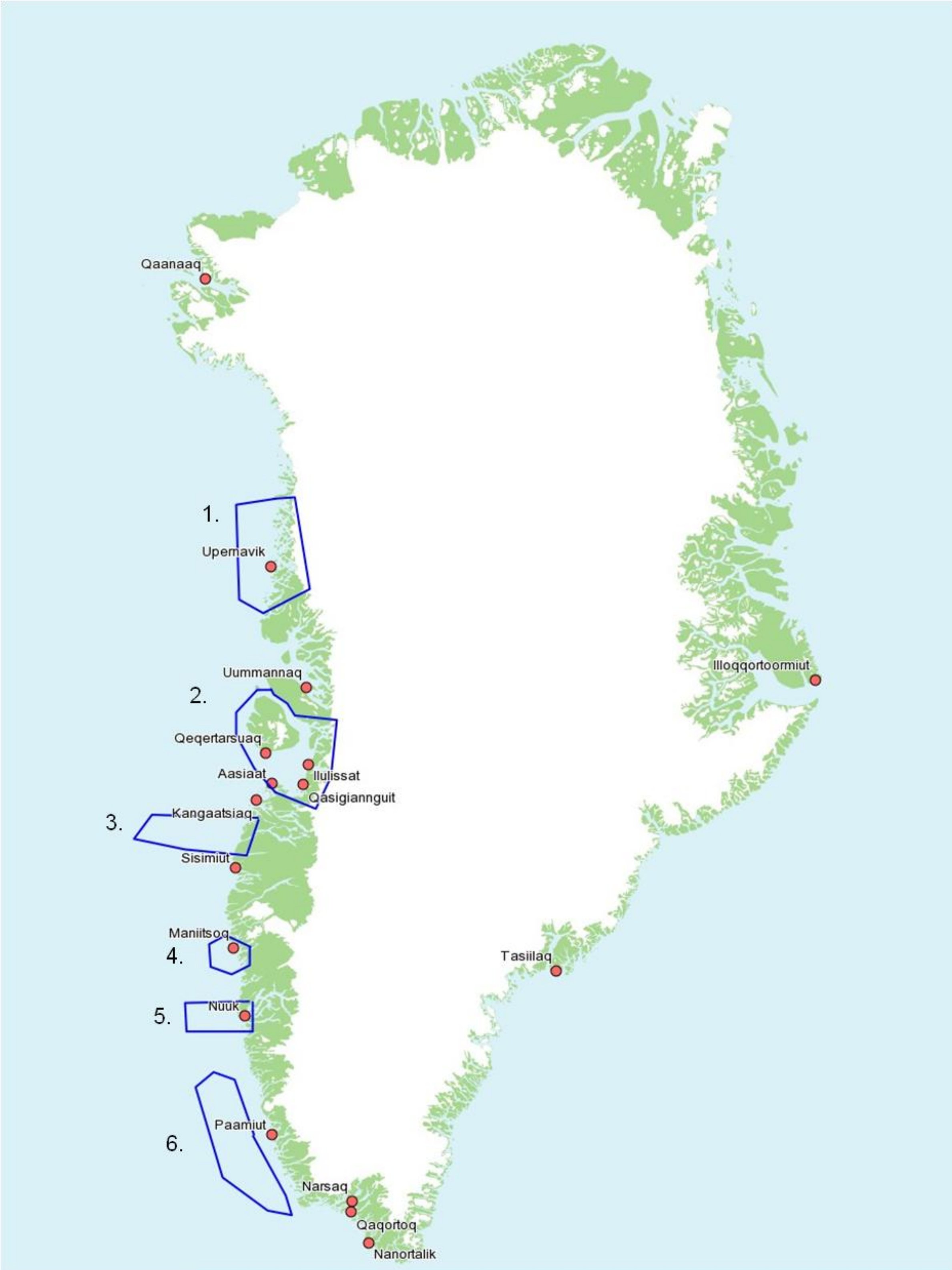

Fig. 4. The six marine key features designated by RACER for the West Greenland Shelf ecoregion: 1. Upernavik Coastal Zone; 2. Disko Bay; 3.Store Hellefiske Bank; 4. The Søndre Isortoq Plume; 5. The Fyllas Bank Area; 6. The Southwest Greenland Shelf and Banks.

GLOBAL CLIMATE MODELLING

RACER uses forecasts from current General Circulation Models (GCMs) to predict climate-related changes to ecologically significant variables within ecoregions for the remainder of this century. GCMs are a broad group of internationally developed computerized models designed and tested to forecast likely effects of global climate change on rain, snow, temperature, ice, and many other variables for different greenhouse gas emission scenarios into the future. GCMs form the basis of the predictions and warnings by the intergovernmental panel on Climate Change (IPCC 2007).

Although the unique relationship between the ocean, land, and atmosphere in the arctic often complicates these forecasts (e.g., through unexpected lag periods or difficult-to-anticipate climate feedbacks), the prediction accuracy of several GCMs has been proven in the region. RACER relies on data from four of these models that have shown the best agreement between climate projections and reality in the arctic (Appendix 5). Similarly, RACER uses GCM results for a realistic greenhouse gas emission scenario that reflects a "business as usual" outlook. The so-called A2 scenario offers results for all four selected GCMs (Fig. 5A). The scenario matches current observations closely and projects a degree of warming for the year 2100 in line with predictions resulting from current global commitments to the reduction of greenhouse gas emissions.

Twenty variables were selected from the GCM data for the RACER analysis. Variable values relevant to the ecoregions were then calculated from nearby GCM values using a weighted average from the GCM data grid to accommodate the irregular shape of the region (Fig. 5B). The details of this method are described in Huard 2010.

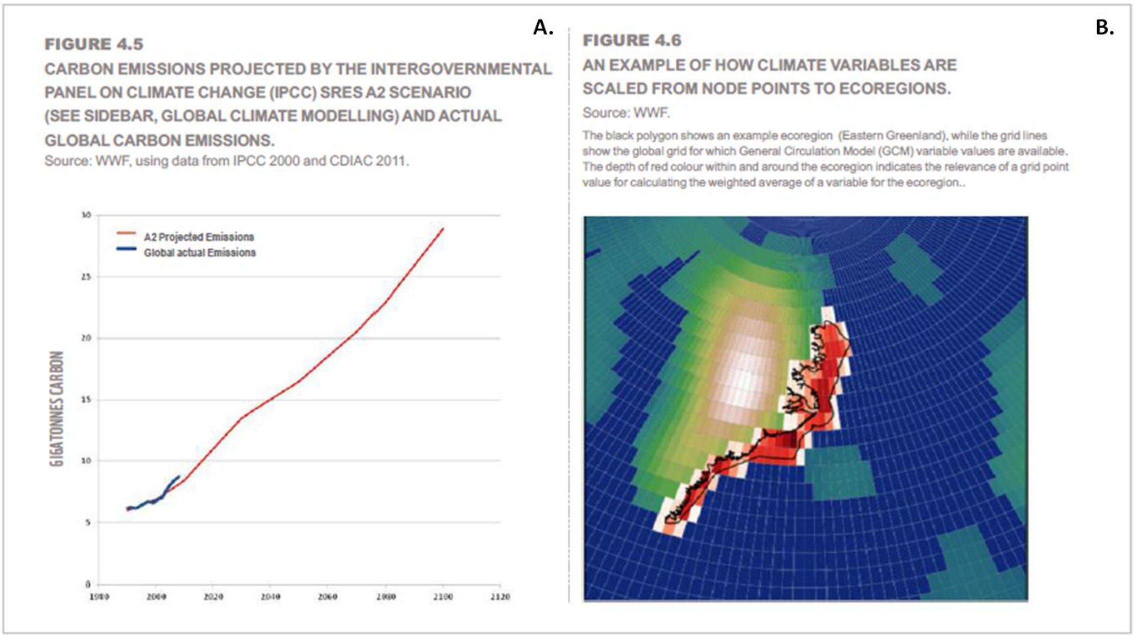

Fig. 5. A. Cabon emissions projected by IPCC SRES A2 scenario and actual global carbon emissions. B. example of how climate variables are scaled from node points to ecoregions (See also RACER: Rapid Assessment of Circum-Arctic Ecosystem Resilience – handbook (Christie and Sommerkorn 2012). Link to handbook: wwf.panda.org/arctic/racer).

ECOREGION CHARACTERISTICS

The West Greenland shelf is biologically rich, and within a year-cycle the ecoregion is of immense importance for a number of marine species. The continental shelf of the West Greenland coast contains shallow areas less than 100 meters and deeper waters of more than 1000 meters furthest from the shore (Fig. 2). The shelf has several steep banks such as Store Hellefiske bank, Sukkertop Bank and Fyllas Bank typically ranging from 20 to 100 meters in depth. Deep channels formed during the last ice age separate these fishing banks (Merkel et al. 2012, Ribergaard et al. 2006). During upwelling events the deeper nutrient rich water layers are mixed with the usually nutrient depleted upper water layers. Upwelling usually occurs along the steep sides of the banks, in the fjord systems, and at the hydrographic front between the West Greenland Current and the Irminger Current (Fig. 6) (Boertmann and Mosbech 2011, Jensen 2003). In fjords along the coastline melting water leads sediments and nutrients from the Greenland Ice Sheet to the coastal areas (Born and Böcher 1999).

The North Atlantic Oscillation[1] more or less regulates the temperature in the ecoregion although the Greenland Ice Sheet and the steep falls of the coast affect temperatures locally (Merkel et al. 2012). Warm water from the West Greenland Current and break-up of the West ice are determining factors for the distribution of the primary production within the region. Phytoplankton spring bloom has its onset during March-April in the open water area located in the southern part of the region (62-67°N). Further north algal growth occurs underneath the sea ice during early spring but the actual spring bloom is constrained by the break-up of the ice (Jensen 2003). Locally, high productivity areas are typically associated with fishing banks and fjord systems where nutrients are supplied by upwelling of bottom water layers or by fresh water input from glaciers, e.g. at Fyllas bank (64°N), Store Hellefiske bank (66-68°N) and Ilulissat Icefjord (69°N) (Born and Böcher 1999, Merkel et al. 2012). The numerous icebergs drifting along the coastline are year round calved from the many glaciers throughout the region. The most active glaciers are located between Melville Bay and Disko bay with the most productive of them all being Sermeq Kujalleq (Jakobshavn Glacier) found near the town Ilulissat in Disko Bay. The West Greenland Current carry icebergs from the Disko bay area northwards to Melville Bay where they exit the region east of Baffin Bay and move south creating a counter-clockwise pattern (Boertmann and Mosbech 2011, Merkel et al. 2012, Born and Böcher 1999). Within the ecoregion polynias occur at multiple sites along the coast or in the shear zone between the fast ice and the drift ice (Hansen 2012). These open water areas are typically characterized by a high productivity due to the

[11] The weather at the West Greenland Shelf ecoregion is largely determined by the North Atlantic Oscillation, which is driven by the difference in atmospheric pressure between the Azores High and the Iceland Low pressure cells. When the North Atlantic Oscillation index is positive the North Atlantic Current is strengthened, causing a decrease of the East Greenland Current and Irminger Current resulting in cold conditions in the region. If the North Atlantic Oscillation index is negative the opposite occur resulting in warm weather conditions in the region (Merkel et al. 2012, Ribergaard et al. 2006).

early spring bloom of phytoplankton and are thus important breathing and feeding areas for marine mammals and sea birds during winter and spring.

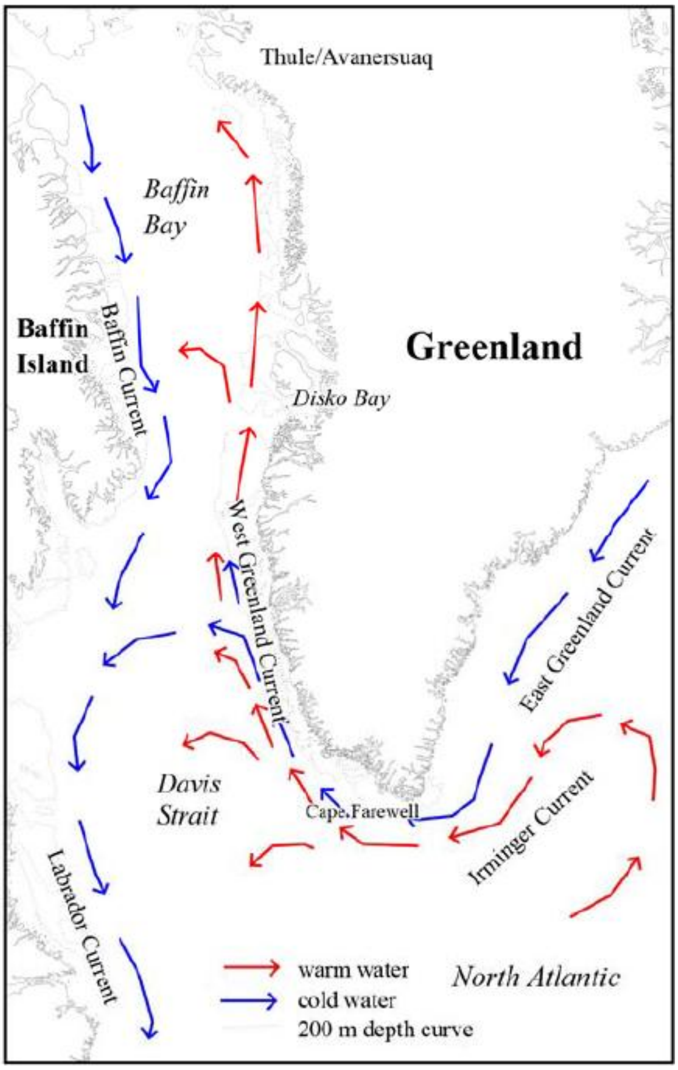

Fig. 6. Surface current patterns in the waters off West Greenland (From Stjernholm et al. 2011). The West Greenland Current flows northward along the coast of the ecoregion. It is impacted by two main components: the East Greenland Current originating from the Arctic Ocean and the Irminger Current derived from the North Atlantic Current. The cold, low salinity water of the East Greenland Current makes up the surface layer (0-150 m) and is diluted by run-off waters from the fjords as it moves north and loses its momentum around Fyllas Banke (64°N). The deeper layer consists of the warm and saline water of the Irminger Current that can be traced along the region from Cape Farewell to Thule (Boertmann and Mosbech 2011, Merkel et al. 2012).

RACER EXPERT WORKSHOP, JANUARY 2014

The RACER marine workshop was held at WWF Verdensnaturfondens location in Copenhagen, Denmark, 8th of January 2014. The workshop participants commented and evaluated on a preliminary version of this report as well as assessed persistence of key feature's future above-average productivity and diversity.

This final report is a product of work produced entirely by WWF Verdensnaturfonden.

Participants/experts:

- Anders Mosbech, senior scientist, Department of Bioscience, Arctic Environment, Aarhus University.
- Christine Cuyler, scientist, Department of Birds and Mammals, Greenland Institute of Natural Resources.
- Flemming Merkel, senior researcher, Department of Bioscience, Arctic Environment, Aarhus University.
- Tom Christensen, advisor, Department of Bioscience - Arctic Ecosystem Ecology, Aarhus University.

Comments and conclusions of workshop:

- RACER focuses on primary productivity and the services that an ecosystem can provide for animals and humans but are not drawing specific attention to threatened endemic species. Using the RACER method ecosystem services will therefore be protected but not implicitly protects those species unique to the Arctic regions and that are vital important species both culturally and economically to the people living here.
- The RACER method works within a context of identifying and designating areas of high netto primary productivity/biological production today and into the future and these areas are important to take into account in regional nature management, but the method is not suitable to ensure the protection of the High Arctic species that are most threatened by climate change.
- The experts pointed out that even though it is assessed that a specific key feature's above-average productivity and diversity will remain high in the future it will not necessarily be the same productivity and diversity consisting of the same species/same food chain structure that characterize that key feature today.
- The experts took reservations to the General Circulation models (GCM's) used in the RACER method as for the West Greenland Shelf ecoregion these models cover a huge area stretching from 60-76°N latitude. The resolution in the models is too low to make precise predictions and assessments of ecosystem resilience and the assessments given in this report are therefore only estimations. There is a need for regional climate models, with sufficient resolution for the ecoregions.

- Remote sensing of productivity does not measure the productivity occurring under the sea ice. The northern part of the West Greenland Shelf ecoregion is covered by sea ice for large periods of the year which makes it challenging to use this essential factor to identify key features at such high latitudes (in the Melville Bay and the northern Upernavik district). The remote sensing primary productivity maps for these areas are therefore probably misleading because only open water productivity is accurately measured. Sea ice cover of high percentages can have very high productivity as there will be lots of sunlight penetration to create productivity between ice floes and under the sea ice.
- The experts distinguished between productivity and biodiversity why the coloumn in Table 1 regarding assessed persistence of key feature's future above-average productivity/diversity is separated into two assessments (productivity and diversity) instead of one assessing these together as shown in the RACER handbook (page 51).
- It gives strength to the RACER method that it designates areas also identified by other methods to be of high ecologically importance.
- Resilience – all experts agreed that this is an important concept and that it is a useful approach, even if challenging to apply.
- The biodiversity of the West Greenland ecoregion has been intensely studied for decades. However, certain fauna and flora groups like benthos and macro algae are still data deficient in most areas along the West Greenland coast line which makes a full picture of the biodiversity in this ecoregion currently unattainable. A report containing a summary of the overall biodiversity found in Greenland is expected to be published from the Danish Centre for Environment and Energy (DCE) within the first half of 2014. This report will give an important overview of the species found within the key features described in this document.

KEY FEATURES

1. UPERNAVIK COASTAL ZONE

The Upernavik Coastal Zone key feature stretches approximately 250 kilometers from northern Nuussuaq located south of Kullorsuaq at approximately 74° 7’ 19.9 N to Skalø just north of the Svartenhuk peninsula at 71° 53’ 22.9 N (Fig. 7a). This coastal area is an archipelago of rocky coast with a countless number of large and small islands, deep fjords and large fjord systems. The coastal areas and some of the fjords are characterized by a high primary production, and life here is more diverse and abundant than in other marine areas in the ecoregion.

The Greenlandic sea currents have major impacts on the primary production and in which areas nutrient-rich up-welling occurs - events that are the basis for high levels of primary production in specific marine areas. The sea currents are also a main factor in the distribution of sea ice; a distribution that varies on a yearly basis. Several large glaciers are found at this key feature, e.g. the Upernavik Isbræ (Fig. 7b). Glaciers and production of icebergs affect the hydrography in these ‘glacier fjords’; when glaciers calve a vast mixing of the water masses occurs and big waves are generated. Also, when glaciers and icebergs melt brackish water rise to the surface bringing along nutrients, hence promote production in the fjords. On the contrary, the production will cease if too large amounts of sediments are transported to the fjord (Jensen 1999). Another pronounced physical feature in this ecoregion is the presence of sea ice and icebergs throughout a large part of the year which is an important element for ice-associated primary production and ice-associated species like seals and polar bear. Polynias (open water areas) are important features in these icy waters and several polynyas are found within the northwest Greenland coastline where early ice break-up and availability of nutrients from up-welling lead to locally very high production. The ice-free period in high-Arctic areas around Northwest Greenland is generally 3-4 months, but in polynyas may be more than 6 months. Near Prøven and Søndre Upernavik, in the southern part of the Upernavik Coastal Zone key feature, an early ice break-up in spring creates an open water area (similar to a true polynya) which is beneficial of early arriving breeding seabirds. Also, a shear zone occurs (with open cracks and leads) between the land fast ice and the drift ice, which is too very important to seabirds as well as marine mammals, particularly in spring when populations are migrating northwards (Boertmann and Mosbech 2011).

The Upernavik Coastal Zone key feature is critical for several species of fish, sea birds, and marine mammals as they use the area for breeding, feeding and as a migration route (Stjernholm et al. 2011). The current knowledge of the benthic community along the West Greenland coastline and shelf areas is however scarce. In general, the abundance of bivalves is highest at shallow depths from 0-50 meters where also the highest species richness is found. Studies have documented high abundance of large kelp, sea urchins and crustaceans at depths from 3-25 meters (Boertmann and Mosbech 2011). The area is of tremendous importance for the seabirds in Greenland. Nearly all of the Greenlandic breeding sea birds have (or had) nesting sites here (Christensen et al. 2012). Large colonies of breeding common eider and thick-billed murre are located in the area (Jensen 1999), although some of the colonies of the latter have disappeared probably due to unsustainable hunting activities. But also colonies of e.g. Arctic tern (*Sterna paradisaea*), northern fulmar (*Fulmarus glacialis*), black guillemot (*Cepphus grylle*), razorbill (*Alca torda*), Atlantic puffin (*Fratercula arctica*), little auk (*Alle Alle*), Black-legged Kittiwake (*Rissa tridactyla*) and species of gulls are found here. Also, important areas for moulting seaducks, mainly king eiders, are located mostly near Upernavik and further south in the key feature area (Boertmann and Mosbech 2011). Also the marine mammals constitute an important element to this key feature. Several species of whales use the area parts of the year as well as do seals, walrus and polar bears. The three Arctic whales; the bowhead, narwhal, and beluga use the area as a migration route to and from winter- and summer grounds north and south to this area, and well-known wintering grounds for the Atlantic walrus are found both within and south of this key feature (Christensen et al. 2012, Boertmann and Mosbech 2011, Jensen 1999). The area is also used by polar bears from the Baffin Bay population (Christensen et al. 2012), and local hunting for polar bears is occurring here.

In the Upernavik Coastal Zone, the economically important Greenland halibut is found and there is a large inshore fishery for the species in the area (Jensen 1999). Also several river outlets with Arctic char are located within this key feature mainly in the southern part of the area (Boertmann and Mosbech 2011).

The area is sparsely human populated with one town and 10 small settlements including a total of approximately 1700 inhabitants. Hunting and fishing is the main subsistence form (Stjernholm et al. 2011).

The combined action result of drivers – the seabed terrain, the archipelago of rocky coast, glaciers, seasonal ice cover, currents, tidal, salinity, and sea surface temperature – creates a key feature that support high productivity and the diverse seabed and oversea terrain provides diverse marine habitats for a range of species. Such shorelines with a high primary production are of high ecological importance. However, experts pointed out that the current species composition of Arctic and high Arctic species in the area could change towards more temperate species as current species might migrate to more northerly regions and temperate species move into and occupy these Arctic regions as climate change progresses. Also, increased precipitation will lead to increased runoff from adjacent terrestrial areas and thereby more nutrients would be added to the ecosystem. This could affect and change the ecosystem with increased primary production as a consequence. Increased precipitation could also have a negatively impact on the many sea bird colonies in the area as chick survival could decline. Moreover, increased melting of glaciers and the Greenland Ice Cap will add significant amounts of freshwater to the marine habitats decreasing salinity. These two effects of climatic changes could have an impact on the copepod composition crucial for the remainder of the marine food chain. A significant uncertainty regarding primary productivity at this key feature is changes to sea ice regimes caused by climatic changes. Such changes could have severe impacts on primary producers thus affecting the ecosystem as a whole. Also, sea ice stabilizes the water column which is significant for the distribution of nutrients in the marine environment.

However, despite the predicted changes to sea surface temperature, salinity, sea ice concentration and the precipitation forecast by General Circulation Models (GCMs) (Appendix 5), habitat heterogeneity, tides, and nutrient upwelling are expected to continue to contribute to exceptional productivity and diversity in a climate-altered future. After consulting with experts, RACER determined that the likelihood was *medium* that this key feature would remain a source of ecosystem resilience for the ecoregion through to 2100.

Fig. 7a. Key feature 1, the Upernavik Coastal Zone, is shown by the dark blue line. Especially the area within the light blue line is highly productive (Fig. 3) and a place of significant conservation value. The defined borders of key features are only indicative.

Fig. 7b. Satellite photo showing part of the Upernavik Coastal Zone key feature, the settlements within the area, the Upernavik glacier (Upernavik Isbræ), and several other glaciers that characterize this area of conservation importance. Source: Moderated from NunaGis.

2. DISKO BAY

The Disko Bay key feature is located between approximately 70° 17’ 38.7 N and 68° 37’ 11.9 N covering inner Disko Bay, Vaigat and the marine area just west and north of the Disko Island (Fig 8a and b). Disko Bay is defined by diverse seabed terrain with areas of rather shallow waters (depths less than 200 meters) near the coast, traversed by deep troughs. West of the shelf there is deep water down to 2,500 meters (Merkel et al. 2012). The coasts of southern Disko Bay consist of bedrock shorelines with many skerries and archipelagos, whereas the western Disko Bay and further north are characterized by straighter coasts often made up from sediments like sand or gravel. On Disko Island several large river deltas with extensive tidal flats are found (Mosbech et al. 2007). The most significant feature in the physical marine environment is the presence of sea ice and icebergs throughout large parts of the year. In the beginning of the melt season a wide lead- or polynya-like feature often forms west of Disko Island and in front of Disko Bay (Mosbech et al. 2007). Numerous glaciers are found in West Greenland, and in Disko Bay hundreds of icebergs are always present. The most active glacier is the Sermeq Kujalleq (Jakobshavn Glacier) located near the town Ilulissat. In 2004 the Ilulissat Icefjord was included into the UNESCO list of World heritage Sites.

Disko Bay is an area of complex oceanographic and bathymetric features, and tidal driven up-welling, which gives rise to a high biological production in spring (with great variation between years) creating favorable conditions for foraging and breeding for many species of marine mammals and seabirds during the year (Christensen et al. 2012). The relatively high production of phyto- and zooplankton during spring and summer is due to up-welling events at the entrance and off the glacier front in the inner part of the bay (Merkel et al. 2012, Mosbech et al. 2007). The relatively high primary production in this area is related to the length of the growth season where reduced sea ice cover and an open water period is generated by the relatively warm waters of the Irminger Current that travel along the West Greenland coast and shelf (Fig. 6) (Rysgaard et al. 1999).

A number of species are dependent on the resources found in Disko Bay. Three species of copepods, two Arctic species *Calanus hyperboreus* and *Calanus glacialis*, and one northatlantic *Calanus finmarchicus*, creates the basis for the high marine biodiversity and density of animal populations found at the Disko Bay key feature. *Calanus hyperboreus* and *Calanus glacialis* contain significantly larger amounts of fat than the temperate species *Calanus finmarchicus* why these two former species are essential food items for species feeding on Calanus such as fish and the bowhead whale (Grenvald et al. 2012). Several large and smaller colonies of breeding, feeding and wintering sea birds are located in the area e.g. Arctic tern, thick-billed murre, northern fulmar, black-legged kittiwake, white-fronted goose, razorbill, atlantic puffin and black guillemot. Also moutling sites for common eider and king eider are located around Disko Island, mainly at the west and northwest coast (Mosbech et al. 2007, Jensen 1999). West of Disko Bay is an important winter ground for Atlantic walrus and belugas overwinter in the area. The bay is also an important feeding ground for several species of baleen whales e.g. the bowhead whale that returns to the area each spring to forage and the humpback whale use the area in the summer period (Christensen et al. 2012). The area is rich in fish and especially Greenland halibut, snow crab (*Chinoecetes opilio*), shrimps, scallops (*Clamys islandica*) and lumpsucker (Cyclopterus lumpus) are economically important species (Mosbech et al. 2007, Jensen 1999) but also e.g. capelin (*Mallotus villosus*) and arctic char (*Salvelinus alpinus*) are utilized by man. Sea birds and marine mammals (e.g. eiders, thick-billed murres, seals, narwhals and belugas) are also utilized species. At this key feature, important benthic species, in an ecosystem context, include the bivalves *Mytilus edulis, Hiatella bysifera, Serripes groenlandicus* and *Mya truncate*, but also many species of polychaetes, echinoderms, amphipods and gastropods are found. Slow growth and long lifespan of several Arctic species makes the benthic community particularly vulnerable to disturbance (Mosbech et al. 2007).

The area has approximately 10.000 inhabitants of whom a good portion is hunters and fishermen (numbers from Grønlands Statistik, Nov. 2013). The area is an attractive tourist destination.

The main drivers that combine to create the high productivity and biological diversity of this key feature are seabed terrain, highly productive glaciers, seasonal ice-cover, sea and tidal currents, salinity and sea surface water temperatures which makes this key feature exceptional, not only in Greenland, but in all of the Arctic. As for key feature 1, experts emphasized that the current species composition could change in the face of accelerating climatic changes why the current composition might not be the same for year 2100. For example, it has already been documented that the temperate and less fat copepod *Calanus finmarchicus* is gaining ground at the expense of the two Arctic and fat species of copepods. This shift in species composition will affect species higher in the food web feeding on Calanus, and which are dependent of a fat diet to survive and reproduce (Riisgaard et al. 2011).

Increased precipitation leading to increased runoff and enhancement of nutrients to the ecosystem could have the same effect here as for key feature 1, as well as increased melting of glaciers and the Greenland Ice Cap could impact the whole ecosystem by decreased salinity and an addition of more and larger ice bergs within the Disko Bay area. Lesser sea ice at the Disko Bay key feature would probably also alter the primary productivity although to what extent is difficult to assess.

Despite of expected changes to sea water temperature, salinity, and sea ice concentration by GCMs, seabed terrain, nutrient upwelling, and currents are expected to continue to contribute to productivity and diversity in this area. RACER determined that the likelihood was *medium* for this key feature to continue to be a source for ecosystem resilience through to 2100.

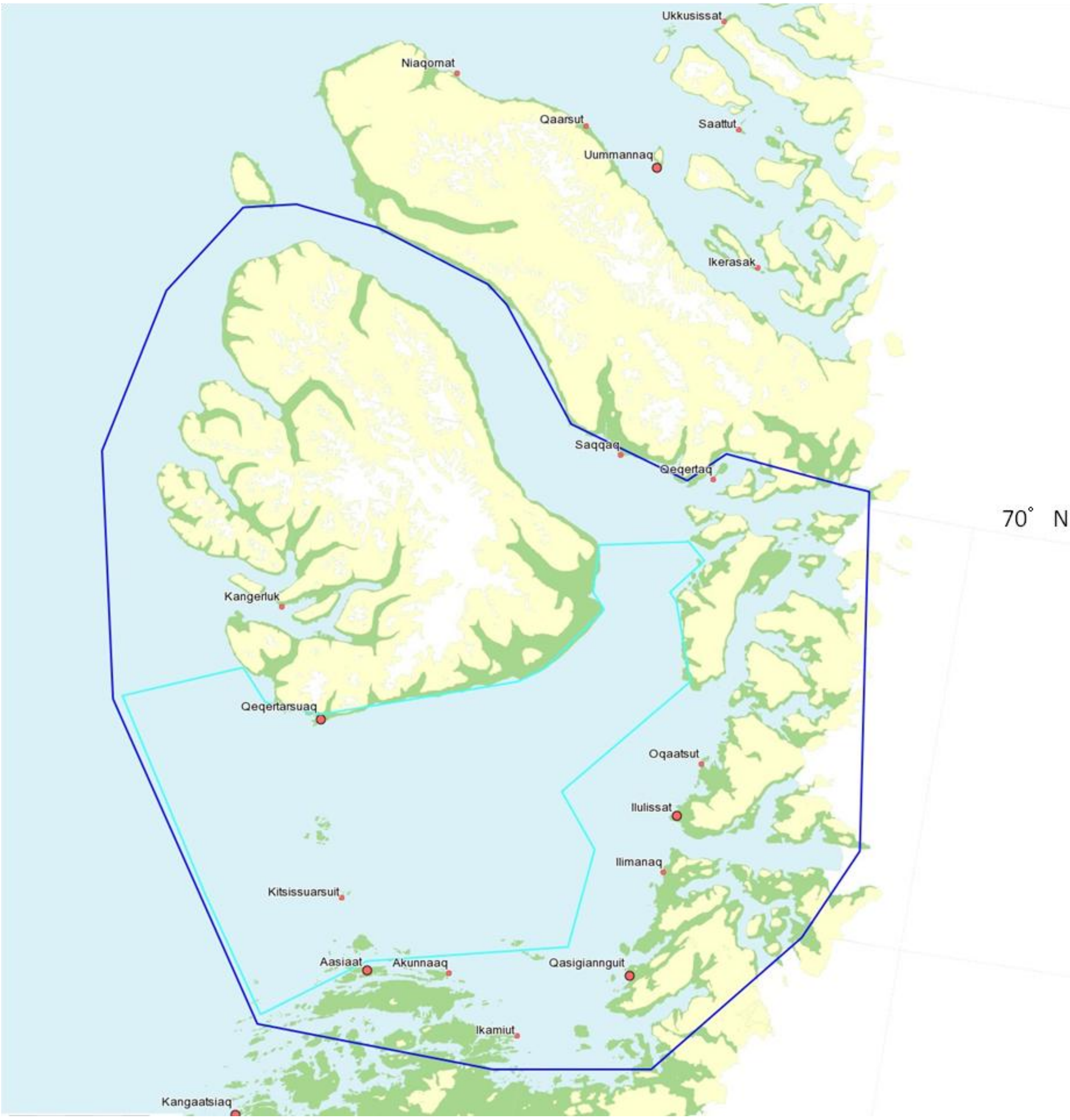

Fig. 8a. Key feature 2, the Disko Bay, is shown by the dark blue line. The area within the light blue line is highly productive (Fig. 3). The defined borders of key features are only indicative.

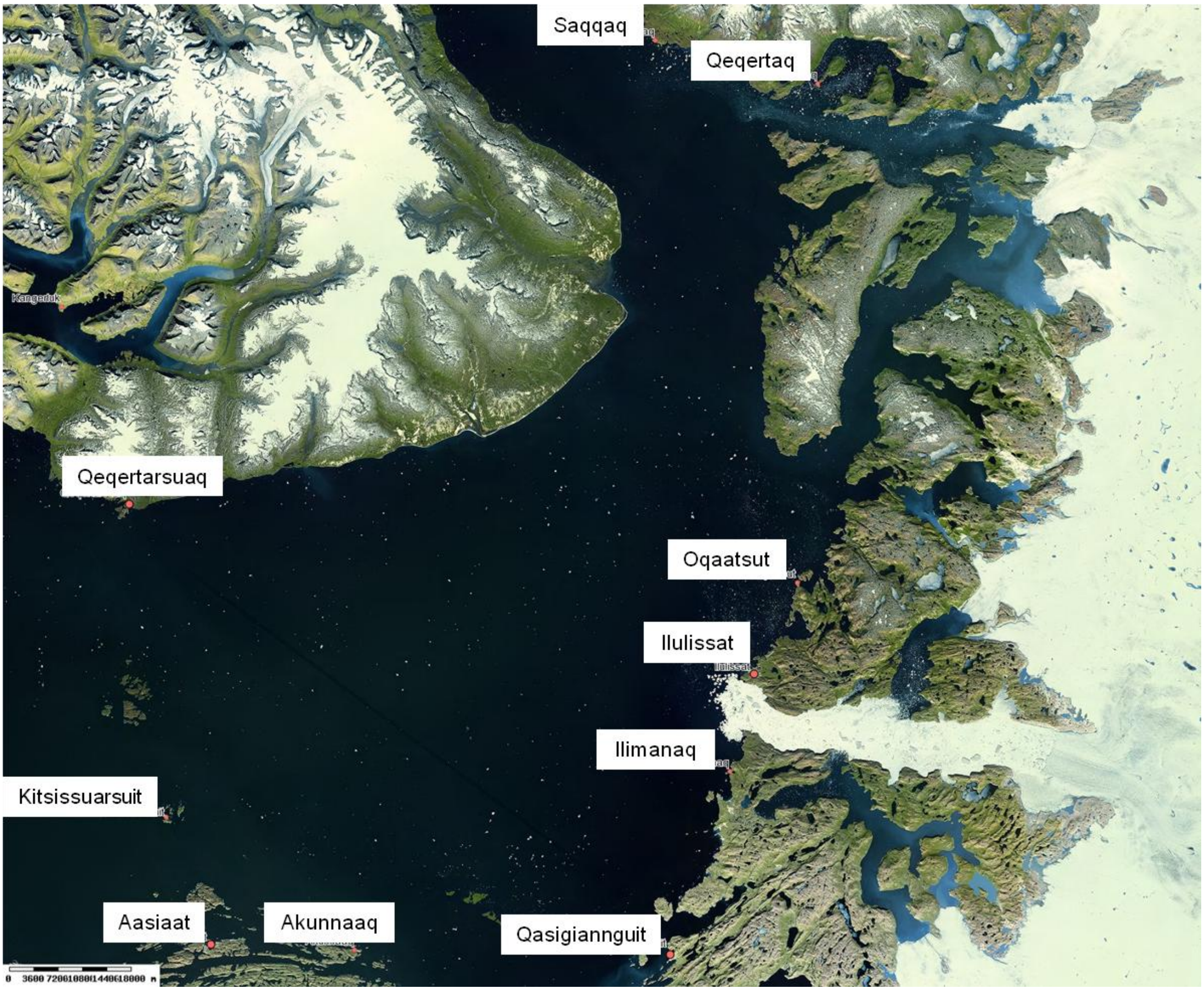

Fig. 8b. Satellite photo showing part of the Disko Bay key feature, towns and settlements within the area, the Ilulissat glacier (Ilulissat Isbræ), and the Disko Island that characterize this area of conservation importance. Source: Moderated from NunaGis.

3. STORE HELLEFISKE BANK

Store Hellefiske Bank is located on the West Greenland Shelf just south of Disko Bay between approximately 68-67°N (Fig. 9). A significant upwelling area is found at the northeast corner of Store Hellefiske Bank, where a deep wedge cuts southwards between the bank and the coast (Mosbech et al. 2007). Tidal currents and wind cause upwelling events supplying nutrients to the upper water layers throughout the year and cause a pronounced and early spring bloom of phyto- and zooplankton. Sea ice is usually found in Davis Strait, including the bank, from November to mid-summer (Merkel et al. 2012). The banks have an extensive benthic community and are important feeding grounds for a diversity of fish, marine mammals and seabirds. On the banks, at water depth between 50-100 meters, the benthic community includes e.g. polychaetes, crustacean, bryozoa and echinoderms. At the slopes of Store Hellefiske Bank the benthic fauna is richer than on the top of the banks (Mosbech et al. 2007). Store Hellefiske Bank is in the winter period (from February to May) a critical habitat for walrus that are dependent on feeding grounds less than 100 meters deep where they dive for bivalves on the seafloor. The walrus is confined to a very distinct area in the North-Northwest part of the bank closest to the ice edge of the West Ice (Mosbech et al. 2007). The bank is also important for the bearded seal (*Erignathus barbatus*) that use the area in the winter- and spring months as a feeding ground. Several whale species visit and use the bank on their annual migrations from southern wintering grounds to the more northerly feeding areas in the Arctic, these include species like harbour porpoise (*Phocoena phocoena*), minke whale, fin whale and humpback whale (Mosbech et al. 2007). The beluga whale uses the bank as a winter ground. They arrive from the Canadian summer grounds to the bank in November and stay until May (Heide-Jørgensen et al. 2003). The Hellefiske Bank is also important to seabirds. Thus, very large populations of king eiders counting hundreds of thousands of birds use the bank areas less than 50 meters deep as a resting and winter ground. This probably approaches the entire population of king eiders wintering in West Greenland (Christensen et al. 2012, Mosbech et al. 2006). Also, relatively large densities of thick-billed murres use the area in spring. Commercial fisheries after shrimps, scallops and halibut are taking place at Store Hellefiske Bank (Christensen et al. 2012, Jensen 1999).

Seabed terrain including the shallow banks, sea and tidal currents, sea surface water temperatures, and nutrients constitute the drivers accounting for the exceptional productivity and diversity found for this key feature. The forecasted changes in precipitation could lead to increased freshwater amounts to the marine ecosystem with increased amounts of nutrients added to the system and decreased levels of salinity as a consequence, as also described for key feature 1 and 2. This might affect primary productivity by increased levels of production. But the main forecasted changes to sea water temperature and salinity are not expected to disrupt this source of ecological strength into the future. Based on expert evaluation, RACER concluded that the likelihood was *high* that this key feature would remain a source of ecosystem resilience for the ecoregion through the remainder of this century.

Fig. 9. Key feature 3, the Hellefiske bank, is shown by the dark blue line. The area within the green line is highly productive (Fig. 3). The defined borders of key features are only indicative.

4. SØNDRE ISORTOQ PLUME

The Søndre Isortoq Plume key feature is located between approximately 65° 30’ 51,1 N and 65° 4’ 8,8 N between the town Maniitsoq and the settlement Napasoq (Fig. 10a and b), covering a distance of roughly 60 kilometres. This key feature is, contrary to key feature 1-3, situated below the Arctic Circle. The Søndre Isortoq Fjord and Plume is located approximately 15 km south of the town Maniitsoq. The fjord is 45 km long and empties into the Davis Strait. The large Majoroq river (71 km long) further inland empties into the Søndre Isortoq Fjord bringing large quantities of glacial silt from its outflow at the Greenland ice sheet into the head of the fjord. Silt and nutrients are carried along with the currents to the Isortoq plume where they probably contribute to the exceptional primary production observed in the area (Fig. 3). North of the fjord mouth several skerries are located. Large colonies of thick-billed murre are found well in the fjord while at the mouth of the fjord large concentrations of foraging thick-billed murre are gathered in the breeding season. Also several colonies of kittiwake and Arctic tern are found in the summer month within and at the mouth of the fjord (Mosbech et al. 1996). The ‘open water area’ extends as far north as to the Maniitsoq area, including the Søndre Isortoq Fjord and can functionally be considered a polynya, although in a very strict technical sense it is not. The area is more or less ice-free throughout the year and from October to April the shelf and the fjords serve as a wintering area for very large amounts of sea birds. In spring, the area is a migration route for both seabirds and several whale species on their way from south to more northern locations (Christensen et al. 2012). Frequently visiting whale species include humpback whales, minke whales and harbor porpoise. Studies have shown that climatic warming on the banks of West Greenland have resulted in improved body conditions for the harbor porpoise in West Greenland due to increased consumption of Atlantic cod and longer residence times at the banks (Heide-jørgensen et al. 2011). Approximately 2600 people live in Maniitsoq. They engage in fisheries for shrimps and crabs as well as hunting for seals and whales. There is a yearly hunt for harbor porpoise with catches of up to 1200 animals and also minke whales are caught here.

The main drivers at work at this key feature are salinity, nutrients, sea and tidal currents, and sea water temperatures which accounts for the exceptional productivity found for this key feature. As for the forecasted changes in precipitation the same mechanisms enter into force at this key feature as for the previous described above. However, the forecasted changes in sea water temperature, salinity, precipitation and surface air temperature are not expected to significantly change the exceptional primary production found at this key feature stemming at least partly from the nutrients lead to the Søndre Isortoq Plume from the river and fjord and catchment area. RACER therefore concluded that the likelihood was *high* that this key feature would keep on contributing to ecosystem resilience through to the 2100 century.

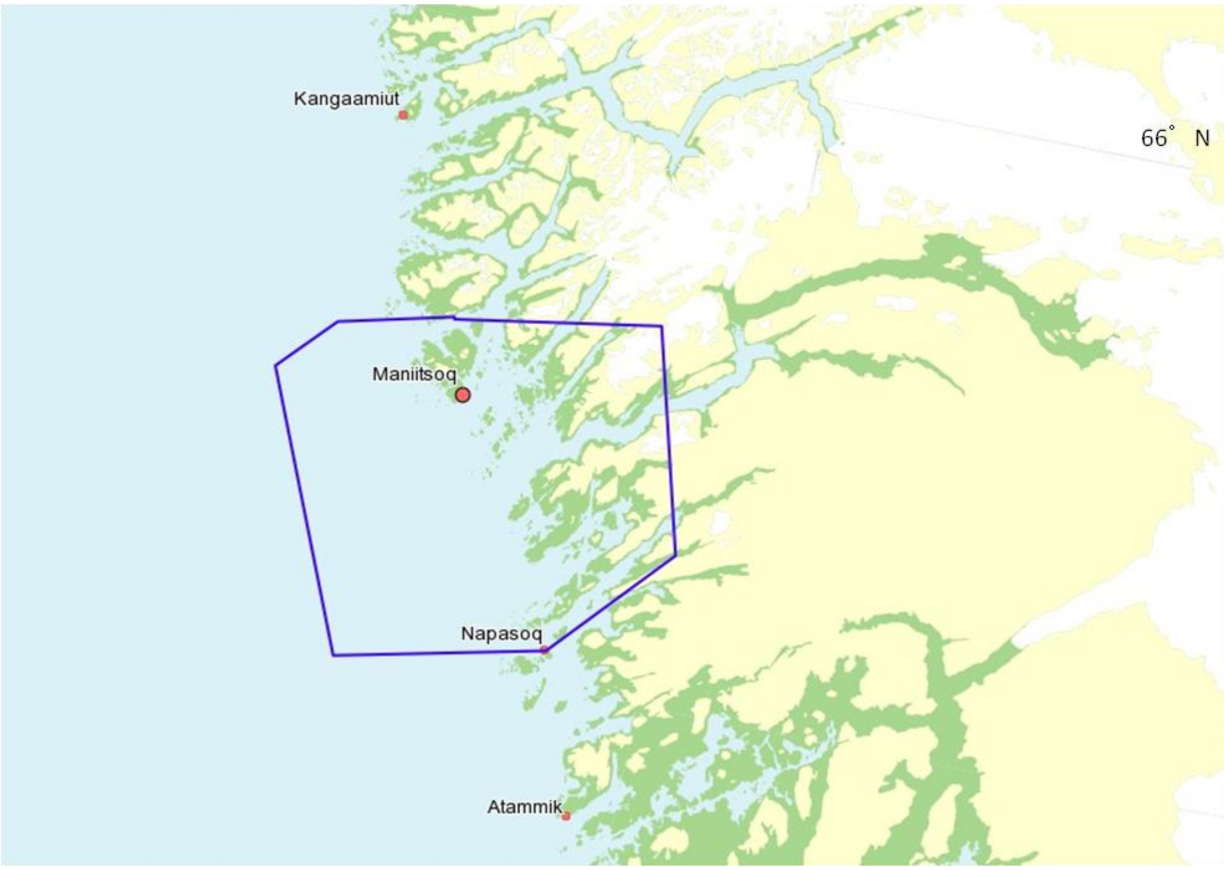

Fig. 10a. The Søndre Isortoq Plume key feature is shown by the dark blue line. The defined borders of key features are only indicative.

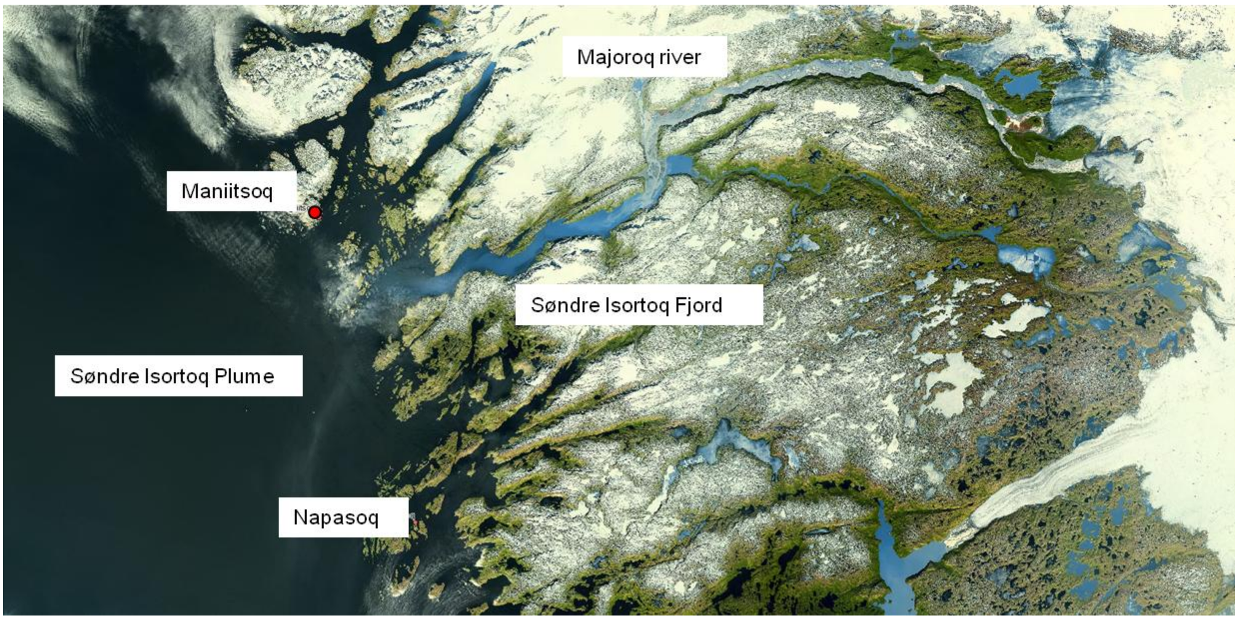

Fig. 10b. Satellite photo showing the Søndre Isortoq Plume key feature, one town and one settlement within the area, the Søndre Isortoq Fjord, and the Majaroq river that characterize this area of conservation importance. Source: Moderated from NunaGis.

5. THE FYLLAS BANK AREA

The Fylla Bank key feature includes part of the Fylla Bank and part of the eastern Davis Strait from approximately 64° 32’ 40.9 N to 63° 22’ 12.8 N (Fig. 11). Fyllas Bank is situated just west of Nuuk, the capital of Greenland. This shallow water fishing bank is one of several found in the Davis Strait within the Western Greenland Shelf ecoregion. The exceptional productivity and richness of fish at this key feature is accounted for by the combination of cold nutrient rich waters from the Godthåbsfjord and relatively warm waters of the Irminger Current. The warm, salty Irminger Current is continuously providing large amounts of heat to the Southwest Greenland waters and high salinities and high temperatures are observed in the deep waters west of the shelf/Fyllas Bank. This affects fish stocks as well as the Greenlandic outlet glaciers that melt more rapidly. The marine environment on the West Greenland fishing banks is mainly controlled by external water masses from both polar and temperate areas (Fig. 6). Hydrographical conditions on the West Greenland fishing banks are determined by the balance of power between the Irminger Current and the East Greenland Current[2]. At Fylla Bank, oceanic fronts have great impact on the growth of fish larvae and the composition and production of plankton organisms. At the outflow of Godthåbsfjord, coastal currents meet out-flowing water from the fjord, which leads to mixing processes and enhanced production[3]. Also upwelling events occurs throughout summer at the slopes sustaining high primary productivity for long periods of time in contrast to productivity in central and western Davis Strait (Mosbech et al. 1996). The area is rich in fish and sea birds. Important offshore fisheries in the area are deep sea shrimp and Greenland halibut. The sand eel is an important prey species in the ecosystem. The many seabirds in the area are adapted to different ecological niches, where some feed on fish, some are plankton feeders and yet some bottom feeders. The outer coast and skerries north and south of Godthåbsfjord has important puffin colonies, and south of the fjord is an isolated thick-billed murre colony. Colonies of razorbill and Arctic tern are also loacted within this key feature and the area is important to little auks and eider that head off in the spring to more northerly located breeding areas. Largest populations of seabirds at the bank are found during winter where the importance of the open water area is unique (Mosbech et al. 1996). Whales frequently visit the area, including the humpback whales that return each spring and summer to forage in the area.

Nuuk has approximately 16.000 inhabitants. Fishing and hunting are common activities and depending on the time of the year different species of fish, sea birds and marine mammals are sold on the markets.

Sea surface temperature, salinity, sea and tidal currents, and nutrients are identified as the main drivers at this key feature. Experts notet that primary productivity at the mouth of the Godthåbsfjord is surpringly low (Fig. 3), since studies have previously shown this area to be highly productive (Smidt 1979). It was furthermore pointed out that the Fyllas Bank area key feature is a highly significant area for populations of high Arctic seabirds during winter. Also, important seabird colonies are located at

[2] www.natur.gl/en/fish-and-shellfish/sea-temperatures/
[3] www.natur.gl/en/climate-research-centre/

the coast line around the mouth of the Godthåbsfjord and humpback whales show site fidelity to the Godthåbsfjord area and Fyllas Banke. The borders of this key feature was therefore expanded to include the coastline from Fiskefjord, north of Godthåbsfjord, to Færingehavn apart from the highly productive area including Fyllas bank, part of Toqqusaq bank, and part of eastern Davis Strait (Fig. 11).

Despite of expected changes to sea water temperature and salinity by GCMs, nutrient upwelling and sea currents are expected to continue to contribute to exceptional productivity and diversity in this important area. RACER determined that the likelihood was *high* for this key feature to continue to be a source for ecosystem resilience through to 2100.

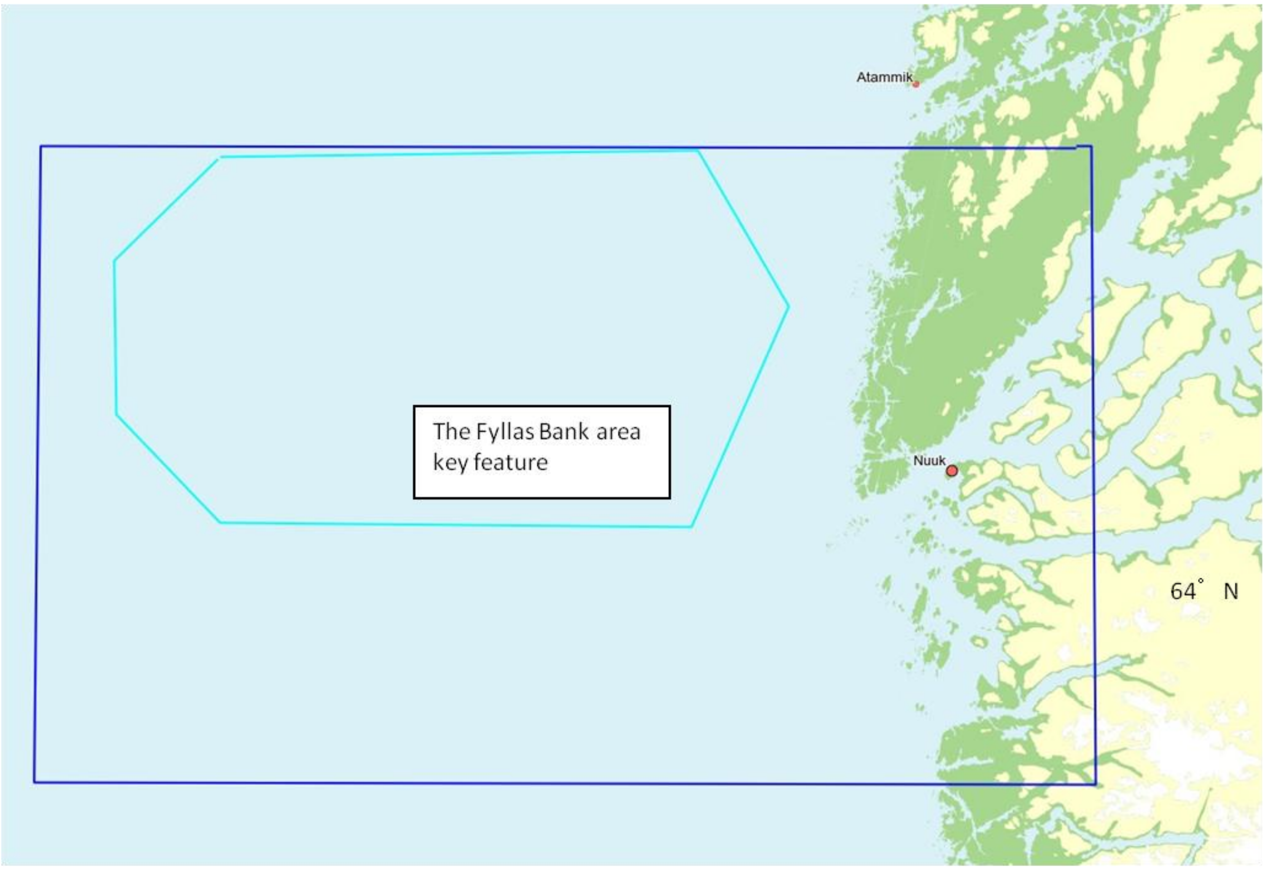

Fig. 11. The Fyllas Bank area key feature is shown by the dark blue line. The area within the light blue line is highly productive (Fig. 3). The defined borders of key features are only indicative.

6. THE SOUTHWEST GREENLAND SHELF AND BANKS

The Southwest Greenland shelf and banks, Danas Bank and Narsalik Bank, located approximately between 62° 49’ 8.3 N and 60° 37’ 23.6 N constitute this last key feature (Fig. 12). The area covers a distance of 250 kilometers measured in a straight line. High rates of water flow in these relatively shallow waters cause up-welling of nutrient-rich water, which is the basis for the high primary production in these areas. The banks are usually more or less ice-free year round, because of the warm waters of the West Greenland Current, and the high primary productivity of the banks are maintained for a longer time period compared to the deeper offshore locations. Another important characteristic is the transition zone where Arctic and temperate ocean currents meet which affects the level of primary and secondary production as well as plankton distribution. Also, the seawater from these coastal areas differs both physically and chemically from oceanic water, as it is mixed with fresh water from the catchment land area (Merkel et al. 2012). The area is important to a wide variety of species including fish, sea birds and marine mammals, e.g. it is an important area for overwintering thick-billed murres and the red listed harbor seal (*Phoca vitulina*) is found here (Christensen et al. 2012). Besides thick-billed murres the open water area is an important winter habitat for eider, king eider, Long-tailed Duck (*Clangula hyemalis*), Red-breasted Merganser (*Mergus serrator*), Black Guillemot (*Cepphus grylle)*, and Iceland Gull (*Larus glaucoides*), and in the summer period the area is used by e.g. Black-legged Kittiwake as well as a small breeding population of Harlequin Duck (*Histrionicus histrionicus*) that also uses the coastal areas for moulting. The open water area is also used summer and fall by a number of cetaceans e.g. fin whale, minke whale and humpback whale. Also the blue whale (*Balaenoptera musculus*) and sei whale (*Balaenoptera borealis*) visit the area. Polar bears are irregularly visiting the area when they are carried by Storisen (the East Greenland pack ice) to southwest Greenland from locations in Eastern Greenland.

Paamiut is the largest town within this key feature. It has approximately 1.500 inhabitants and fishery is the main occupation here. Also hunting for seal and whales, especially minke whales, are common activities for the inhabitants at the southwest banks.

The drivers defining this key feature are sea currents, sea surface temperatures, nutrients and salinity. Despite the forecasted changes to sea water temperature, salinity, precipitation and surface air temperature the Southwest Greenland shelf and banks are expected to continue to contribute to ecosystem resilience mainly because of the undersea terrain and upwelling events that supply the banks and shelf area with sufficient nutrients to maintain a high primary productivity. RACER therefore assessed that the likelihood was *high* that this keyfeature would remain an important source of ecosystem resilience for the remainder of this century.

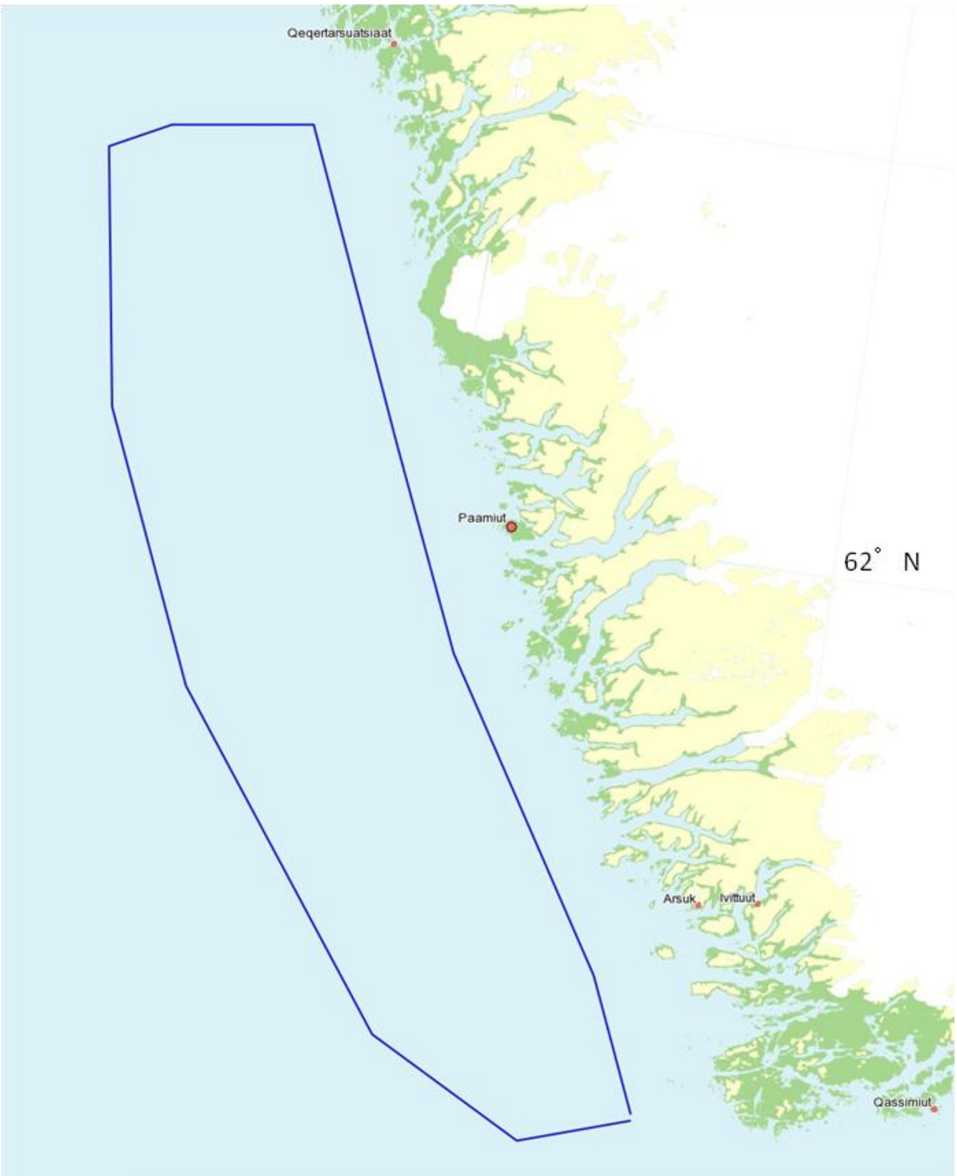

Fig. 12. The Southwest Greenland shelf and banks key feature is shown by the dark blue line. The defined borders of key features are only indicative.

Table 1. The likely persistence of key features in the face of climate change. The likelihood that key features will continue to confer resilience to the ecoregion in the future is scored as high (H), medium (M), or low (L) based on projected changes to main climate variables using GCMs and their effect on geophysical drivers.

Key feature	Main driver	Current biological productivity & habitat heterogeneity	Main changes to GCM climate variables¶	Assessed persistence of key feature's future above-average productivity/diversity* (High, Medium, Low)
1. Upernavik Coastal Zone	Seabed terrain Archipelago Glaciers Seasonal ice cover Sea and tidal currents Salinity Nutrients Sea surface temperature	High productivity; high marine species diversity; Up-welling driven by currents and glaciers ; sea ice driven spring bloom	Sea Surface Temp (SST) Sea Ice (SIC) Salinity (S) *Precipitation (P)*	M** / M
2. Disko Bay	Seabed terrain Glaciers Seasonal ice-cover Sea and tidal currents Salinity Nutrients Sea surface temperature	High productivity; high marine species diversity; Tidal-driven Up-welling	Sea Surface Temp (SST) Sea Ice (SIC) Salinity (S) *Precipitation (P)* *Surface air temp (SAT)*	M / M
3. Store Hellefiske Bank	Seabed terrain Sea and tidal currents Sea surface temperatures Nutrients	Nutrient-rich up-welling; high productivity; marine species diversity; extensive benthic community	Sea Surface Temp (SST) Salinity (S) *Sea Ice (SIC)* *Precipitation (P)* *Surface air temp (SAT)*	H / H
4. Søndre Isortoq Plume	Salinity Nutrients Sea and tidal currents Sea surface temperatures	Sediment-laden nutrient inputs; glacier outflow and catchment outflow affects nutrient amounts	Sea Surface Temp (SST) Salinity (S) Precipitation (P) Surface air temp (SAT)	H / H
5. Fyllas Bank area	Salinity Sea and tidal currents Sea surface temperatures	High productivity; high biodiversity; rich fish resources; mixing of water masses	Sea Surface Temp (SST) Salinity (S) *Precipitation (P)* *Surface air temp (SAT)*	H / H
6. Southwest Greenland shelf and banks	Salinity Nutrients Sea and tidal currents Sea temperatures	High productivity; high diversity; nutrient rich waters; sea currents influence nutrient availability	Sea Surface Temp (SST) Salinity (S) *Precipitation (P)* *Surface air temp (SAT)*	H / H

¶Climate variables: Sea Surface Temperature (SST); Salinity (S); Sea-Ice Thickness, Sea-Ice Concentration (SIC); Precipitation (P); Surface Air Temperature (SAT). Persistence index: H – High; M – Medium; L – Low. Relevant, though not the main climate variables are shown in italics.

* Diversity of species may change from the current composition consisting of both high Arctic, Arctic, and temperate species to a composition mainly consisting of more temperate species as climate change progresses for the remainder of this century. High Arctic and Arctic species will potentially migrate further north as temperate species move into the Arctic regions from more southerly latitudes. The assessments of diversity presented in this table is therefore not an indication of whether Arctic biodiversity as we know it today will remain at the designated key features but an indication of whether 'any' biodiversity will remain high, medium or low.

**Uncertainty regarding the assessment of productivity at changed sea ice regimes caused by climatic changes.

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APPENDICES

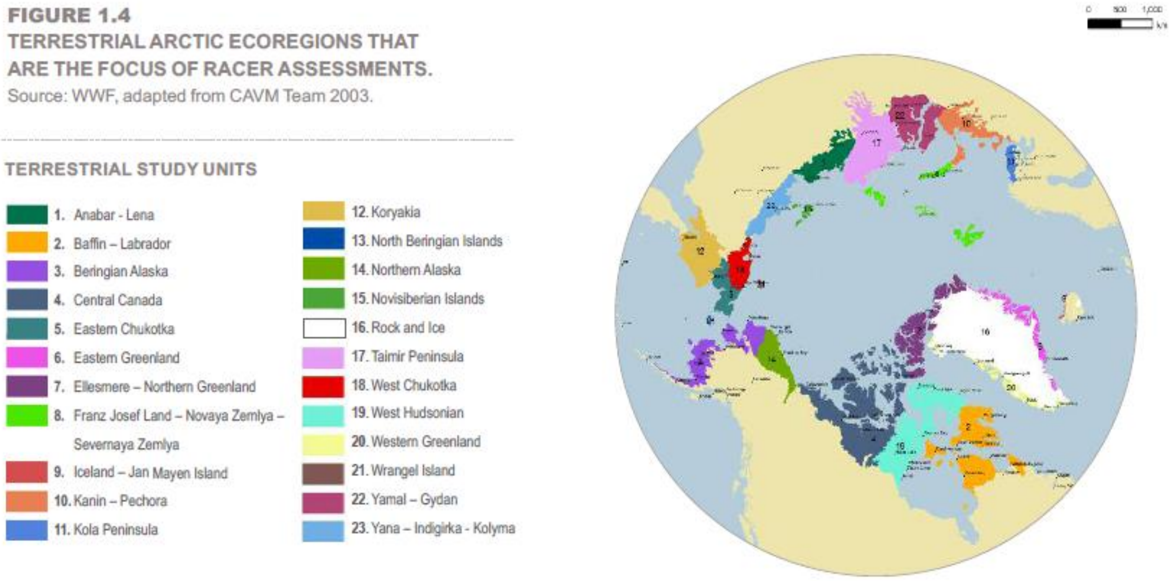
Appendix 1

ECOREGIONS

The Arctic is home to 50 representative ecoregions that reflect the wide range of unique ecosystems and varieties of life found throughout the far north. These regions are distinguished and located on a map using two broad biogeographic ecological classification methods: the Circumpolar Arctic Vegetation Map (CAVM team 2003; Walker et al. 2005) for regions on land and, at sea, the Marine Ecoregions of the World project (Spalding et al. 2007) (Fig. Ap1).

CAVM classifies the variation in plant species groups and communities found in clearly recognizable regions across the Arctic. Although many plants occur throughout the circumpolar north, variation in other species groups reflects the Arctic's diverse glacial histories, topography, and other factors that may have isolated plant populations and contributed to regional differences. Importantly, the CAVM classes also fall into categorical distinctions according to regional differences in the soil type, soil moisture, and temperature.

At sea, ecoregions are classified based on distinctions described by the recent Marine Ecoregions of the World (MEOW) project. The team of international researchers involved in MEOW used recognizable species groups of both plants and animals to make regional distinctions. Marine ecoregions are defined as "areas of relatively homogeneous species composition that clearly differ in this regard from adjacent systems." These identifiable species groupings are likely the consequence of characteristics in the seascape that encourage biological isolation and difference, such as seafloor mountains and canyons, temperature, ice, currents, upwelling, or coastal complexity (Spalding et al. 2007).



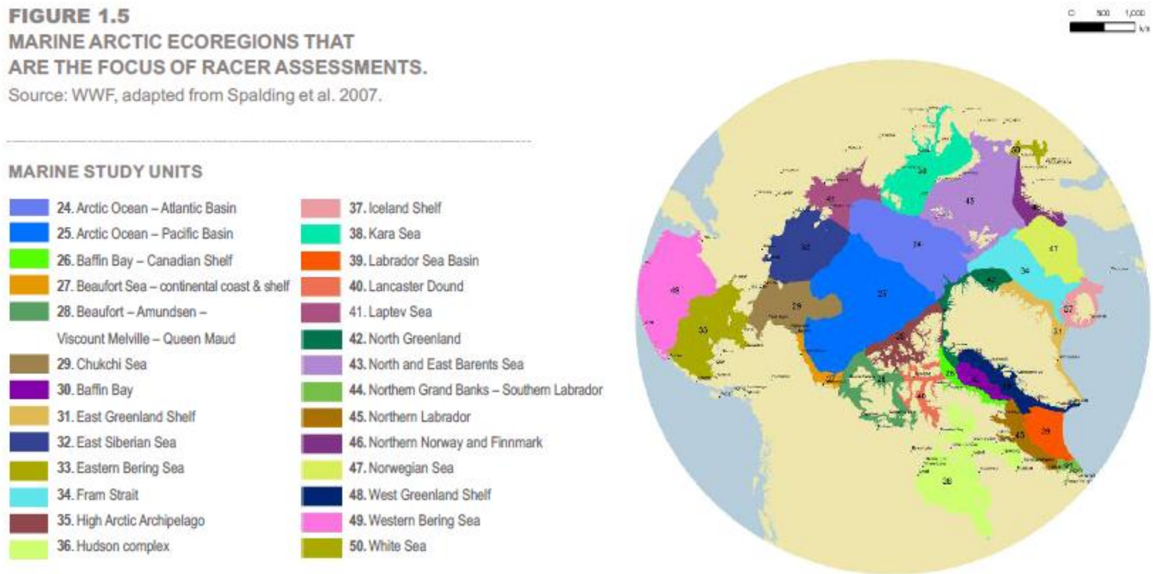


Fig. Ap1. Terrestrial and marine ecoregions that are the focus of RACER assessments. Source RACER: Rapid Assessment of Circum-Arctic Ecosystem Resilience – handbook, p. 18-19 (Christie and Sommerkorn 2012).

Appendix 2

BIODIVERSITY

Primary production

Three sources contribute to total primary production in Arctic regions: phytoplankton, ice algae embedded in fast or drift ice, and benthic algae. The relative importance of the three sources is likely to vary geographically with depth and extent of ice cover. Phytoplankton is contributing the most to total primary production, however the contribution from ice algae are locally important (Boertmann and Mosbech 2011).

The spring bloom in Greenland has its onset in the open water area in southern Greenland before it moves northwards. North of the open water area the primary production starts under the sea ice but the actual spring bloom depends upon the retraction of the ice. The species composition of the phytoplankton changes throughout the season. At the onset of the spring bloom it is dominated by the diatoms *Nitzschia*, *Thalassiosira*, *Navicula*, *Fragilaria* and *Coscinodiscus* whereas minor species such as *Phaeocystis*, *Chaethoserus, Ceratium* and the dino- and nanoflagellate will take over after the spring bloom (Jensen 2003).

Zooplankton

The zooplankton are the secondary producers, they feed on the primary producers and are themselves food for higher organism in the pelagic ecosystem. Zooplankton includes uni- and multicellular organisms that can be grouped into heterotrophic micro- and macroorganisms. The heterotrophic microorganisms consists e.g. of bacteria and protozoa's, whereas the macroorganisms consists of e.g. crustaceans and jellyfish. The copepods are the most dominant of the zooplankton in the West Greenland Shelf ecoregion and make up the majority of the zooplankton biomass (86%). They graze on the phytoplankton and are of great importance for the carbon cycling. The genus *Calanus* are with no comparison the largest group consisting of 84% of the copepods. It is thus one of the most important animal groups in the Arctic regions and is a key group in the food chain (Jensen 2003). Highest abundances of *Calanus* are found at the fishing banks along the West Greenland coast. It is an important food item for fish larvae, benthic animals, marine birds and marine mammals (Boertmann and Mosbech 2011, Merkel et al. 2012). The two Arctic species *Calanus hyperboreus* and *Calanus glacialis* are adapted to the cold waters of the Arctic regions while a third species, er *Calanus finmarchicus*, is a northatlantic species adapted to warmer temperatures. The two former species contain large amounts of fat which are important for the species higher in the food web feeding on Calanus (Grenvald et al. 2012).

Benthos

The benthic invertebrates can be divided into three groups: the infauna that is buried in the sea floor e.g. worms and clams, epifauna that lives on the sea floor e.g. anemones, barnacles and northern shrimp, and interstitial fauna that live in the sand e.g. kinorhyncha and loricifera (Jensen 2003).

Information about benthos diversity and distribution in Greenland are sparse. Studies of the Godthåbsfjord and the shelf region from 63-68°N suggest that the West Greenland Shelf ecoregion have a highly heterogeneous substrate and that the associated benthic community is dense and diverse compared to other Arctic areas (Anon 1978, Sejr et al. 2010). It has been estimated that 90% of the 5000 invertebrate species present in the Arctic live on the sea floor and an estimated 25% of all the species present in Greenland (including terrestrial flora and fauna) are marine benthos (Boertmann and Mosbech 2011). Furthermore, the benthic habitats in Greenland are considered to play a key role in the marine food web since they provide an important food source for fish, seabirds and marine mammals. Benthos in the Arctic generally has long life spans compared to similar species at more southern latitudes. Changes in these communities happen very slowly and as recovery is prolonged, they are exceptionally vulnerable if disturbed (Boertmann and Mosbech 2011). The most important areas in relation to marine benthos is expected to be in shallow waters as well as in areas seldom affected by sea ice and thus with a high annual production of phytoplankton (Merkel et al. 2012).

Benthic diversity often decline significantly along a shelf-slope-basin gradient. In addition to depth, other factors such as sediment heterogeneity, disturbance, food availability, geographical setting, sea-ice cover, particle load from land and hydrographical regimes also influence benthic diversity and species composition (Boertmann and Mosbech 2011).

There are three commercially relevant species associated with the benthic community in the West Greenland Shelf ecoregion region: the northern shrimp, the snow crap (*Chionoecetes opilio*), and the scallop (*Chlamys islandica*). Northern shrimp is a key species in the West Greenland marine ecosystem as well as for the local economy, and it is widespread throughout the ecoregion. Northern shrimp feeds on pelagic crustaceans, benthos and dead organic material at the sea floor and in turn it is fed upon by fishes, birds and whales. It lives at depths ranging from 9 - 1450 m but is mostly found between 100 - 600 m. In recent years the shrimps have moved northwards and highest abundances are now found north of 67°N (Ziemer et al. 2010). The fishery for northern shrimp in Greenland is extensive and it is the most economically important (Hammeken and Kingsley 2010, Boertmann and Mosbech 2011, Merkel et al. 2012).

The snow crab is present along the west coast of Greenland between 60-74°N. Adult snow crabs live on the sea floor where they prey on e.g. fish, clams, and worms. Commercial fisheries for snow crabs are mainly occurring from Paamiut (60°N) to Disko Bay (71°N). The conservation status of the snow crab in Greenlandic waters is critical due to years of extensive fisheries (Burmeister 2010).

The scallop is present along the west coast of Greenland at depths between 20 – 80 m. They grow on high current locations with hard substrates, sand, gravel or rocks (Jensen, 2003). Scallops are caught at a number of smaller locations along the coast, mainly in the Nuuk-Godthåbsfjord area (64°N), south of Kangaatsiaq (68°N), at Disko Island (70°N) and south of Upernavik (71°N) (Jensen 2003, NunaGIS 2012).

Benthic macrophytes

In general, there is a lack of data on macro algal biomass, production, species specific coverage and associated fauna for the West Greenland ecoregion.

A relatively dense flora can be found until 20-30 meters depth, but macro algae may occur as deep as 50 meters (Merkel et al. 2012). The marine macro algae are found along shorelines with hard and stable substratum, such as stones, boulders and rocky coast. The most important environmental conditions for the macro algal flora in the more northerly parts of the West Greenland ecoregion are the low temperatures, strong seasonal changing light regime and ice cover throughout a large part of the year. The littoral- and sublittoral canopy of macro algae is important for higher trophic levels of the food web by providing substrate for sessile animals, shelter from predation, protection against wave action, currents and desiccation or directly as a food source. Climate change will probably affect the macro algal vegetation by especially longer season with open water, and thereby a longer season for growth. This coupled with oceanic warming therefore may change many species distribution towards north. On the other hand, melting of glaciers leads to increased runoff of freshwater with suspended material, which results in lowered salinity and increasing water turbidity, and which again may have a negative impact on the local macro algae vegetation (Boertmann and Mosbech 2011).

A list of the marine algae of Greenland found between 71-78° N can be viewed in Table 1 in Boertmann and Mosbech 2011.

Fish

The West Greenland Shelf waters are characterized by a high number of fish species, many of which are exploited by humans. Four species/genus of commercial and/or ecological importance are described here. These are the cod, the halibut, the capelin, and the sandeel.

The Atlantic cod is, due to its large size, the most commercially important species of cod in the ecoregion. It lives primarily off the West Greenland coast from 60-70°N and breeds in the fjords. The Atlantic cod is rated vulnerable on the IUCN red list which is primarily ascribed an extensive fishery. Other cod species in the area include the polar cod (*Boreogadus saida*) and the Arctic cod (*Arctogadus glacialis*), and where the polar cod can be found along the coastline, the Arctic cod is confined to the Melville Bay area (Jensen 2003).

The Greenland halibut is a slow growing deep-water flatfish present along the entire coast of the West Greenland Shelf ecoregion. Highest abundances are found at Fyllas Bank, Store Hellefiske Bank and the Disko Bay area. The Greenland halibut spawns in the southern Davis Strait area, and the eggs are carried with the currents northwards where they settle as larvae. The lifecycle of the Greenland halibut is poorly known. Juveniles mainly feed on crustaceans and smaller benthic invertebrates, whereas adults prey on a variety of fish species in the pelagic layers. Inshore and offshore fisheries of Greenland halibut is of key importance for the Greenlandic community, both as a source of food and as a commercially exported product (Boertmann and Mosbech 2011, Merkel et al. 2012).

The capelin is present from Cape Farewell (60°N) to the Uummanaq area (73°N). They live in the upper pelagic layers from 0-150 m in depth and migrate in large schools to the fjords to spawn in April-

June. The capelin belongs to the smelt family which, like the salmon, has the ability to store fat in the body tissue and in that way the capelin serves as an important link for transfer of energy from lower to higher trophic levels. Capelin mainly feeds on copepods, krill and parathemisto (a kind of seaweed flea) whereas harp seals (*Pagophilus groenlandica*), whales and various seabirds prey on capelin and it is the single most important food item for the Atlantic cod. Capelin is also of economic importance, and is used as animal fodder, for fish oil production, and its roe is sold as "masago" which is highly valued in the sushi kitchen. Traditionally, it is an important food source in the summer months and is also used for drying in order to store it as sledge dog fodder (Boertmann and Mosbech 2011, Merkel et al. 2012).

There are two species of sandeel present within the ecoregion: lesser sandeel (*Ammodytes marinus*) and northern sandeel (*Ammodytes dubius*). Highest abundances are found from Fyllas Bank and northwards to Store Hellefiske Bank. Sandeels are bentho-pelagic fish which spend most of their time buried in sandy sediments. They feed at night mainly on copepods. They are ecologically important as a food item for a variety of larger fish species, marine mammals, and sea birds. It is not commercially exploited (Boertmann and Mosbech, 2011, Merkel et al. 2012).

Marine mammals

Polar bears live primarily on the sea ice and are mainly present in the ecoregion during winter in areas covered by the West ice. Polar bears found in the ecoregion mainly belong to the Baffin Bay sub-population that spends their summer on Baffin Island in Canada. Some bears stay throughout the summer in Greenland in the fast ice in the Melville Bay area (Boertmann and Mosbech 2011).

Five species of seals are found along the coast of West Greenland. These are the harp seal, ringed seal (*Pusa hispida*), hooded seal (*Cystophora cristata*), bearded seal and harbour seal. The grey seal (*Halichoerus grypus*) is only a rare visitor. Except for the harbor seal and the grey seal, the Greenlandic seals depend on sea ice for e.g. reproduction, foraging and moulting. The ringed seal is the primary food item for polar bears (Boertmann and Mosbech 2011, Merkel et al. 2012). The walrus are present in the ecoregion between 66 – 70°N. They are benthic feeders and forage mainly on mussels on the shallow water banks near the coast (Merkel et al. 2012).

Several species of whales visit the ecoregion including both baleen and toothed whales (Table Ap2). Three whales remains in the Arctic areas throughout the year. These are the bowhead whale, the narwhal and the beluga whale. Other species of whales visit the West Greenland Shelf ecoregion in the summer months where they feed on a variety of fish and plankton.

Many of these whale species, e.g. narwhal and beluga whale, are hunted by man and are considered an important cultural and economic resource (Boertmann and Mosbech 2011, Merkel et al. 2012).

Seabirds

Seabirds are numerous in the West Greenland ecoregion and constitute a very important ecosystem component. A high number of birds breed in the districts of Disko Bay, Upernavik and Qaanaaq during the ice free period (Boertmann and Mosbech 2011). During October-May the open water area from

62-67° N is an important winter quarter. Here the most numerous birds are common eider, king eider, thick-billed murre and species of gulls (*Laridae*). Local seabird hunting is a valued part-time activity and is considered as being highly culturally important. The most commonly hunted species are common eider, thick-billed murre, and black-legged kittiwake (*Rissa tridactyla*) (Merkel et al. 2012).

Baleen whales	**English name**	**Latin name**
	Bowhead whale	*Balaena mysticetus*
	Fin whale	*Balaenoptera physalus*
	Minke Whale	*Balaenoptera acutorostrata*
	Humpback whale	*Megaptera novaeangliae*
	Sei Whale	*Balaenoptera borealis*
	Blue whale	*Balaenoptera musculus*
Toothed whales	Narwhal	*Monodon monoceros*
	Beluga whale	*Delphinapterus leucas*
	Harbour porpoises	*Phocoena phocoena*
	Killer whale	*Orcinus orca*
	Sperm whale	*Physeter macrocephalus*
	Longfinned pilot whale	*Globicephala melas*
	White-beaked dolphin	*Lagenorhynchus albirostris*
	Northern bottlenose whale	*Hyperoodon ampullatus*

Table Ap2. Baleen and toothed whales found in Greenlandic waters. The bowhead whale, narwhal and beluga whale are endemic to the Arctic regions.

Appendix 3

REMOTE SENSING OF PRIMARY PRODUCTIVITY

Abstract

A 13-years time series of SeaWiFS imagery was employed to estimate the primary productivity (PP) rates taking place in the Arctic Ocean and its surrounding seas. The objective is to identify regions of biological interest and to assess how they are responding to the recent climate changes. A semi-analytic PP model ingesting satellite observations of cloud cover, sea ice concentration (SIC) and ocean inherent optical properties as determined ocean color (OC) measurements were employed to assess PP in both phytoplankton-dominated and colored dissolved organic matter (CDOM)-dominated waters. A preliminary validation suggested that the model produced PP rates within the range observed in situ over the arctic interior shelves, but may be underestimating PP in other regions. Unlike the previous satellite-based PP estimates, our model shows realistic estimates over the continental shelves supporting the necessity of using semi-analytical approaches to estimate both chlorophyll-a (CHL) concentration and diffuse attenuation coefficient to minimize the CDOM contamination. Hot-spots of high productivity, identified at the ecoregional scale, were found in areas influenced by large arctic rivers, in the marginal ice zone, at shelf breaks or in straits. A statistically significant trend in the temporal variation of PP was found at the pan-arctic scale (5.05 Tg C y-1). To explain the sources of this variation, the PP model was run several times with different input parameters set as constant. It was found that the main parameter that controlled the temporal trend reported above was the changes in OC (2.88 Tg C y-1). The second most important parameter (1.1 Tg C y-1) was SIC which incorporates light availability for photosynthesis through measurements of the shrinking of the sea ice cover. The ecoregional trends analysis indicates that both type of changes (OC versus SIC) operate in different proportions among regions. In general, increasing light availability explained most of the increase in PP over the arctic interior shelves, while changes in biomass are responsible for the increase in PP in permanently open waters. Although positive trends were observed in most ecoregions, significant negative trends were also observed in regions that are normally recognized for their great biological importance. This is the case with the North Water Polynya in the Canadian Arctic where the decrease in PP reaches as much as 5.6 gC m-2 y-1, corresponding to a >100% relative decrease in PP over 13 years. These results suggest that major environmental changes, yet not well understood, can locally have negative impacts on the marine ecosystem productivity. Finally, a more detailed analysis at ecoregional scale was exemplified at two ecoregions : the Beaufort Sea - continental coast and shelf and the Laptev sea.

Abstract from: Rapid assessment of the marine primary productivity trends in the Arctic Ocean and its surrounding seas. ACTUS inc. and WWF 2011. Link to full report: http://awsassets.panda.org/downloads/rapid_assessment_of_the_marine_primary_productivity_trends_in_the_arctic_ocean_and_its_s.pdf

Appendix 4

PRIMARY PRODUCTION AT THE WEST GREENLAND SHELF

Primary production (PP) at the West Greenland Shelf. Figs. Ap4a-b from 'Rapid assessment of the marine primary productivity trends in the Arctic Ocean and its surrounding seas'. ACTUS inc. and WWF, 2011.

West Greenland Shelf
Area study unit (1000 square km): 442.8
Area image within study unit (1000 square km): 362
Percentage covered: 81.7%
Mean Yearly Primary Production (gC/m^2/Year): 32.06
90th percentile of Primary Production (gC/m^2/Year): 54.79
Total Yearly Primary Production (TgC/Year): 11.61
Total Yearly Primary Production of 90th percentile(TgC/Year): 2.2
Part of total Primary Production by 90th percentile: 19%

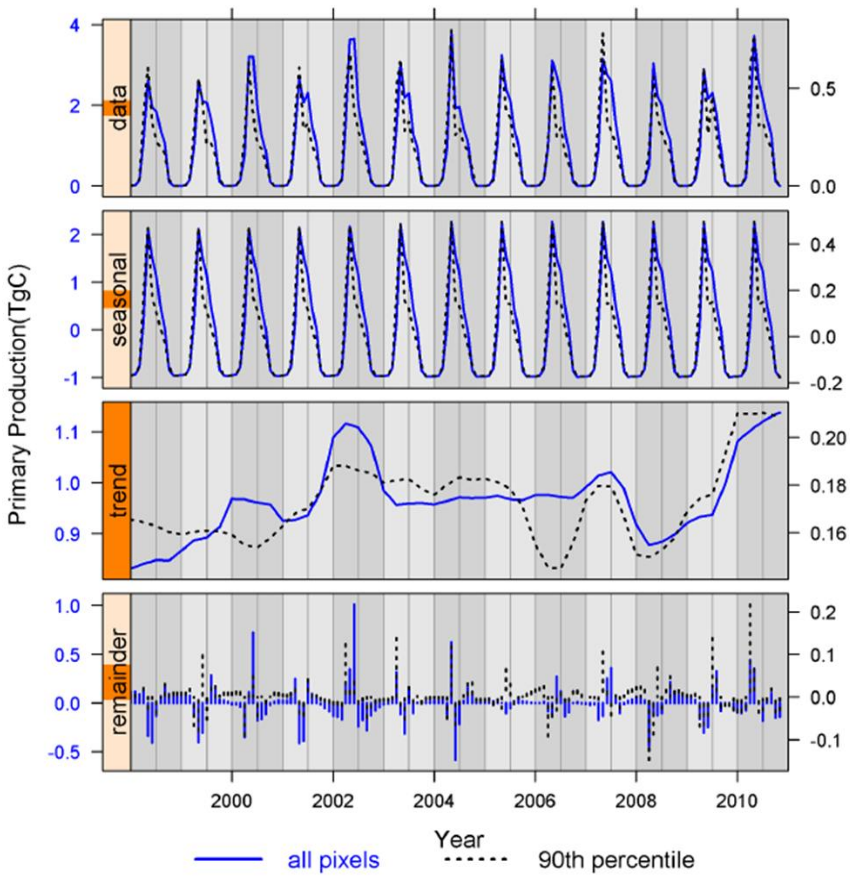


Fig. Ap4a. Monthly decomposed total PP time series of the West Greenland Shelf for all pixels (blue) and the 10% most productive pixels (black).

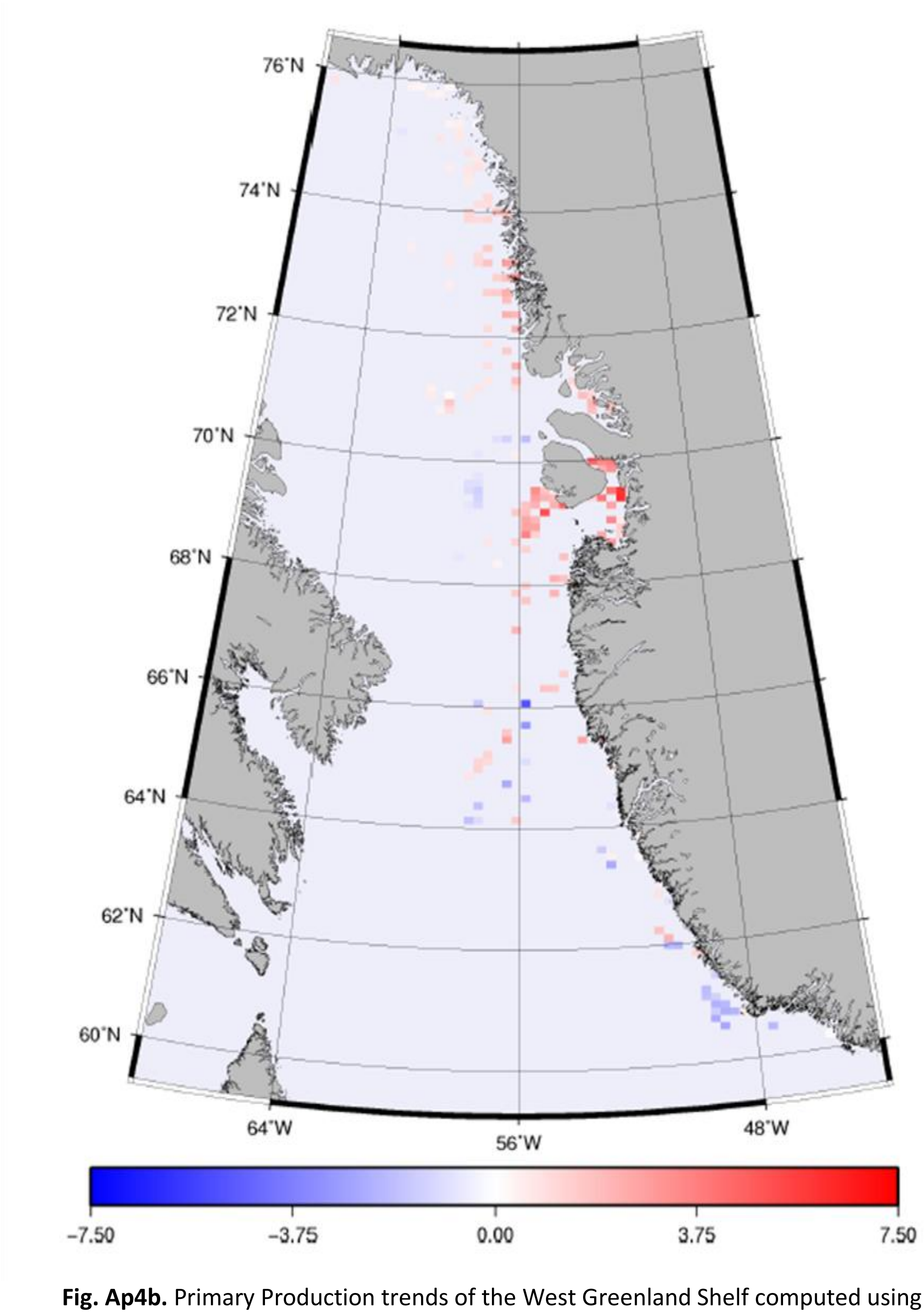
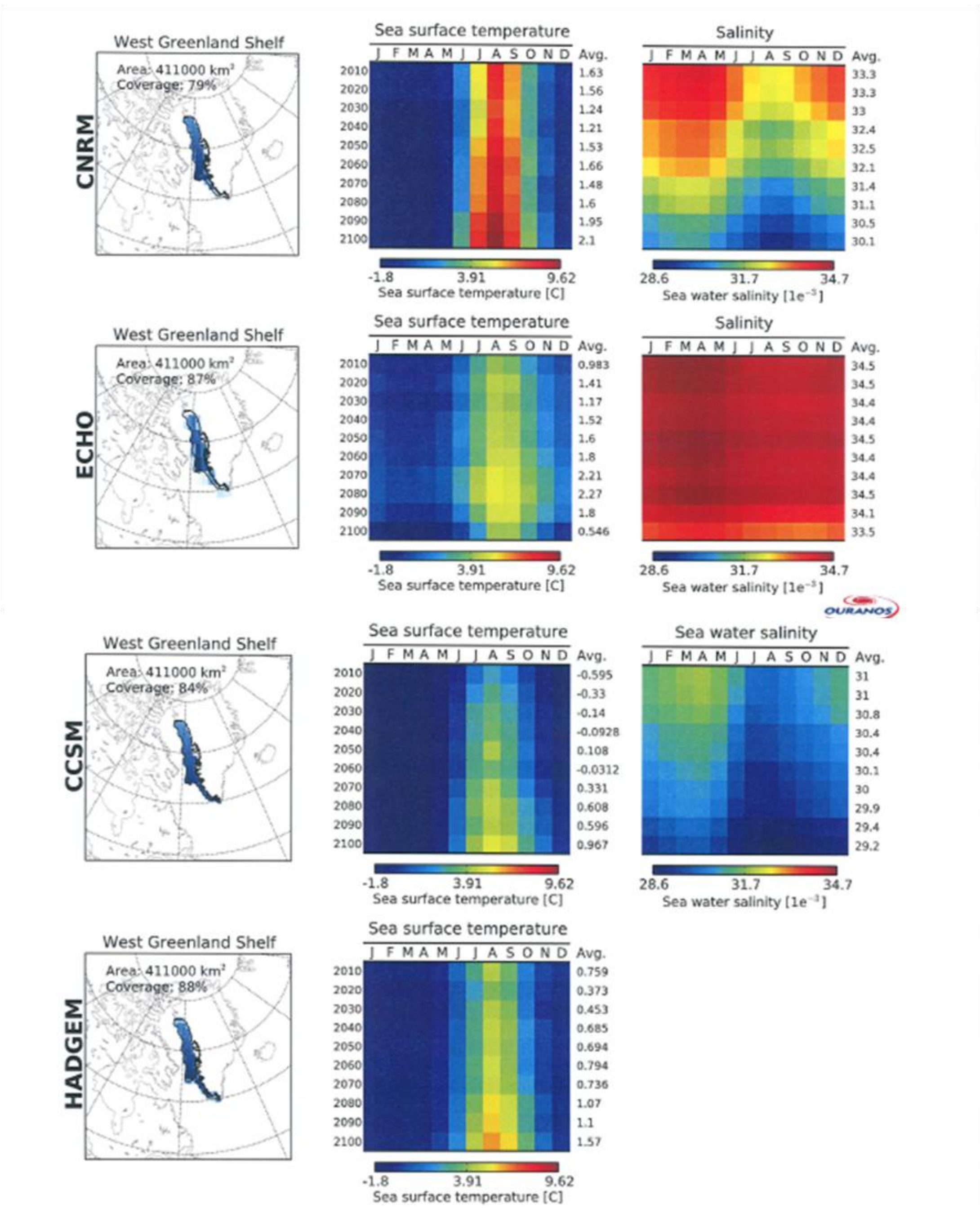


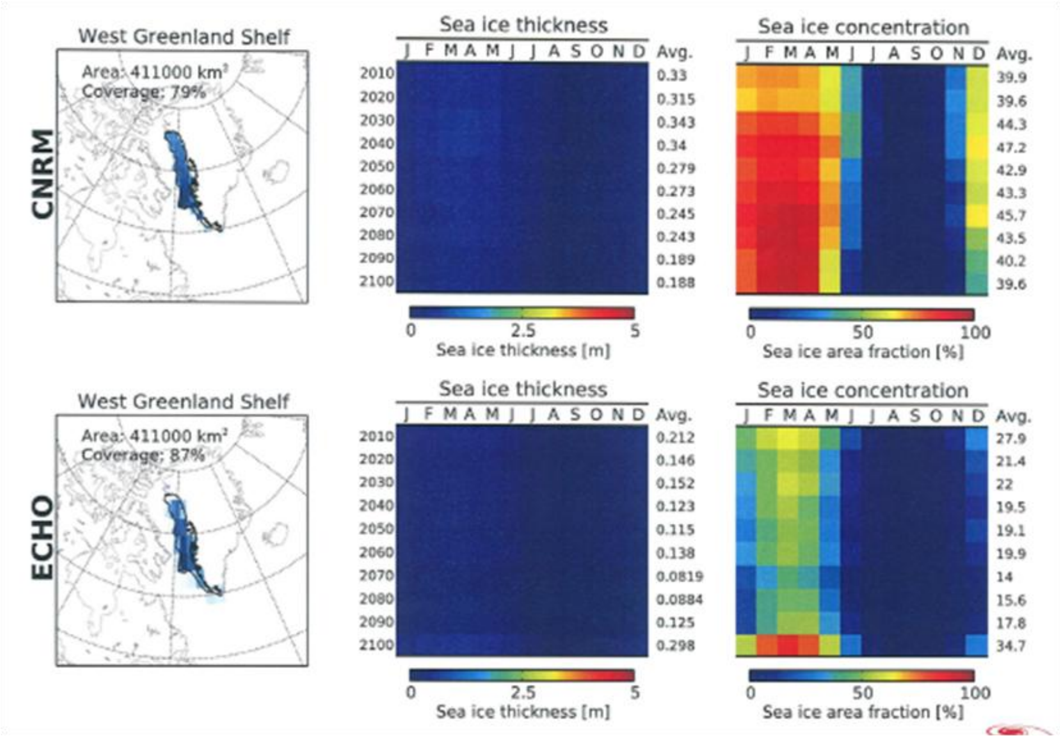
Fig. Ap4b. Primary Production trends of the West Greenland Shelf computed using TSA (The trend estimator). Only pixels with significant trend (90% confidence level) are plotted.

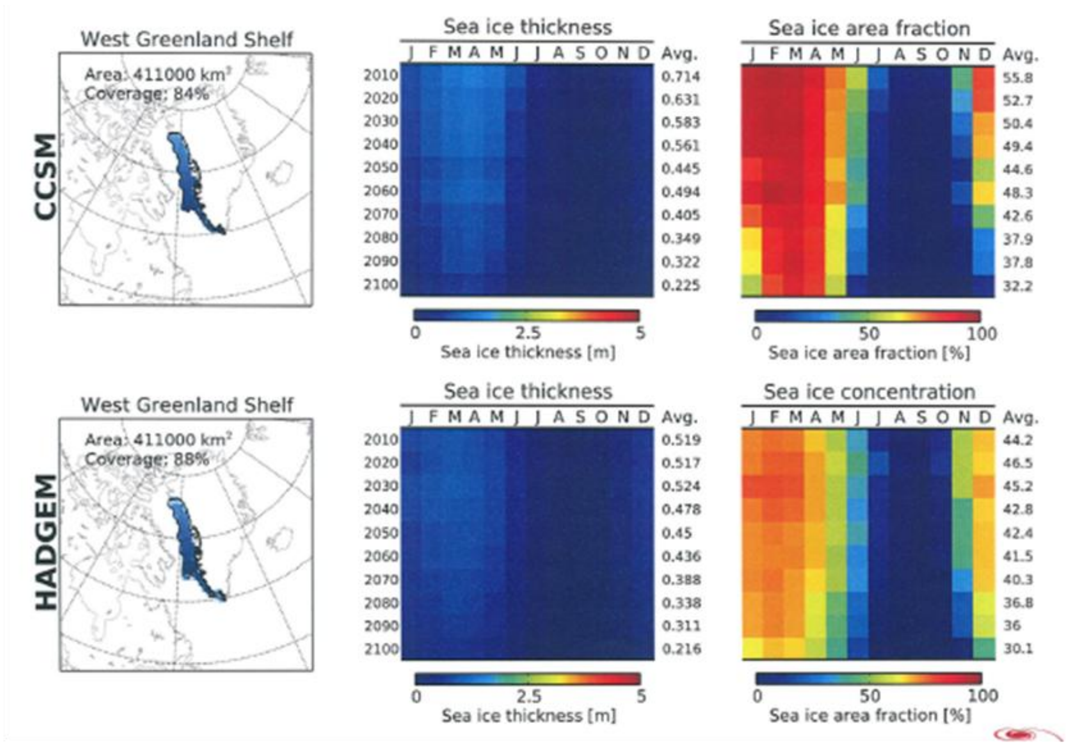
Appendix 5

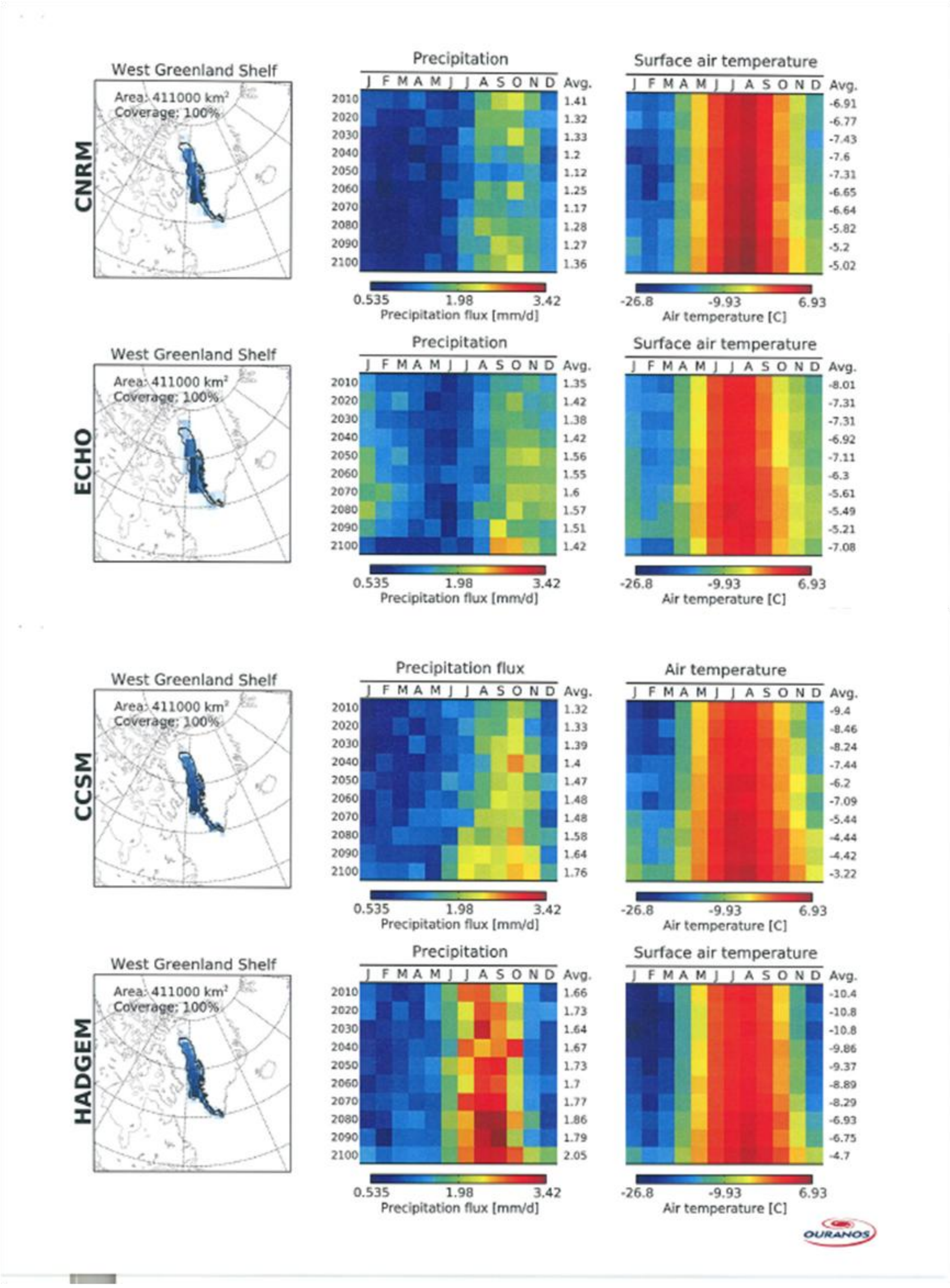
GENERAL CIRCULATION MODELS (GCM'S) FOR THE WEST GREENLAND SHELF

Projections for sea surface temperature, salinity, sea ice thickness, sea ice concentration, precipitation and air temperature based on General Circulation models (GCM's) for the West Greenland Shelf ecoregion through to the 21st century.




CNRM
West Greenland Shelf
Area: 411000 km²
Coverage: 79%
Sea ice thickness
J F M A M J J A S O N D Avg.
2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
0.33 0.315 0.343 0.34 0.279 0.273 0.245 0.243 0.189 0.188
0 2.5 5
Sea ice thickness [m]
Sea ice concentration
39.9 39.6 44.3 47.2 42.9 43.3 45.7 43.5 40.2 39.6
0 50 100
Sea ice area fraction [%]
ECHO
West Greenland Shelf
Area: 411000 km²
Coverage: 87%
Sea ice thickness
0.212 0.146 0.152 0.123 0.115 0.138 0.0819 0.0884 0.125 0.298
Sea ice thickness [m]
Sea ice concentration
27.9 21.4 22 19.5 19.1 19.9 14 15.6 17.8 34.7
Sea ice area fraction [%]


CCSM
West Greenland Shelf
Area: 411000 km²
Coverage: 84%
Sea ice thickness
J F M A M J J A S O N D Avg.
2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
0.714 0.631 0.583 0.561 0.445 0.494 0.405 0.349 0.322 0.225
0 2.5 5
Sea ice thickness [m]
Sea ice area fraction
55.8 52.7 50.4 49.4 44.6 48.3 42.6 37.9 37.8 32.2
0 50 100
Sea ice area fraction [%]
HADGEM
West Greenland Shelf
Area: 411000 km²
Coverage: 88%
Sea ice thickness
0.519 0.517 0.524 0.478 0.45 0.436 0.388 0.338 0.311 0.216
Sea ice thickness [m]
Sea ice concentration
44.2 46.5 45.2 42.8 42.4 41.5 40.3 36.8 36 30.1
Sea ice area fraction [%]



Trend: Sea surface temperature – Increasing; Salinity – Decreasing; Sea ice thickness – Status qou/slightly decreasing; Sea ice concentration – Decreasing; Precipitation – Increasing; Surface air temperature – Increasing.