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Rapid Assessment of Circum-Arctic Ecosystem Resilience (RACER)

WESTERN GREENLAND

WWF Report



Ilulissat, West Greenland. Photo: Eva Garde

WWF – Denmark, May 2014

Report

Rapid Assessment of Circum-Arctic Ecosystem Resilience (RACER). Western Greenland.

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Front page photo

Ilulissat, West Greenland. Photo by Eva Garde.

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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 terrestrial West Greenland, a region we call the Western Greenland ecoregion. This ecoregion stretches from the southern tip of Greenland to the most northerly locations in the high Arctic. The region is home to a variety of flora and fauna species including endemic Arctic species as well as more temperate species. The Greenlandic people, inhabiting the region, are dependent on the living resources harvested here. They fish in lakes and streams, hunt near towns and settlements or in more remote locations far from the beaten track, and collect edible wild plants and berries. These traditional activities contribute significantly to the income of the many families living in small and larger settlements in Western Greenland. Today, Greenland faces new developments as changes in climate allows for new industrial activities, e.g. mineral extraction. Often these developmental activities are placed in areas essential for the Arctic wildlife and near traditional hunting and fishing grounds, potentially creating conflicts of interests.

This report points at ten areas within the terrestrial Western Greenland ecoregion that show above-average productivity and diversity. We hope with this report to put focus on these ten terrestrial areas in Western Greenland and that the results will be useful as a contribution to designation of important nature areas in Greenland. Relevant issues to discuss include:

- During the course of data collection and analyses for this report we realized that there is a general knowledge-gap regarding the terrestrial ecosystems in Greenland. We therefore suggest further scientific research in terrestrial biological and physical conditions as well as mapping of traditional land-use that can be used in designation and conservation of important land areas in Western Greenland. The ten designated areas in this report can be used as input and inspiration for selection of such important land areas.
- Improved public involvement in mineral resource activities and mining projects.
- Long-term management plans that ensure sustainable use of the land and its resources.
- Establishment of zones without any mining activities within designated conservation areas.

Gitte Seeberg, CEO WWF Denmark

ENGLISH ABSTRACT

The Western Greenland ecoregion is the stretch of land from the tip of Greenland in the south at Kap Farvel (60°N) to the far north of Greenland at Inglefield Land (78°N). It lies in between the Greenland Ice Cap and the marine West Greenland Shelf and covers more than 2000 km from low Arctic areas in the south to High Arctic areas at the top of the world. The region spans three climatic zones: subarctic, low Arctic, and high Arctic, and large differences in climate, soil conditions, and ecosystems are found within the region. Also, Greenland is intersected by the Arctic Circle why there is considerable variation in day length and light conditions across the region. Primary productivity on land in Greenland is limited by low summer temperatures and a short growing season. Across the ecoregion as well as locally there are large differences in climate and topography and the magnitude of net primary productivity and distribution of flora varies greatly as a consequence.

The ecoregion is home to a variety of fish, birds, and mammals, from annually migrating species to indigenous species. Among the terrestrial mammals, indigenous species include e.g. caribou (*Rangifer tarandus*), Arctic hare (*Lepus arcticus*) and Arctic fox (*Alopex lagopus*), whereas the musk ox (*Ovibos moschatus*) originally were introduced from East Greenland to West Greenland, where it now thrives at various places throughout the region.

Inuit peoples have inhabited West Greenland for millennia, where they have lived off the land and sea. In recent years, there have been a growing interest in industrial developments and mining activities for iron, gemstone, gold, and rare earth minerals are either up-and-running or about to become a reality. Also recreational human activity on land and on sea is increasing. These new human activities pose a potential risk for the vulnerable Arctic habitats, the sensitive vegetation, some of the animal populations, and the traditional way of life in Greenland.

The present RACER report of the Western Greenland ecoregion involves analysis of satellite remote sensing data, relevant scientific literature and reports, and expert evaluation. The data used reflects landscape heterogeneity, biodiversity, and the location of local communities. Ten terrestrial key features have been identified based on their medium or high levels of productivity, their varied topography/landscape heterogeneity, and/or more direct evidence of high biodiversity. As such the ten key features represent sites of potentially conservation importance. The ten designated key features are: 1. Inglefield Land; 2. Qaanaaq area/Inglefield Bredning; 3. The Northwest Coastal Zone; 4. Part of Svartenhuk peninsula, Nussuaq peninsula, Disko Island; 5. Coastal land area between Nordre Strømfjord and Nordre Isortoq fjord; 6. Paamiut area; 7. Inner Nordre Strømfjord area; 8. Inner Godthåbsfjord area; 9. Grønnedal area; and 10. South Greenland. An evaluation of the likelihood that key features will continue to contribute to region-wide resilience for the next century was not included in this report as it was concluded that this was not feasible due to insufficient data and a general knowledge-gap regarding the terrestrial ecosystems in Greenland.

The designated key features and the results within this report are intended to inform discussions about the best management approaches to safeguard the productivity and diversity of these unique places in Western Greenland.

IMAQARNERSIUGAQ

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RESUMÉ

Den terrestriske Vestgrønlandske økoregion er landstrækningen fra spidsen af Grønland i syd ved Kap Farvel (60°N) til den nordligste del af Grønland ved Inglefield Land (78°N). Denne landstrækning ligger mellem Indlandsisen og den marine Vestgrønlandske kontinentalsokkel økoregion og dækker et område på mere end 2000 km fra lav arktiske egne syd til høj arktiske egne i nord. Regionen dækker tre klimazoner: sub Arktis, lav Arktis og høj Arktis, og på tværs af regionen findes store forskelle i klima, jordbundsforhold og økosystemer. Polarcirklen gennemskærer Grønland ved 66°N, og der er således stor variation i dagslængde og lysforhold indenfor regionen. Den terrestriske primærproduktivitet i Grønland er begrænset af lave sommertemperaturer og en kort vækstsæson. På grund af de store regionale, såvel som lokale, forskelle i klima og topografi er graden af netto primærproduktionen og fordelingen af vegetationen over regionen varierende.

Vestgrønland er hjemsted for mange forskellige arter af fisk, fugle og pattedyr, hvoraf nogle migrerer til området hvert år fra sydligere egne og andre er oprindelige, hjemmehørende arter. Blandt landpattedyrene, omfatter hjemmehørende arter for eksempel rensdyr (*Rangifer tarandus*), snehare (*Lepus arcticus*) og polarræv (*Alopex lagopus*), mens moskusoksen (*Ovibos moschatus*) oprindeligt blev introduceret fra Østgrønland til Vestgrønland, hvor den nu trives flere steder i regionen.

Inuit har været bosat i Vestgrønland i årtusinder, hvor de har ernæret sig af de levende ressourcer på land og til vands. I de senere år har der i Grønland været en stigende interesse indenfor industriel udvikling og minedrift efter jern, ædelsten, guld og sjældne jordarter er allerede en realitet eller er ved at blive det. Også rekreative aktiviteter på land og til vands er stigende. Alle disse nye tiltag udgør en potentiel risiko for de sårbare arktiske økosystemer og den arktiske vegetation, for nogle af dyrebestandene og for den traditionelle levemåde i Grønland.

I denne rapport er anvendt analyser af satellitdata, relevant videnskabelig litteratur og rapporter samt ekspertvurderinger til udpegelsen af ti områder indenfor den Vestgrønlandske økoregion. De anvendte data afspejler heterogenitet i landskabet, biodiversitet, og placering af lokalsamfund. De ti terrestriske udpegede områder er blevet identificeret ud fra deres medium til høje produktivitet, deres varierede landskab heterogenitet/topografi, og/eller høj biodiversitet. De ti udpegede områder er på denne baggrund potentielt bevaringsværdige. Områderne er: 1. Inglefield Land; 2. Qaanaaq området/Inglefield Bredning; 3. Den nordvestlige kystnære zone; 4. Dele af Svartenhuk, Nuussuaq, og Disko; 5. Det kystnære landområde mellem Nordre Strømfjord og Nordre Isortoq fjord; 6. Paamiut området; 7. Indlandsområdet ved Nordre Strømfjord; 8. Indlandsområdet ved Godthåbsfjord; 9. Grønne dal området; og 10. Sydgrønland. En evaluering af sandsynligheden for, at de ti områder fortsat vil bidrage til hele regionens modstandskraft, trods klimaændringer, er ikke inkluderet i rapporten, da det blev konkluderet, at dette ikke var muligt på grund af et utilstrækkeligt datagrundlag og en generel mangel på viden om de terrestriske økosystemer i Grønland.

De udpegede områder samt øvrige resultater i denne rapport kan bruges som grundlag for diskussioner om forvaltningstiltag for at sikre den produktivitet og diversitet som findes på disse unikke steder i det vestlige Grønland.

A TERRESTRIAL STUDY: WESTERN GREENLAND

THE WESTERN GREENLAND ECOREGION is a biologically and geographically varied thin strip of land that lies in between the Greenland Ice Cap and the marine West Greenland Shelf. It stretches more than 2000 km from the low Arctic areas in the south to the High Arctic at the top of the world.

The Greenland Ice Cap covers approximately 80% of Greenland and only a narrow edge of land along the rim of the coast line is ice free. The Western Greenland ecoregion is the stretch of land from the tip of Greenland in the south at Kap Farvel (60° N) to the top of Greenland in the far north (78° N) (Fig. 1; Appendix 1). The largest ice-free land areas in the ecoregion are found between 65-68°N. The coast line is characterized by deep fjords, high mountains and a countless number of islands and skerries. The ecoregion spans three climatic zones: subarctic, low Arctic, and high Arctic, and large differences in climate, soil conditions, and ecosystems are found within the region. Greenland is intersected by the Arctic Circle (66° 33' 39" N), where areas north of the circle have midnight sun for a period in summer and polar darkness in winter. Thus the region experiences considerable variation in day length and light conditions (Jensen 2003).

Generally, primary productivity on land in Greenland is low, limited by low summer temperatures and a short growing season. However, because of large differences in climate and topography/landscape heterogeneity throughout the region, the magnitude of net primary productivity and distribution of vegetation varies greatly across the ecoregion as well as locally. Most land areas have only relatively recently been exposed following ice sheet retreat and pioneer species with low nutrient requirements typically dominate in these areas. In the mid-southern parts of the Western Greenland ecoregion, where the ice cap is smaller and areas have been ice-free for millennia, the diversity of plants is higher (Jensen 2003). The ecoregion is home to a variety of fish, birds, and mammals. Among the anadromous freshwater fish found in rivers and lakes are Atlantic salmon (*Salmo salar*) and Arctic char (*Salvelinus alpinus*) (Appendix 2). Birds of prey includes peregrine falcon (*Falco peregrinus*), gyrfalcon (*Falco rusticolus*), and white-tailed eagle (*Haliaeetus albicilla*). The rock ptarmigan (*Lagopus mutus*) and raven (*Corvus corax*) are found throughout the year in the region, while the arrival of the small snow bunting (*Plectrophenax nivalis*) announces the coming of spring. Indigenous land mammals include caribou (*Rangifer tarandus* spp.), Arctic hare (*Lepus arcticus*), Arctic fox (*Alopex lagopus*), Arctic wolf (*Canis lupus arctos*), and polar bear (*Ursus Maritimus*) that have denning areas in the far north. Muskoxen (*Ovibos moschatus*) were introduced from East Greenland in the 1960's and have thrived at various places in West Greenland ever since. Semi-domestic reindeer were introduced in the last century and through releases or failure of husbandry feral populations now exist in the Qaanaaq area, at the Nuussuaq peninsula and in the Nuuk areas, where they coexist or mix with indigenous caribou (Appendix 2). Reindeer husbandry continues today in the most southern part of the ecoregion.

Humans have inhabited Greenland for millennia, where they have lived off the land and sea. Today, the Inuit population in Greenland is mainly concentrated along the West Greenland coast with a few settlements sparsely located in the North and on the East coast. In Northeast Greenland the world's largest national park is found¹. It was established in 1974 and covers an area of 972.000 km². In

¹ The area is a National Park according to Greenland's own definition but does not meet the IUCN international criteria for National Parks because of, among other things, mining activities in the area. The area is also designated as a UNESCO Biosphere Reserve. <http://naalakkersuisut.gl/da/Naalakkersuisut/Departementer/Natur-og-Miljoe/Naturafdelingen/Nationalparken-i-Nord-og-Oestgroenland>.

recent years, there have been a growing interest in mineral and oil- and gas exploration and exploitation in Greenland and industrial development is expected to intensify significantly in the coming years. Mining activities for iron, gemstone, and rare earth minerals are about to become a reality and several hydro-power projects have been developed and proposed. In addition to this new 'industrial age' in Greenland recreational human activity on the land and on sea is increasing. These new human activities pose a potential risk for the vulnerable Arctic habitats, the sensitive vegetation, some of the animal populations, and the traditional way of life in Greenland.

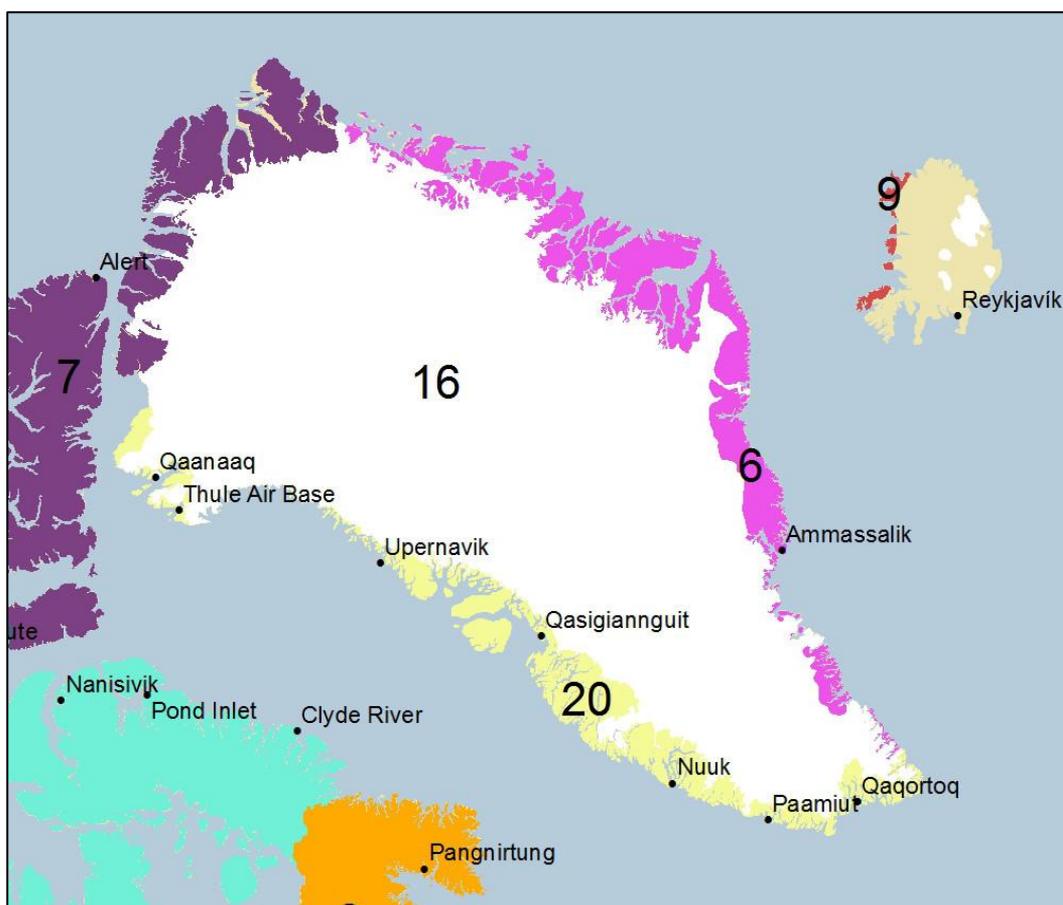


Fig. 1. Terrestrial Arctic ecoregions. The pale yellow area is terrestrial ecoregion T20 – Western Greenland. Source: Adapted from CAVM (Circumpolar Arctic Vegetation Map) TEAM 2003. See also Appendix 1 for more information on the classification of the ecoregions.

KEY FEATURES IMPORTANT FOR RESILIENCE

The present RACER report of the Western Greenland ecoregion involves analysis of satellite remote sensing data (Box 1), relevant scientific literature and reports, and expert evaluation. The data used reflects landscape heterogeneity, biodiversity, and the location of local communities (reflecting traditional land-use and use of natural resources). Ten terrestrial key features have been identified. The ten key features were designated by WWF together with experts into Arctic biology.

Distinguished by their medium or high levels of productivity (Fig. 2), their varied topography/landscape heterogeneity (Fig. 3), and/or high biodiversity, the ten key features represent sites of potentially conservation importance. The key feature map (Fig. 4) is intended to inform discussions about the best management approaches to safeguard the productivity and diversity of these unique places.

Within the RACER method lays an evaluation of the likelihood that key features will continue to contribute to region-wide resilience when 21st century climate change affects the drivers at work in ecologically vital places. Drivers include those susceptible to the impacts of climate change, such as temperature, precipitation, soil moisture, as well as those impervious to climate effects (on a centennial time scale/for the next 100 years), such as topography and soil type. 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 (Appendix 3). However, this evaluation is not included in the report. It was concluded by the experts at a RACER workshop in January 2014 that it was not feasible to obtain reliable assessments of the persistence of key features and their future above-average productivity/diversity based on the available data and the current knowledge of the terrestrial ecosystems in Greenland (see section RACER Expert Workshop, p. 19).

Box 1**Detecting productivity and diversity**

Satellite measures of primary productivity rely on the detection of reflected and absorbed light that reveals concentrations of the pigments involved in plant photosynthesis, chlorophyll, at the earth's surface. On land, the annual amount of biomass produced by plants and plankton, called primary productivity, is determined through an adjusted analysis of the intensity of "greenness" reflected into space by ground vegetation. RACER identifies land areas of high primary productivity – exceptional plant growth – in each bioclimatic (temperature) subzone using the Normalized Difference Vegetation Index (NDVI). The NDVI data reveals areas (at a scale of two-square kilometres) where productivity levels are in the top 25 per cent of productivity for each bioclimatic subzone in each ecoregion (Fig. 2).

To measure biological diversity on land, RACER uses satellite-derived radar measures of landscape topography that reveal its hills, valleys, plains, etc. The richness of different landforms represents a wealth of habitats that can support a larger variety of sets of interacting species through differences in landform effects on available water, nutrients, and heat. Diversity of plants, even within the vegetation classes mapped by the CAVM, is also strongly affected by the richness of topographic landforms within the landscape. RACER uses computer-derived digital elevation models (DEMS) to picture landscape topography from satellite remote data, assessing whether places within an ecoregion show an exceptional variety of landforms packed within a single area (Fig. 3).

Bioclimatic subzones of the Western Greenland ecoregion

Zone 3, mean July temperature 5-7°C

Zone 4, mean July temperature 7-9°C

Zone 5, mean July temperature 9-12°C

Zone 6, non Arctic

Areas of Comparatively High Terrestrial Net Productivity: Study Unit: Terrestrial 20, Western Greenland

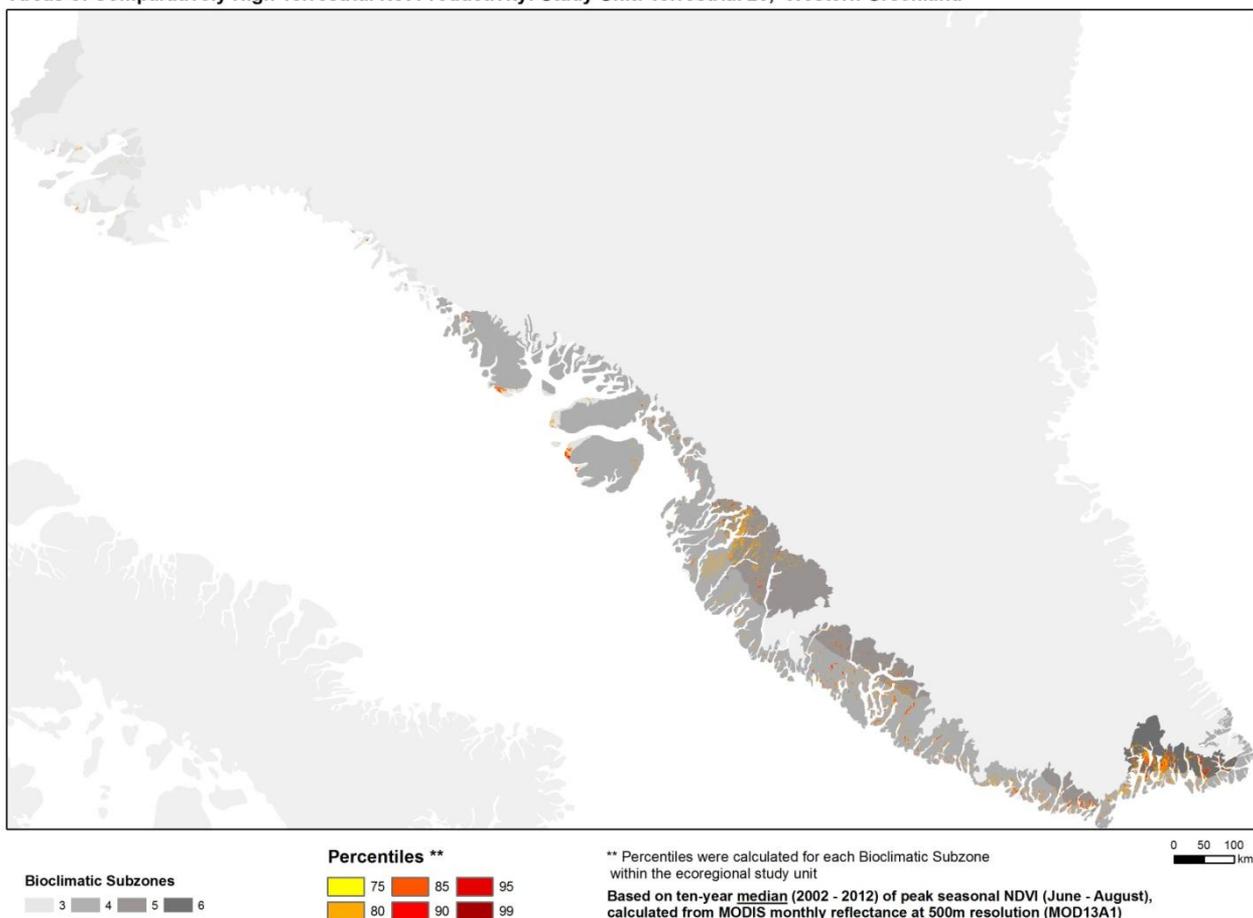


Fig. 2. Areas of exceptionally high terrestrial net primary productivity for the Western Greenland ecoregion (Bioclimatic subzone 3-6). Source WWF.

Areas Exceptional Landform Heterogeneity for Western Greenland Study Unit

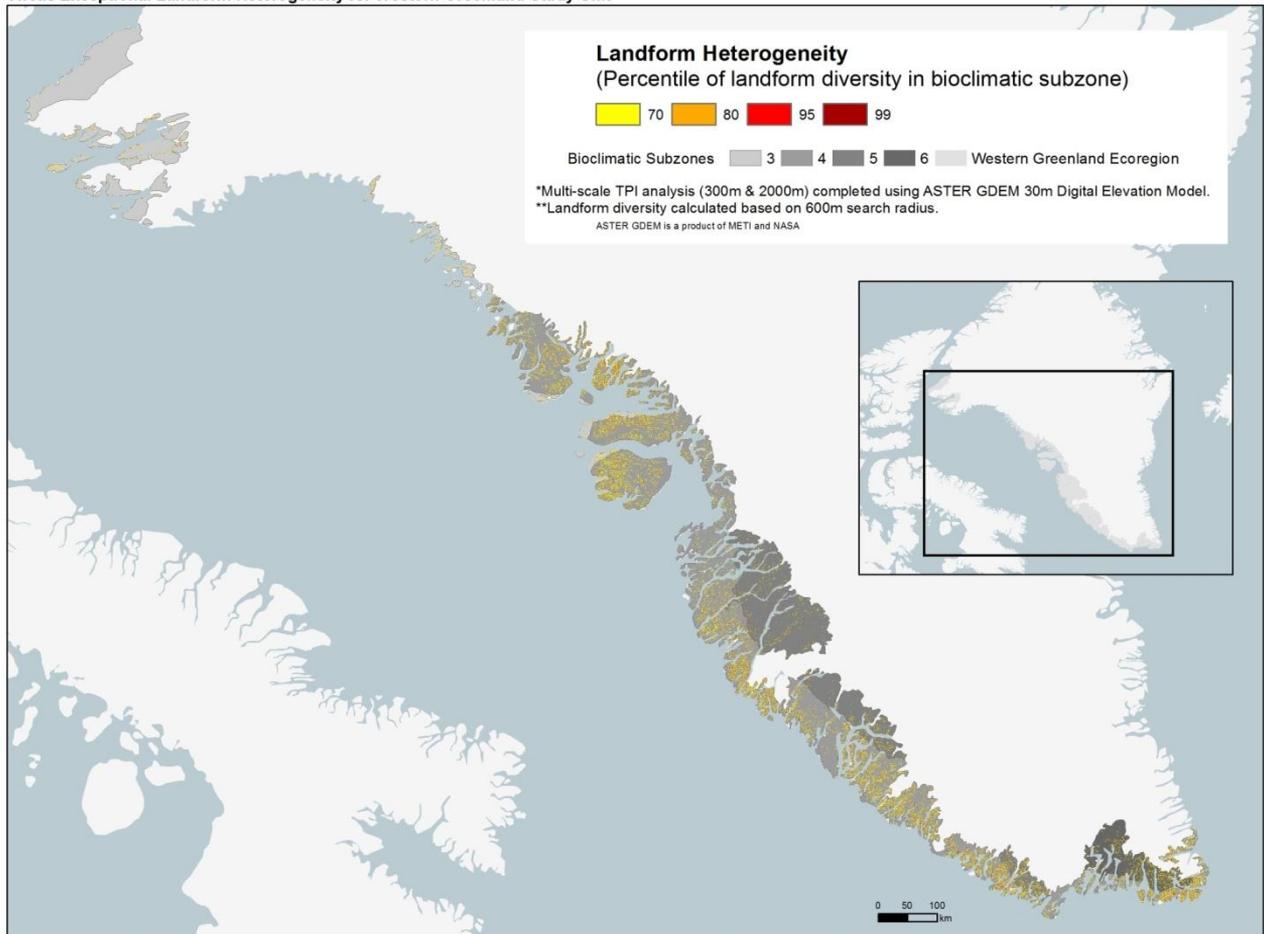


Fig. 3. Areas of significant landform heterogeneity in the Western Greenland ecoregion (Bioclimatic subzone 3-6). Source WWF.

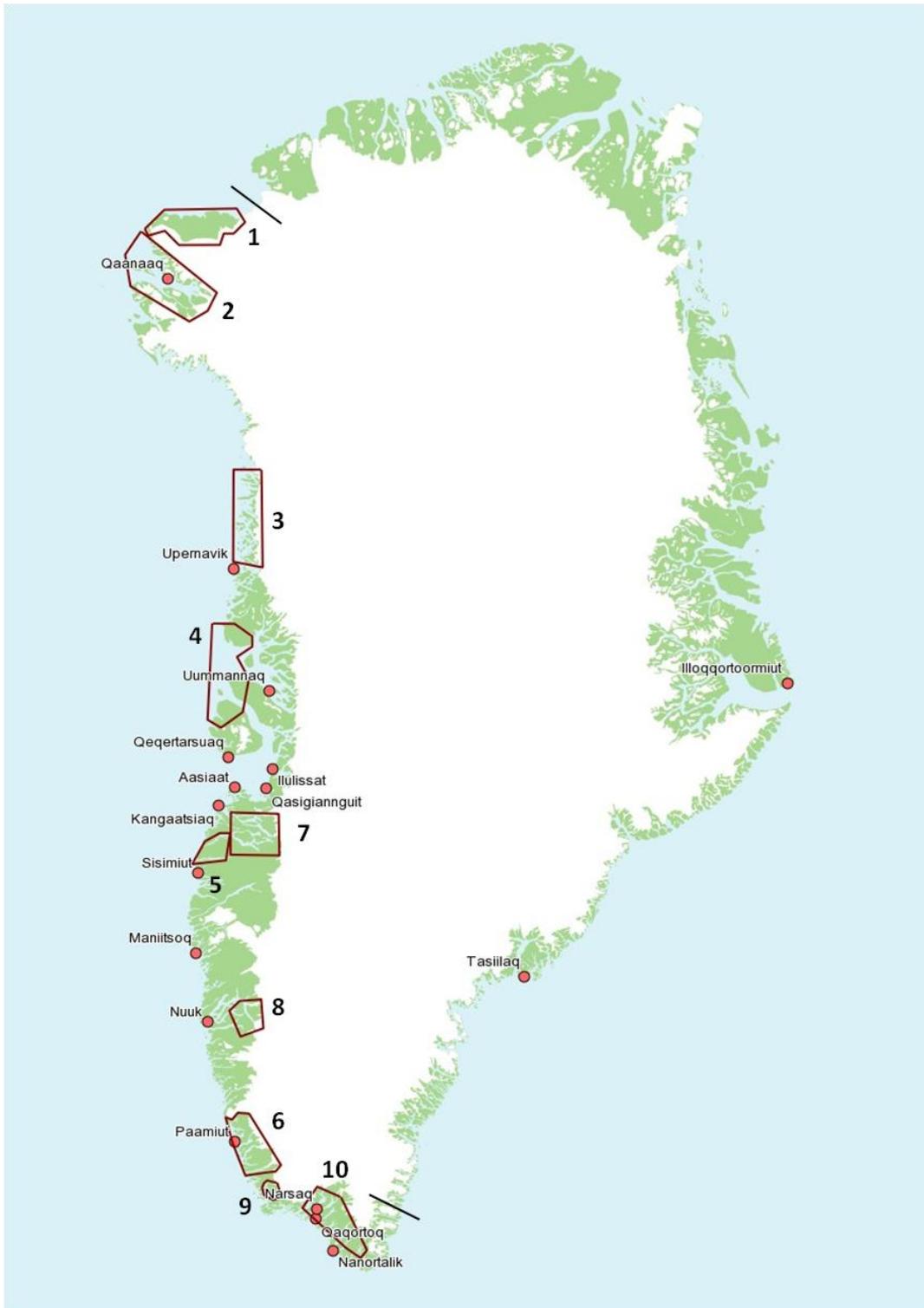


Fig. 4. The ten designated terrestrial key features of the Western Greenland ecoregion are marked by a brown line. 1. Inglefield Land; 2. Qaanaaq area/Inglefield Bredning; 3. The Northwest Coastal Zone; 4. Svartenhuk peninsula, Nussuaq peninsula, Disko Island; 5. Coastal land area between Nordre Strømfjord and Nordre Isortoq fjord; 6. Paamiut area; 7. Inner Nordre Strømfjord area; 8. Inner Godthåbsfjord area; 9. Grønnedal area; 10. South Greenland.

ECOREGION CHARACTERISTICS

Western Greenland, extending more than 2000 km from south to north, experiences great differences in physical factors like temperature, irradiance, and precipitation. Mean summer temperature is the main factor for the distribution of vegetation, and irradiance and snow cover limits the growth season. Variation in topography and distance to the coastline determine the local distribution of plants and primary productivity. Hilltops tend to be nutrient poor while low land areas are more lush and productive (Jensen 2003). The most northern part of the ecoregion has mean July temperatures between 5-7°C, the central part 7-9°C, and the southern part 9-12°C (Box 1). Also day length varies greatly along the latitudinal gradient of the region with annual net irradiance (and thus length of the growth season) decreasing towards the north. Differences in sunlight are exemplified by the most northern town of the region, Qaanaaq, where the sun never sets for approximately four months in the spring/summer period and never rises for approximately four months in winter. Meanwhile, areas below the Arctic Circle have day lengths between approximately 6 and 19 hours throughout the year (Born and Böcher 1999). Precipitation also varies greatly from north to south with mean annual precipitation in Qaanaaq around 141 mm and in Qaqortoq in the south with 1285 mm (1993-2005 annual mean, Statistics Greenland (I) 2010). Generally, snow cover increases from north to south and from the coast to the inland areas closer to the ice cap (Jensen 2003). North of Disko Island permafrost is continuous whereas it is more sporadic in the south. In permafrost soils, the top active soil layer thaws in the summer, typically a few centimeters in the north and up to several meters in the south (Jensen 2003). Thus Northern Greenland is dominated by dry permafrost desert soils with low humus content, low decomposition rates and sparse vegetation, whereas Southern Greenland has moist or wet soils, thick humus layers, and a dense vegetation (Born and Böcher 1999).

Vegetation and plant communities (Fig. 5 and 6) found in the Western Greenland ecoregion include: (1) Low- sub- and high Arctic heath inland and at the coast (e.g. dwarf-birch (*Betula nana*), bell heather (*Erica cinerea*), bog bilberry (*Vaccinium uliginosum*), mountain crowberry (*Empetrum nigrum hermaphroditum*)); (2) Low Arctic shrub tundra (e.g. willow (*Salix sp.*) and in-land in the south e.g. alder (*Alnus sp.*) and birch (*Betula sp.*) forest); (3) low Arctic herbs (e.g. alpine speedwell (*Veronica wormskjoldii*), hawkweed (*Hieracium sp.*), dandelion (*Taraxacum sp.*)); (4) Low- sub- and high Arctic marshes (e.g. sedges, rushes, cotton grass (*Eriophorum sp.*)); (5) low Arctic grass (e.g. bent grass (*Agrostis sp.*), Lady's Mantle (*Alchemilla sp.*)); (6) Low and subarctic inland steppe/plain (e.g. sedges and bent grass); (7) Dry and wet low- sub- and high Arctic mountain field (e.g. sedges, mountain-poppy (*Papaver sp.*), bluegrass (*Poa sp.*), saxifrage (*Saxifraga sp.*)) (Jensen 2003).

Vegetation Types for Western Greenland Terrestrial Ecoregion (T20)

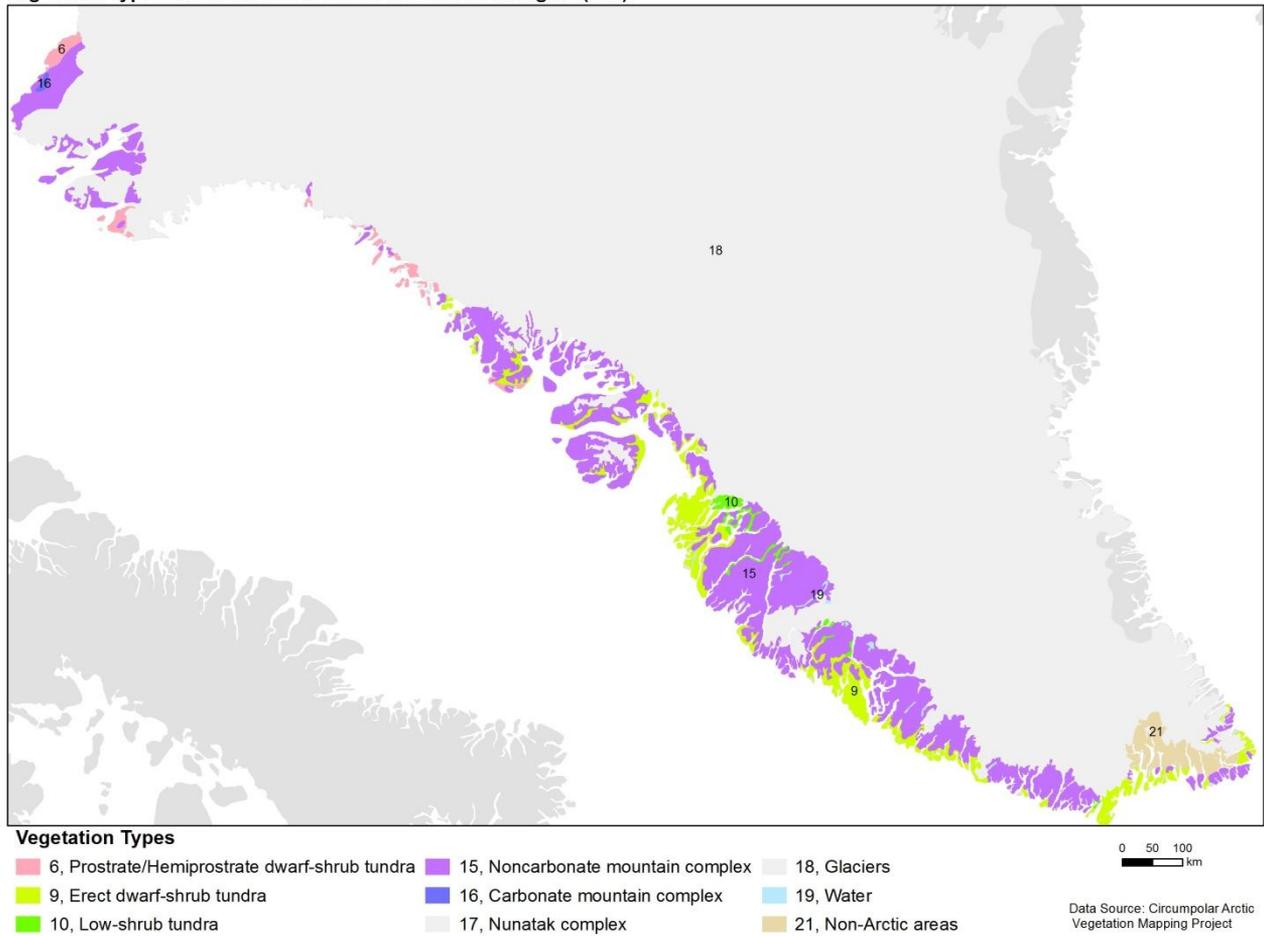


Fig. 5. Arctic vegetation types for the Western Greenland ecoregion. Source: WWF and CAVM Project.



Fig. 6. Vegetation at the Western Greenland ecoregion (locations Nuuk and Ilullissat). Photos Eva Garde, WWF.

- A) Mountain crowberry / Fjeld-revling
- B) Dwarf birch / Dværg-birk
- C) Gray willow / Blågrå pil (*Salix glauca*)
- D) Lapland rosebay / Arktisk alperose (*Rhododendron lapponicum*)
- E) Blue mountain heath / Blålyng (*Phyllococe caerulea*)
- F) Alpine azalea / Kryblyng (*Loiseleuria procumbens*)

RACER EXPERT WORKSHOP, JANUARY 2014

The terrestrial RACER workshop was held at WWF Verdensnaturfondens location in Copenhagen, Denmark, 9th of January 2014. The workshop participants commented and evaluated on a preliminary version of this report.

The final report presented here is a product of work produced entirely by WWF Verdensnaturfonden.

Participants/experts:

- Christine Cuyler, Scientist, Department of Birds and Mammals, Greenland Institute of Natural Resources.
- Elmer Topp-Jørgensen, Member of Administrative Staff, Department of Bioscience - Arctic Ecosystem Ecology, Aarhus University.
- Peter Aastrup, Section Manager, Department of Bioscience, Arctic Environment, Aarhus University.
- Signe Normand, Postdoc, Swiss Federal Research Institute, Switzerland.
- Toke Thomas Høye, Senior Researcher, Department of Bioscience - Biodiversity and Conservation, Aarhus University.

Results and conclusions:

WWF presented the three themes high terrestrial productivity, landform heterogeneity, and CAVM vegetation zones to the experts. Experts noted that designation of important nature areas with regard to e.g. biodiversity would require a thorough review of existing knowledge. The three themes however were acknowledged as useful contribution to designation of important nature areas in Greenland.

The ten key features were selected based on the three themes: high terrestrial productivity (Fig. 2), medium to high landform heterogeneity (Fig. 3), and the number of CAVM vegetation zones (Fig. 5) (Table 1).

It was decided at the workshop to designate three key features within each of bioclimatic subzones 3, 4 and 5 (Fig. 7, 11, and 15) and one key feature in bioclimatic subzone 6, based on the geographical restriction of this subzone to the very south of the ecoregion (Fig. 19).

Given restricted data of the physical environment at the designated key features as well as limited knowledge of plant communities and plant species present in large parts of Greenland, the experts at the workshop concluded that it was not possible to identify the specific drivers for each of the key features.

Furthermore, the experts evaluated that it was not feasible to obtain reliable assessments of the persistence of key features and their future above-average productivity/diversity based on the

available data and the current knowledge of the terrestrial ecosystems in Greenland. Main conclusions of the workshop were:

- It was pointed out by the experts that the given climate models, covering a huge latitudinal gradient from 60-78°N, were too general to be useful for the Western Greenland ecoregion, (Ap. 3). The resolution in the models was too low to make precise predictions and assessments of ecosystem resilience. There is a need for regional climate models, with sufficient resolution for the ecoregions.
- It was noted that the CAVM vegetation map (Fig. 5) does not reflect the regional gradient from the coast to the inland at the Greenland Ice Cap.
- It was further noted that the net primary productivity map (Fig. 2) is partly incorrect in showing high terrestrial productivity. For instance, in the Godthåbsfjord area two large lakes have been given the same colour on the map as the colour of high terrestrial productivity. This is confusing for interpretation of the map.
- Given the size of the Western Greenland ecoregion the experts felt that the maps of net primary productivity and landform heterogeneity were too coarse, and that unique small areas were lost using such a large scale.

Experts suggested the possibility of placing GIS files from the net primary productivity analysis and files from the landform heterogeneity analysis 'on top of each other' to let the computer point out places of combined high terrestrial productivity and significant heterogeneity to be designated as key features.

It was emphasized that a further specified choice of key features and their borders than presently reported will require additional studies to provide a better data foundation for pointing out designated areas.

Experts noted that the RACER concept of resilience is important and useful even though challenging to apply.

The RACER method for terrestrial areas works within a context of identifying and designating areas of high net primary productivity and landform heterogeneity today and in the future. 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. However, by selecting at least one key feature within each bioclimatic subzone, this can somewhat be accounted for.

KEY FEATURES	TERRESTRIAL PRODUCTIVITY	LANDFORM HETEROGENEITY	CAVM VEGETATION ZONES
1. Inglefield Land	-	-	3*
2. Qaanaaq area/Inglefield Bredning	-	Medium – High	1
3. The Northwest Coastal Zone	-	High	3
4. Svartenhuk peninsula, Nussuaq peninsula, Disko Island	High	Medium – High	2-3
5. Coastal land area between Nordre Strømfjord and Nordre Isortoq fjord	High	High	3
6. Paamiut area	High	High	2
7. Inner Nordre Strømfjord area	High	High	3
8. Inner Godthåbsfjord area	High	Medium	1
9. Grønnedal area	High	High	3
10. South Greenland	High	Medium	2**

*One vegetation zone (#16) found at Inglefield Land is unique to the Western Greenland ecoregion.

**Part of this area has been defined as non-Arctic (Fig. 5).

Table 1. Three key features were designated in each bioclimatic subzone (3-5) along the Western Greenland ecoregion. One key feature was designated in bioclimatic subzone 6 as this subzone is geographically restricted to the very south of the ecoregion. The ten key features presented in this table were designated based on three criteria: high terrestrial productivity (Fig. 2), medium to high landform heterogeneity (Fig. 3), and number of CAVM vegetation zones (Fig. 5). A more detailed description of each key feature is found in the text.

KEY FEATURES

Key features located in bioclimatic Subzone 3.

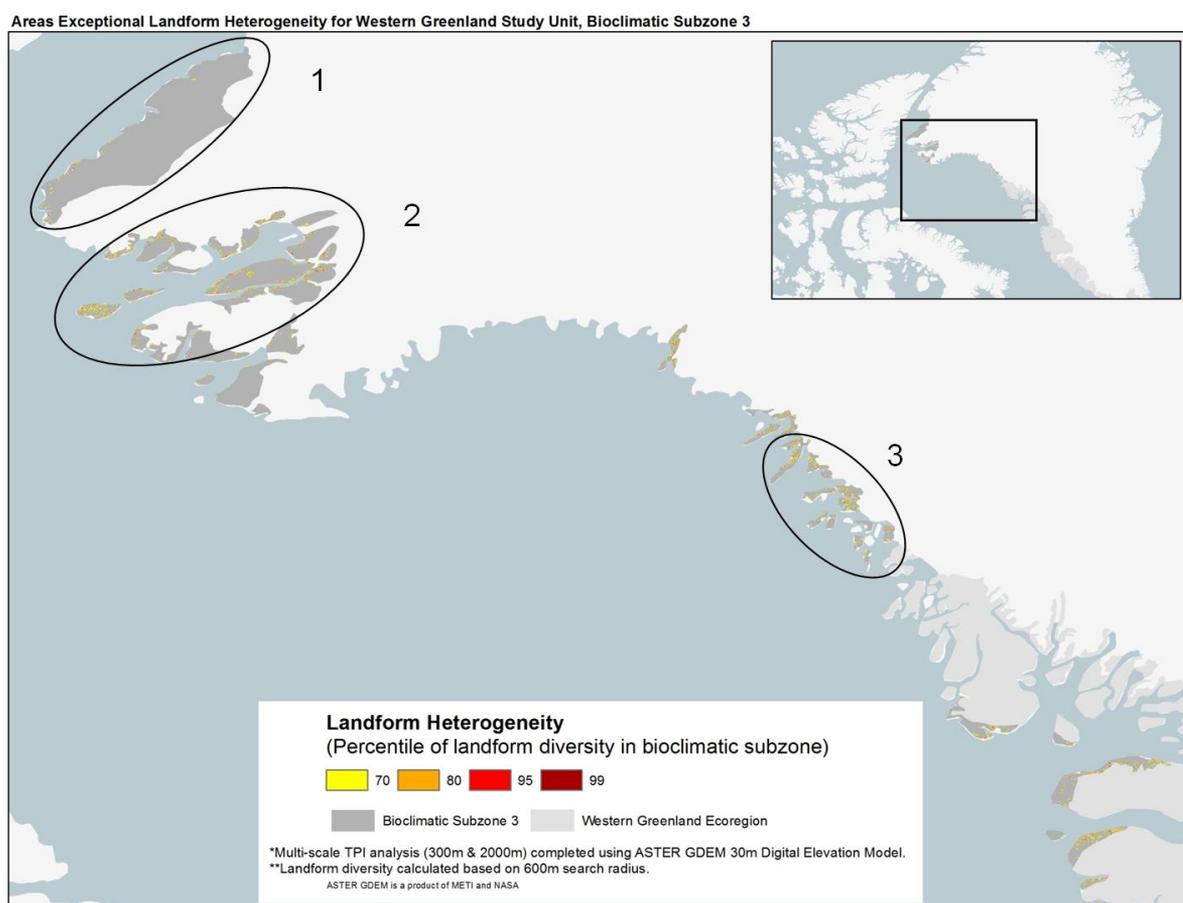


Fig. 7. The three key features located in bioclimatic subzone 3. Designation of key feature 1, Inglefield Land, was based on the three CAVM vegetation zones present (Fig. 5), whereas key feature 2, Qaanaaq area/Inglefield, and 3, the Northwest Coastal Zone, was partly based on landform heterogeneity.

1. INGLEFIELD LAND

The designation of key feature 1, Inglefield Land, was based on three CAVM vegetation zones (zone 6, 15 and 16; Fig. 5), where vegetation zone 16 is unique within the Western Greenland ecoregion. All of Inglefield Land has been designated as a key feature as there was no basis within the RACER method for identifying a subset of this area.

Inglefield Land is located at 78°N on the northwest coast of Greenland (Fig. 8a and b), next to Smith Sound, Nares Strait and Kane Basin and east of the North Water polynya. This high Arctic area is a rectangular ice-free land strip nearly 200 kilometres long, 50 kilometres wide at the widest point, and approximately 6,500 km² (Landa et al. 2000a, Jensen 1999). The landscape is diverse consisting of mountains and valleys as well as large plains. Four terrestrial mammals live here; caribou, musk ox, Arctic hare, and Arctic fox, and the area is also known as a place for polar bear maternity denning (Jensen 1999). The estimated population number of the caribou was in 1999 at 2300 individuals (Landa et al. 2000b) however current status of the population is unknown. Nearest human settlement is Siorapaluk that currently holds 57 inhabitants (Grønlands Statistik, January 2014) and the nearest town is Qaanaaq with a population of 656.

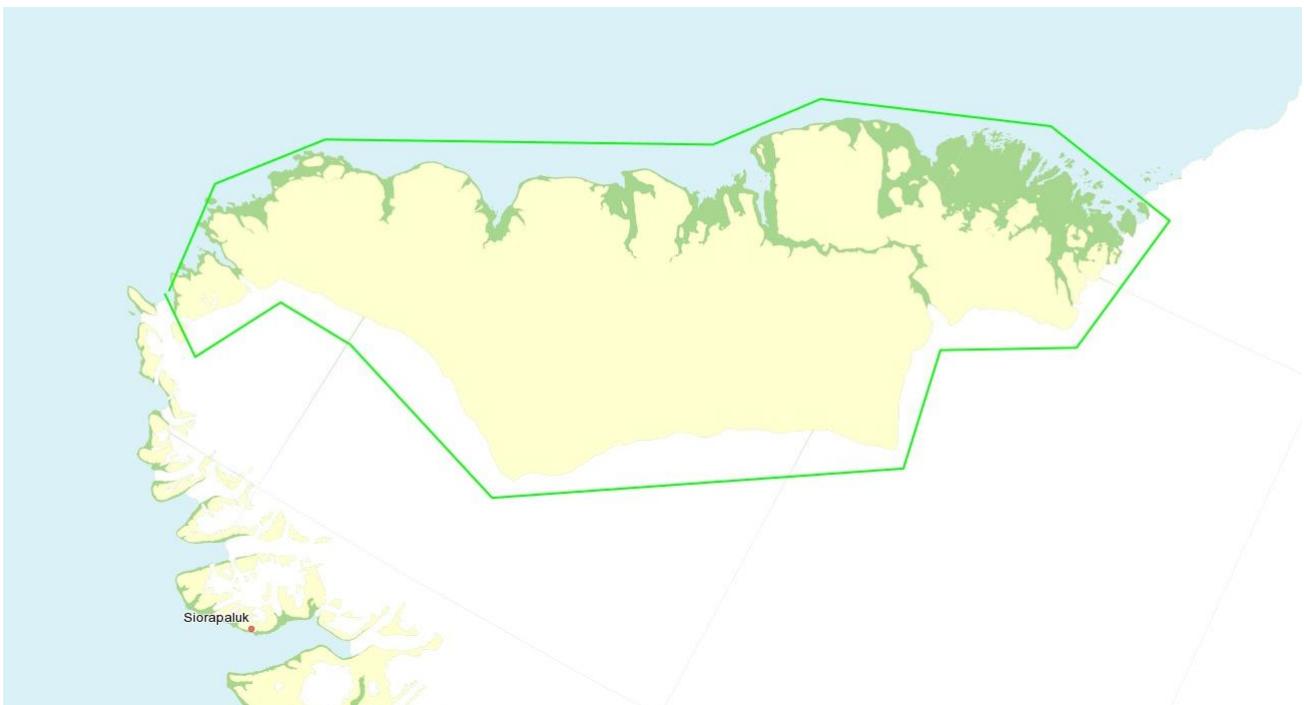


Fig. 8a. Key feature 1, Inglefield Land, is shown by the green line. The defined borders of key features are only indicative.



Fig. 8b. Satellite photo showing the Inglefield Land key feature and the nearest settlement within the area Siorapaluk. Source: Moderated from NunaGis.

2. QAANAAQ AREA/INGLEFIELD BREDNING

Key feature 2, the Qaanaaq area/Inglefield Bredning, has been designated based on landform heterogeneity. There are several small areas with high landform heterogeneity within this key feature (Fig. 9a and b).

Qaanaaq is the most northerly town in Greenland located within the Qaasuitsup Kommunia. Qaanaaq is found at the mouth of Inglefield Bredning, an approximately 100 kilometres long and 15-20 kilometres wide inlet at 77° N latitude. The thin stretch of land between Inglefield Bredning, the surrounding glaciers/the Greenland Ice Cap and the two islands Herbert Ø and Northumberland Ø at the mouth of the inlet constitute this key feature. The landscape consists of mountains, glaciers, high rock cliffs, and sand and stone beaches. Inglefield Bredning is an important summer ground for narwhals (*Monodon monoceros*) from the Baffin Bay population (Christensen et al. 2012) and the whales are a hunted resource for the inhabitants of Qaanaaq and nearby settlements. In the bottom of the inlet a small settlement, Qeqertaq, is located, and just north of the mouth of Inglefield Bredning Siorapaluk is found.



Fig. 9a. Key feature 2, Qaanaaq area/Inglefield Bredning, is shown by the green line. The defined borders of key features are only indicative.

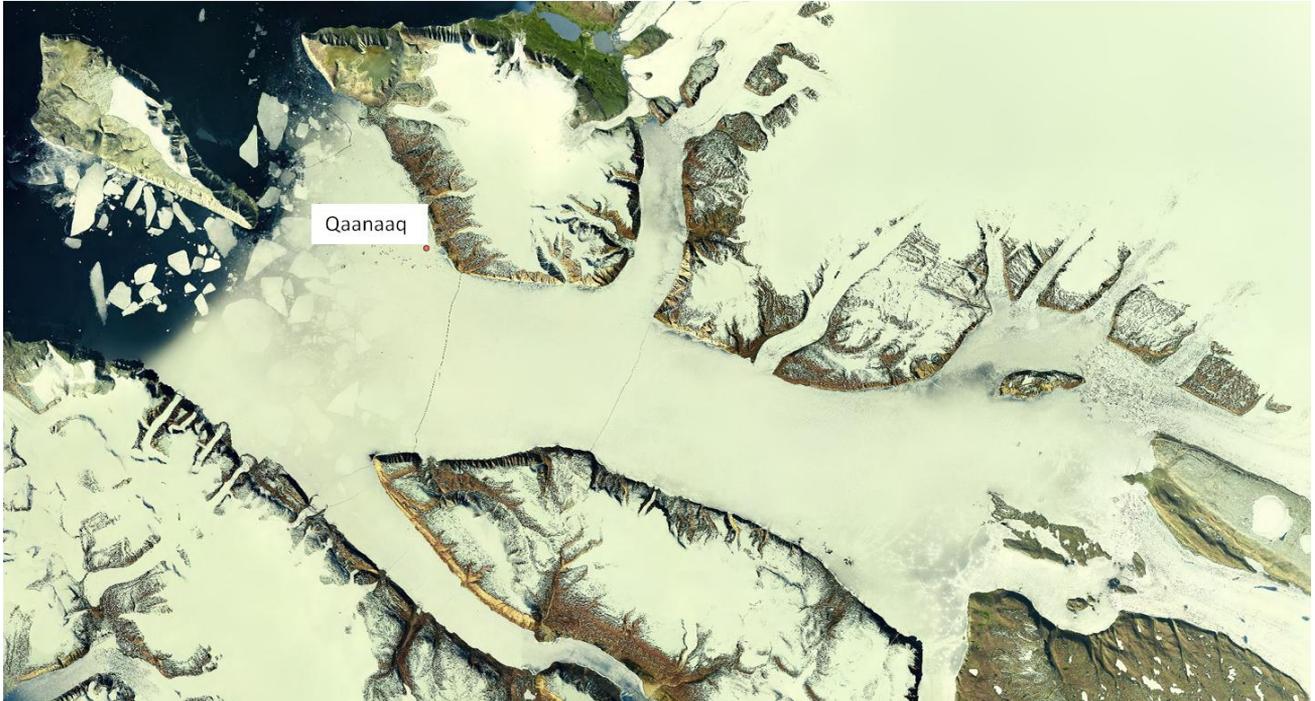


Fig. 9b. Satellite photo showing part of the Qaanaaq area/Ingfield Bredning key feature and the town Qaanaaq. Source: Moderated from NunaGis.



Shore line of Ingfield Bredning. Photo: Eva Garde.

3. THE NORTHWEST COASTAL ZONE

Key feature 3, the Northwest Coastal Zone, has been designated based primarily on landform heterogeneity and because the area includes three different CAVM vegetation zones (zone 6, 9 and 15; Fig. 5). Also, in the northern part of the key feature there are important breeding areas for seabirds.

The Northwest Coastal Zone key feature stretches from the settlement Kullorsuaq at approximately 74° 34' 45.4 N to the abandoned settlement Tussaaq at approximately 73° 3' 25.5 N. The Northwest Coastal Zone key feature 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 (See also RACER report 'The West Greenland Shelf'). The land areas are characterized by cliffs and rocks with sparse vegetation. Birds on land include the raven, snow bunting, Northern wheatear (*Oenanthe oenanthe*), and Lapland Longspur (*Calcarius lapponicus*) as well as a lot of other smaller bird species. Nearly all of the Greenlandic breeding sea birds have (or had) nesting sites here (Christensen et al. 2012). Large colonies of breeding common eider (*Somateria mollissima*) and thick-billed murre (*Uria lomvia*) 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 (*Cephus grylle*), razorbill (*Alca torda*), Atlantic puffin (*Fratercula arctica*), little auk (*Alle Alle*), Black-legged Kittiwake (*Rissa tridactyla*) and species of gulls are found here (Boertmann and Mosbech 2011). There are three bird protected areas within this key feature².

The area includes five more settlements besides Kullorsuaq and Tussaaq which are Nuussuaq, Nutaarmiut, Tasiusaq, Innaarsuit and Naajaat. These seven settlements have a total human population of 1123 (Grønlands Statistik, January 2014).

² <http://www.qaasuitsup.gl/da-DK/Om-kommunen/Fakta-om-kommunen/~media/Files/Om-kommunen/Fakta-om-kommunen/fuglebeskyttelsesomraader.ashx>



Fig. 10a. Key feature 3, the Northwest Coastal Zone, is shown by the green line. The defined borders of key features are only indicative.



Fig. 10b. Satellite photo showing the Northwest Coastal Zone key feature and settlements within the area. Source: Moderated from NunaGis.

Key features located in bioclimatic Subzone 4.

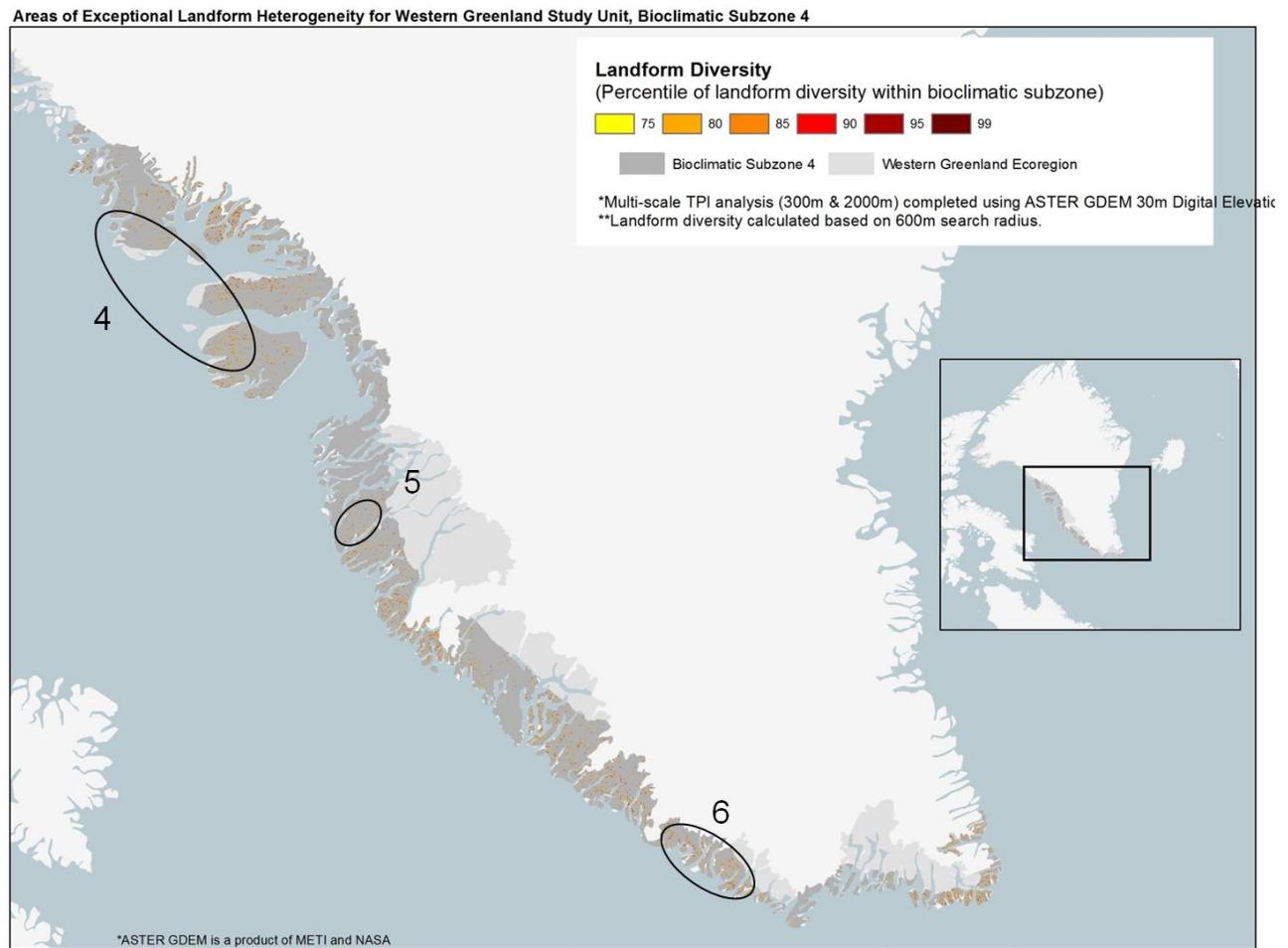


Fig. 11. The three key features located within bioclimatic subzone 4. The designation of these three key features was partly based on landform heterogeneity. Key features: 4. Parts of Svartenhuk peninsula, Nuussuaq peninsula and Disko Island; 5. Coastal land area between Nordre Strømfjord and the Nordre Isortoq fjord; 6. The Paamiut area.

4. SVARTENHUK PENINSULA, NUUSSUAQ PENINSULA AND DISKO ISLAND

Key feature 4 is composed of three subareas consisting of the southern part of Svartenhuk peninsula, the western part of Nuussuaq peninsula and the northwestern part of Disko Island located at 70-71°N (Fig. 12a and b). All three areas consist of two bioclimatic subzones (3 and 4), high terrestrial productivity at the coastal tip of the peninsulas/Island, and Svartenhuk consists of three different vegetation zones (6, 9 and 15). Nuussuaq and Disko Island consists of two vegetation zones (9 and 15) (Fig. 5).

The landscape diversity and heterogeneity at the three sites includes plains, slopes, hills, mountains and river valleys. The vegetation is mainly dominated by Arctic tundra. The extraordinary primary productivity at the western tip of the Svartenhuk peninsula coincides with the location of a large river valley cutting through the landscape probably causing a high level of productivity at this exact spot. At Nuussuaq Peninsula a marine up-welling area is located right at the tip of the peninsula and at Disko Island large fjords are found incl. the Nordre Fjord at the North East side of the Island.

Svartenhuk peninsula and Disko Island are known moulting sites for geese, and common and king eider (*Somateria spectabilis*), respectively. Caribou/reindeer are found at Svartenhuk and Nuussuaq peninsulas and musk oxen are also present at Svartenhuk peninsula. Individuals from the original musk ox population in North East Greenland were moved to Kangerlussuaq in West Greenland in the 1960s. This population thrived and individuals were subsequently moved to other areas on the West coast, among these the Svartenhuk peninsula (Appendix 2). There is also a known winter ground for Atlantic walrus at the North West side of Disko Island. The settlement, Nuaqornat, is located within this key feature. The settlement has 52 inhabitants that primarily live of fishing and hunting.



The settlement Nuaqornat within key feature 4 in the Western Greenland ecoregion. Photo: Eva Garde.



Fig. 12a. Key feature 4, Svartenhuk peninsula, Nuussuaq peninsula and Disko Island, is shown by the green line. The defined borders of key features are only indicative.

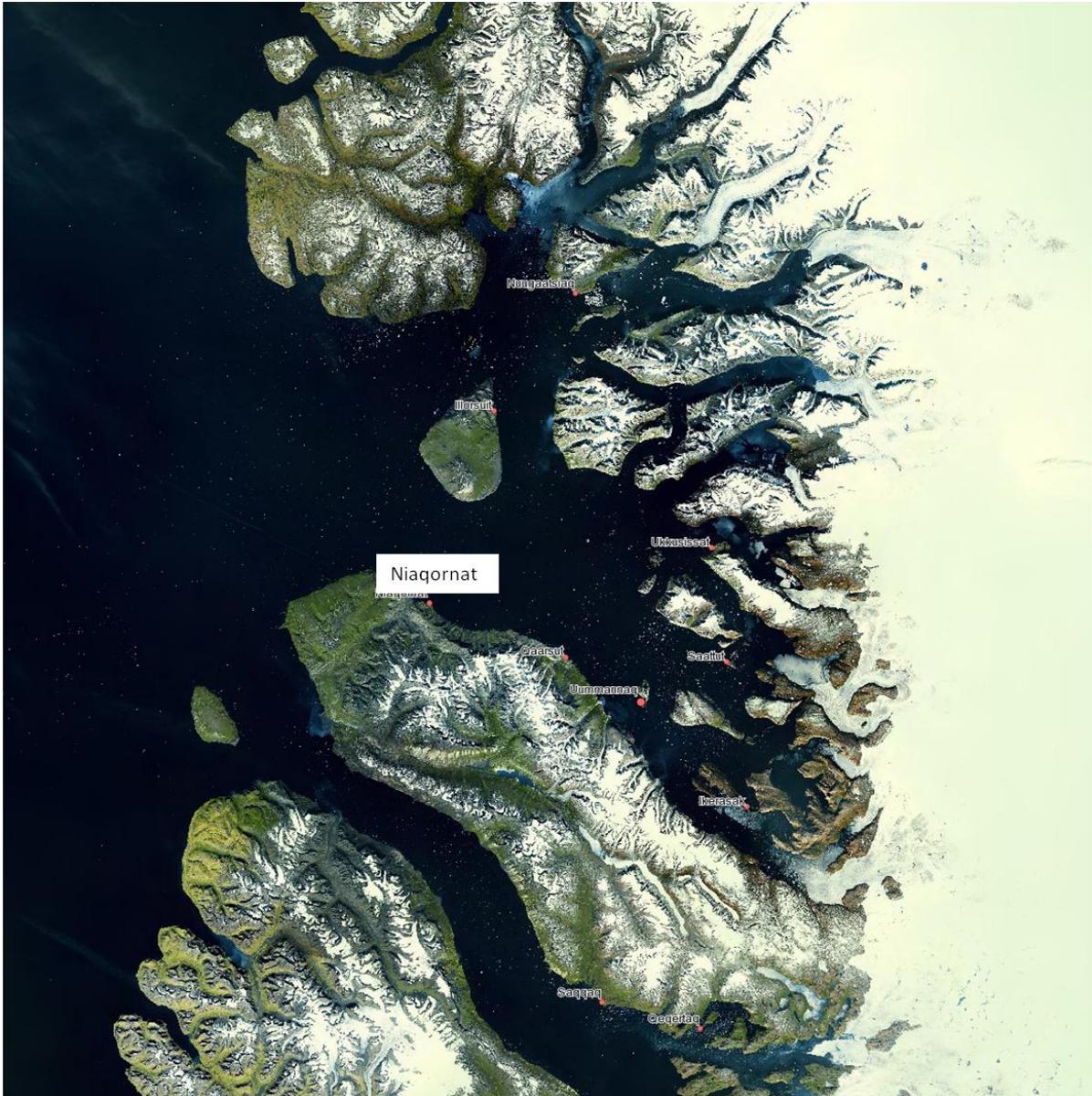


Fig. 12b. Satellite photo showing the Svartenhuk peninsula, Nuussuaq peninsula and Disko island key feature and the settlement, Niaqornat, within the area. Source: Moderated from NunaGis.

5. LAND AREA BETWEEN NORDRE STRØMFJORD AND NORDRE ISORTOQ FJORD

Key feature 5, the coastal land area between the Nordre Strømfjord and the Nordre Isortoq fjord, has been designated based on a combination of high landform heterogeneity and high terrestrial productivity. Also, the area include three different vegetation zones (9, 10 and 15; Fig. 5).

This coastal land area is located between the Nordre Strømfjord at approximately 67° 28' 23.5 N and the Nordre Isortoq fjord at 67° 10' 45.1 N, north of the town Sisimiut (Fig. 13a and b). The fjord systems uphold a rich bird life in summer. The Naternaq caribou population belongs to this area, which is one out of 12 caribou populations in Greenland.



Fig. 13a. Key feature 5, the coastal land area between Nordre Strømfjord and Nordre Isortoq fjord, is shown by the green line. The defined borders of key features are only indicative.

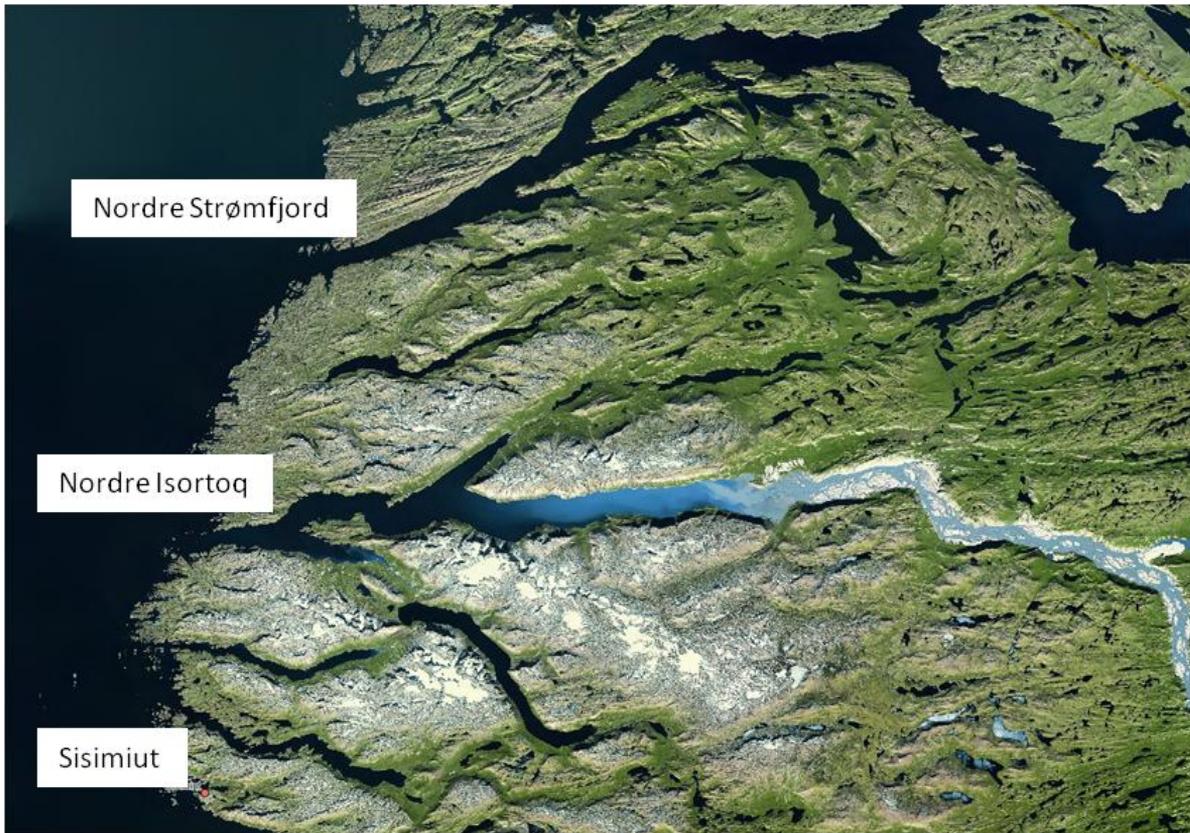


Fig. 13b. Satellite photo showing key feature 5, the coastal land area between Nordre Strømfjord and Nordre Isortoq fjord, and the town, Sisimiut, to the south. Source: Moderated from NunaGis.

6. THE PAAMIUT AREA

Key feature 6, the Paamiut area, is located between the glacier Frederikshåb Isblink at approximately 62° 26' 34.8 N and the area just south of the fjord Sermiligaarsuk at approximately 61° 22' 25.0 N in the southern part of bioclimatic subzone 4 (Fig. 14a and b). This area has been designated as a key feature based on its high productivity and the heterogeneous landscape including many rare and endemic vascular plants.

The area is 130 kilometers long and around 60 kilometers wide, from the coast to the Greenland Ice Cap, measured in a straight line. The area is highly productive with a heterogeneous landscape characterized by a countless number of smaller islands and skerries at the coastline and several larger and smaller fjordsystems cutting through the landscape. The area closer to the Ice Cap is diverse with lakes, ridges, valleys, mountain tops and glaciers. The vegetation includes many rare and endemic vascular plants (Jensen et al. 1999).

The town of Paamiut is found within this key feature. It has approximately 1.500 inhabitants and fishery is the main occupation here. Also hunting for seals and whales are common activities.

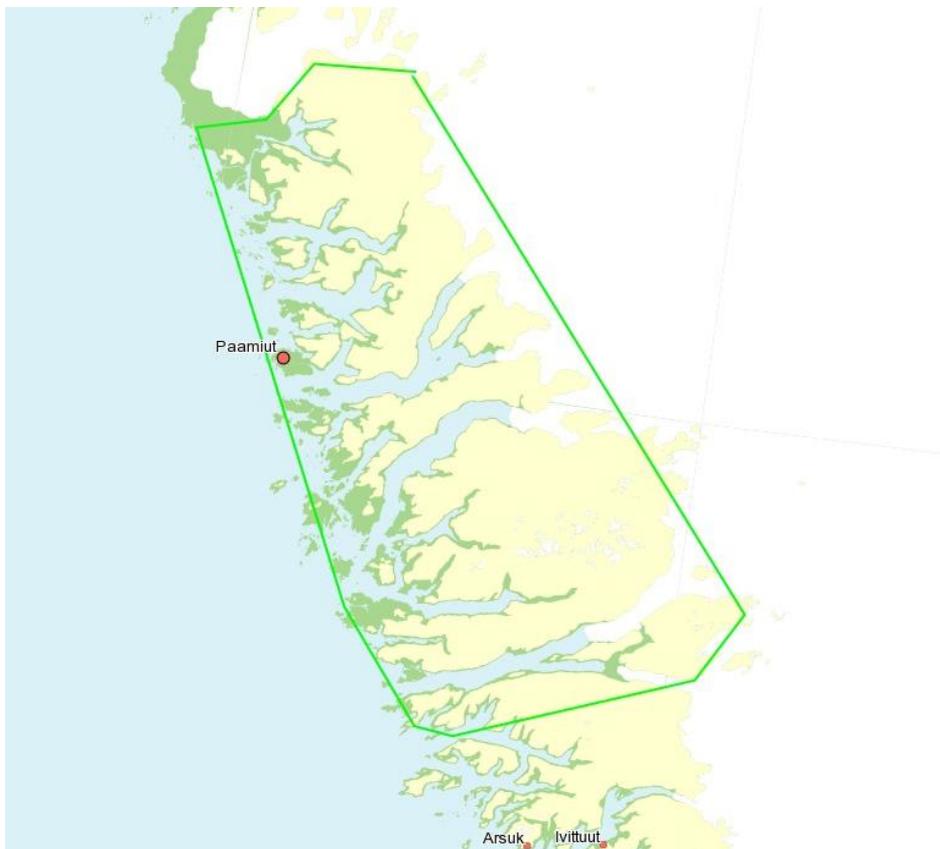


Fig. 14a. Key feature 6, the Paamiut area, is shown by the green line. The defined borders of key features are only indicative.

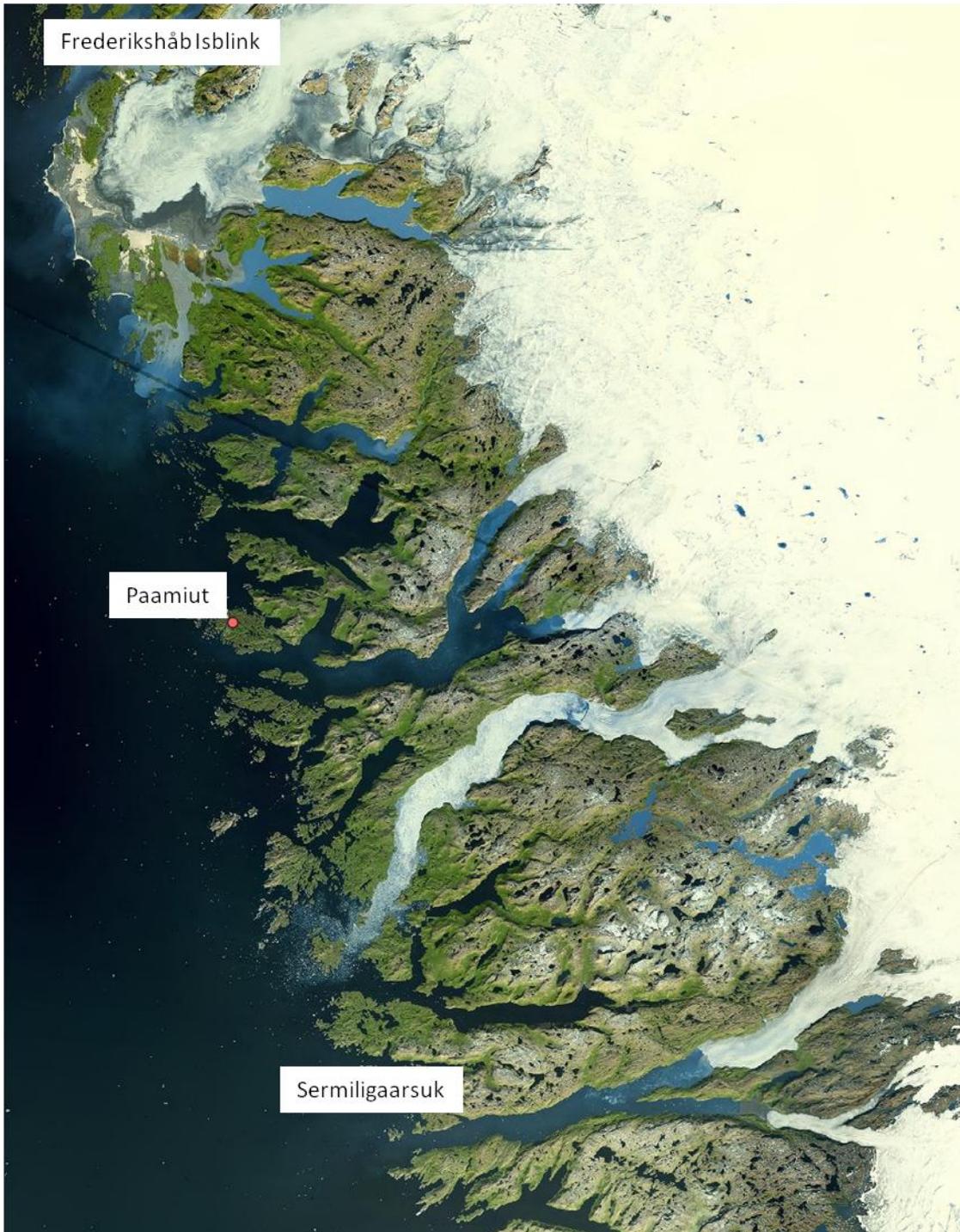


Fig. 14b. Satellite photo showing key feature 6, the Paamiut area, between Frederikshåb Isblink and Sermiligaarsuk, and the town of Paamiut. Source: Moderated from NunaGis.

Key features located in bioclimatic Subzone 5.

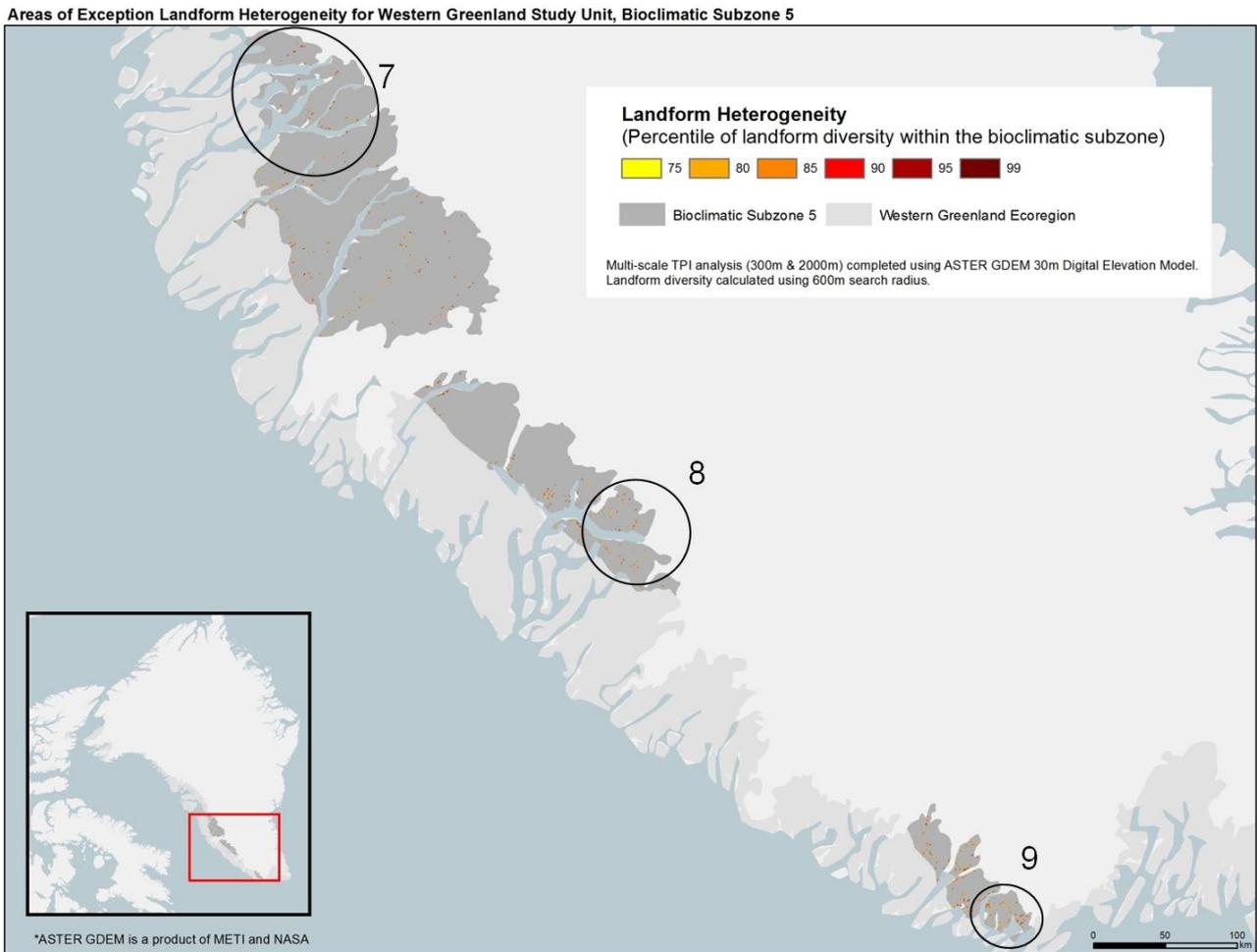


Fig. 15. The three key features located in bioclimatic subzone 5. The designation of these three key features was partly based on landform heterogeneity. Key feature 7. Inner Nordre strømfjord area; 8. Inner Godthåbsfjord area; 9. South Greenland.

7. INLAND NORDRE STRØMFJORD AREA

Key feature 7 is the inner Nordre strømfjord area near the Greenland Ice Cap (Fig. 16a). This area is highly productive with subareas of high landform heterogeneity. There are three different vegetation zones (9, 10 and 15) within this area.

The inner Nordre strømfjord area key feature is located between 67-68°N and bounded by the Nordenskiöld Glacier to the north and the smaller glacier Inugpait qûat in the south (Fig. 16b). Inugpait qûat flows into a river valley and the fjord arm Kûp Akua. This key feature is located next to key feature 5. The landscape is diverse with hilltops, valleys, lakes and streams. The area is one of the most productive in Greenland in terms of net primary productivity (Fig. 2). As is the case for key feature 5, the Naternaq caribou population is also found at this key feature.



Fig. 16a. Key feature 7, the inner Nordre strømfjord area, is shown by the green line. The defined borders of key features are only indicative.

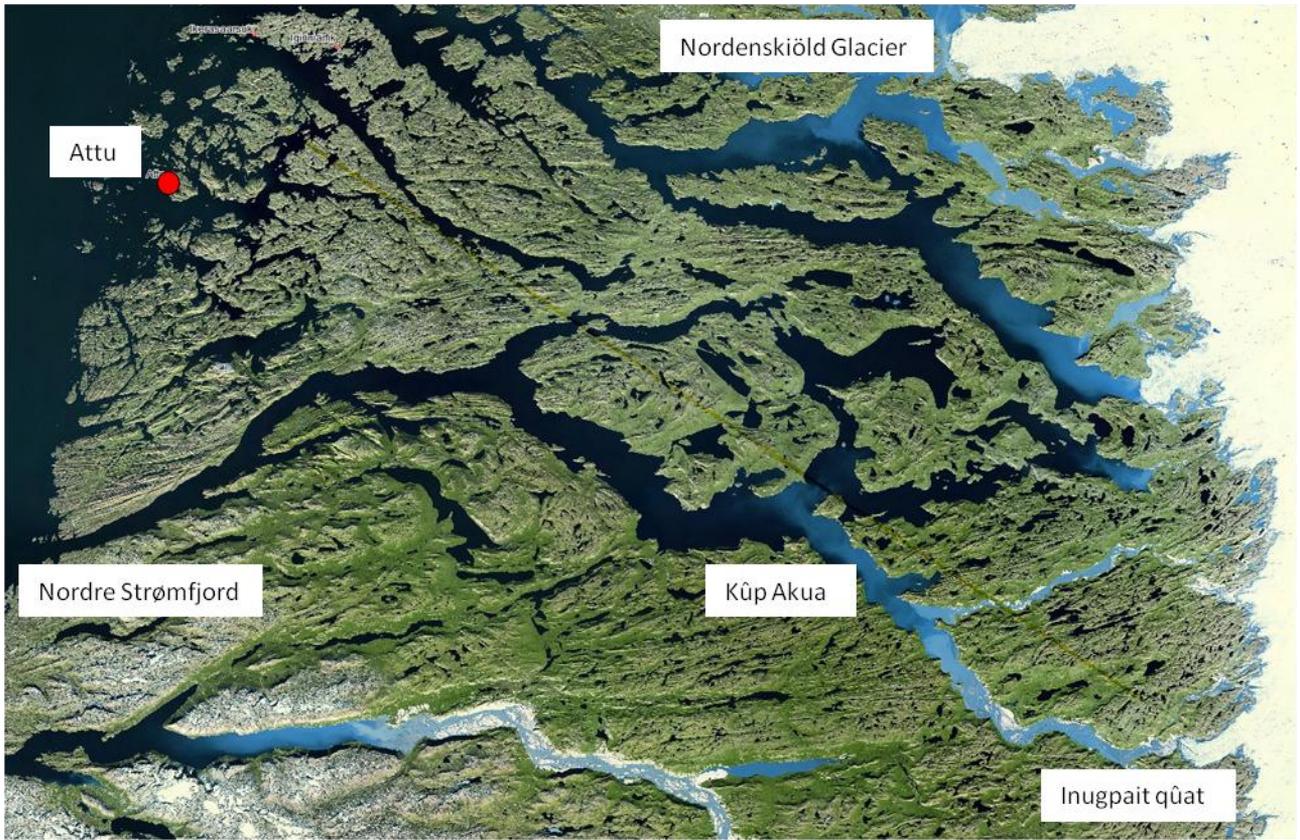


Fig. 16b. Satellite photo showing key feature 7, the inner Nordre strømfjord area, located between the glaciers Nordenskiöld and Inugpait qûat and next to the Greenland Ice Cap. Source: Moderated from NunaGis.

8. INNER GODTHÅBSFJORD AREA

Key feature 8, the inner Godthåbsfjord area located at 64°N, is highly productive and with medium landform heterogeneity (Fig. 17a and b).

This key feature includes the areas Nunatarssuaq and Kapisigdlit timat, where the fjord arm Kangersuneq runs through. The area is characterized by river valleys, lakes, plains, open slopes, ridges, mountain tops and glaciers. This diverse topography creates an exceptional variety of habitats for diverse species of plants, birds and other wildlife. The dry desert-steppe portions of the region are very attractive to caribou and other animals, and large populations of caribou and feral reindeer thrive in the area (Cuyler et al. 2007 and 2011). Also traditional caribou hunting grounds are found here. Austmannadalen and the surroundings, located within this key feature, are protected with the aim of preserving the area's appearance and cultural relics as well as to protect the area against attrition. The aim of this conservation is also to protect the population of feral domestic sheep in the area. The settlement of Kapisilit, also located within this key feature, currently has 78 inhabitants that sustain themselves through hunting, fishing and tourism (Grønlands Statistik 2013). Kapisilit, meaning 'the salmons', is the only spawning ground for salmon (*Salmo salar*) in Greenland³. Botanical investigations, related to the Isua mining project located just north of this key feature, were performed in 2011-2012. A flora list has been completed showing the flora in the study area (Appendix 4). The mining area is in close proximity to key feature 8 and the flora list thus gives an indication of the flora species found within this key feature.



Fig. 17a. Key feature 8, the inner Godthåbsfjord area, is shown by the green line. The defined borders of key features are only indicative.

³ <http://www.natur.gl/en/fish-and-shellfish/fish/laks/unique-salmon-population-in-kapisillit/>.

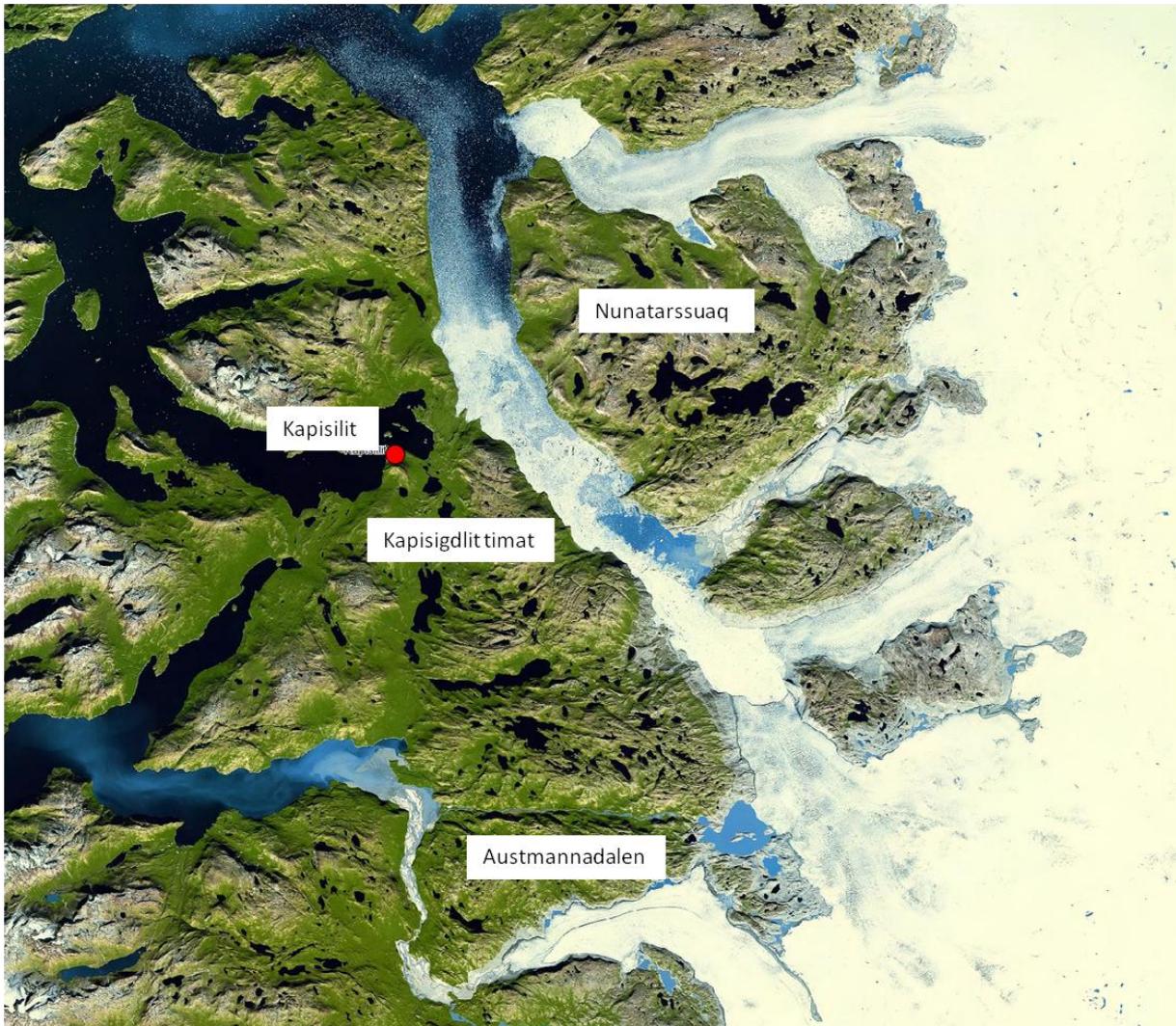


Fig. 17b. Satellite photo showing key feature 8, the inner Godthåbsfjord area. The settlement Kapisilit and the protected Austmannadalen is located within this key feature. Source: Moderated from NunaGis.

9. GRØNNEDAL AREA

Key feature 9, the Grønnedal area, was designated because of high productivity and high landform heterogeneity. Also, it contains three different vegetation zones (9, 10 and 15) (Fig. 18a).

The Grønnedal area is located at 61°N. The area is encircled by the Arsuk Fjord and the Arsuk Glacier to the north, the Arsuk Island to the West, the Nordre Qipisarqo Glacier to the southeast and the Greenland Ice Cap to the east (Fig. 18b). The area consists of mountains, valleys, lakes, fjords, and glaciers. The fauna here is rich including species of e.g. caribou, musk ox, Arctic fox, Arctic hare, rock ptarmigan, salmon and trout. A former military station (Grønlands Kommando) was recently situated at Grønnedal. The station was closed down 1st of January 2013. Approximately 5 kilometers from Grønnedal the abandoned mining town Ivigtut is found, where mining for kryolit was performed for more than a 100 years from the mid 1800s to the late 1900s. The settlement Arsuk is today the nearest populated settlement with 106 inhabitants.



Fig. 18a. Key feature 9, the Grønnedal area, is shown by the green line. The defined borders of key features are only indicative.



Fig. 18b. Topographic map showing key feature 9, Grønnedal area, illustrated by a star symbol. The abandoned settlement Ivittut (Ivigtut) is located just south of Grønnedal. Source: Moderated from NunaGis.

Key features located in bioclimatic Subzone 6

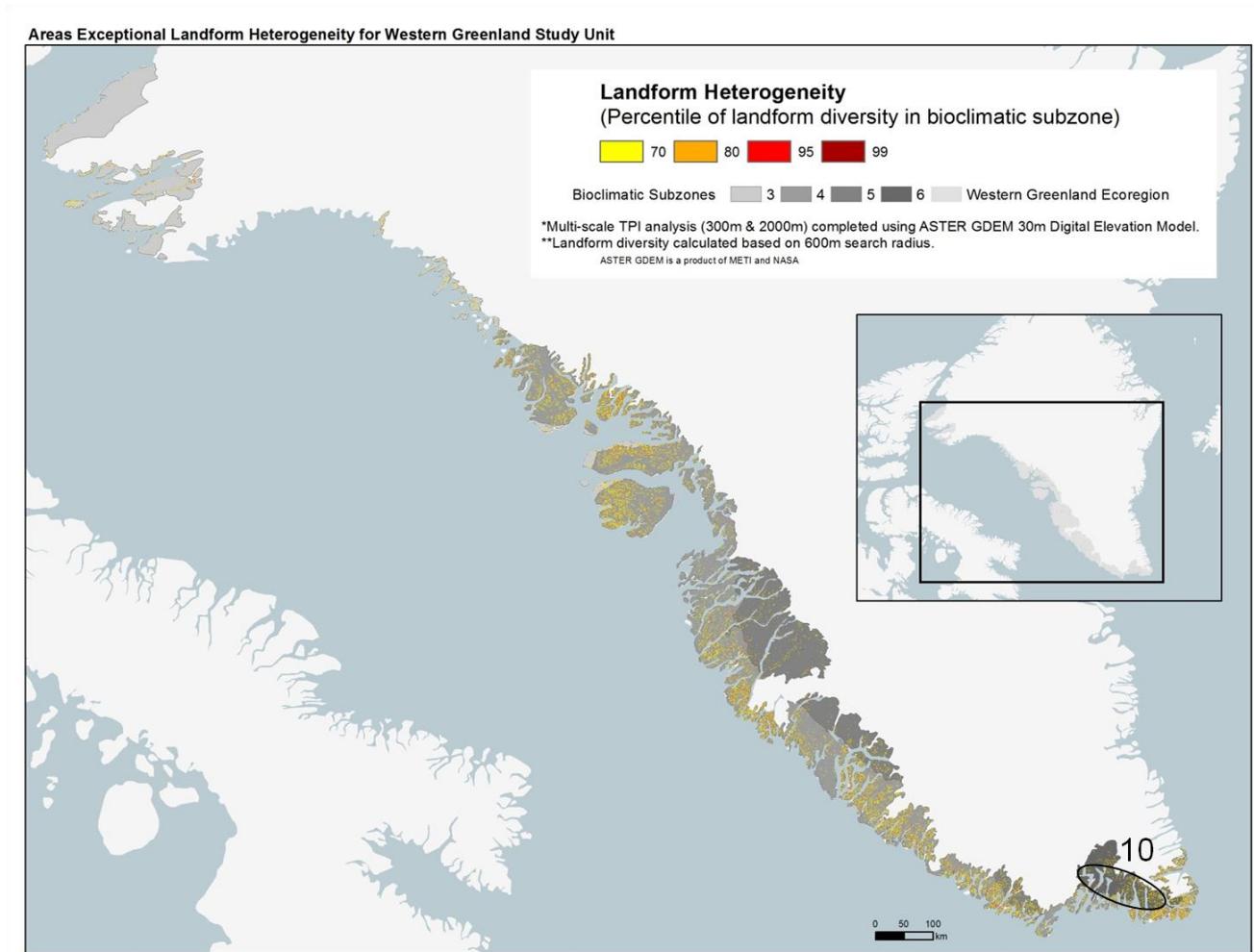


Fig. 19. Key feature 10, South Greenland, is the only key feature located within bioclimatic subzone 6.

10. SOUTH GREENLAND

Key feature 10, South Greenland, was designated based primarily on the exceptional high productivity found in this area which also has a relatively varied landscape. The area closest to the Greenland Ice Cap belongs to a subarctic continental plant belt which is not considered a part of this key feature because of low productivity and low landscape heterogeneity in this specific area.

This key feature is located at the southern tip of Greenland at 60°N (Fig. 20a and b). The area is characterized by islands and fjords, lakes, valleys, low vegetation hills and mountain areas above 1000 meters (Tamstorf 2001). The area has perhaps the highest terrestrial primary productivity in all of Greenland, high vegetation diversity and the highest levels of endemic and rare vascular plants in Greenland (Jensen 1999). The area around Narsaq is the only place within the ecoregion that has actual forests and therefore species of flora and fauna found nowhere else in Greenland thrives here. Several towns and settlements are located within this key feature. Sufficiently high temperatures and an adequate amount of rainfall support agriculture in the area (Tamstorf 2001). Approximately 50 registered sheep farms and a modest amount of miscellaneous farms (horse-, cattle-, caribou-, winter fodder-, potato- and vegetable farming) are present in the area, mainly around Narsaq (Agricultural Consulting Services; Statistics Greenland (II) 2011). Indeed, exceptional primary production, landform heterogeneity, and plant biodiversity make this key feature unique for not only the ecoregion but all of Greenland.



Fig. 20a. Key feature 10, South Greenland, is shown by the green line. The defined borders of key features are only indicative.



Fig. 20b. Satellite photo showing part of key feature 10, South Greenland, and some of the towns and settlements in the area. Source: Moderated from NunaGis.

APPENDICES

Appendix 1.

THE ARCTIC 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 (Fig. A1) using two broad biogeographic ecological classification methods: the Circumpolar Arctic Vegetation Map (CAVM team 2003; Walker et al. 2005) for regions on land (A) and, at sea (B), the Marine Ecoregions of the World project (Spalding et al. 2007).

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).

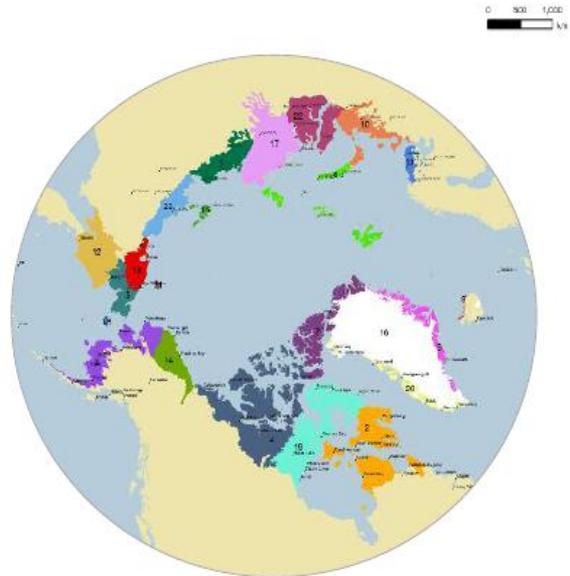
A.

FIGURE 1.4
TERRESTRIAL ARCTIC ECOREGIONS THAT
ARE THE FOCUS OF RACER ASSESSMENTS.

Source: WWF, adapted from CAVM Team 2003.

TERRESTRIAL STUDY UNITS

- | | |
|---|-------------------------------|
| 1. Anabar - Lena | 12. Koryakia |
| 2. Baffin - Labrador | 13. North Beringian Islands |
| 3. Beringian Alaska | 14. Northern Alaska |
| 4. Central Canada | 15. Novisiberian Islands |
| 5. Eastern Chukotka | 16. Rock and Ice |
| 6. Eastern Greenland | 17. Taimir Peninsula |
| 7. Ellesmere - Northern Greenland | 18. West Chukotka |
| 8. Franz Josef Land - Novaya Zemlya -
Severnaya Zemlya | 19. West Hudsonian |
| 9. Iceland - Jan Mayen Island | 20. Western Greenland |
| 10. Kanin - Pechora | 21. Wrangel Island |
| 11. Kola Peninsula | 22. Yamal - Gydan |
| | 23. Yana - Indigirka - Kolyma |



B.

FIGURE 1.5
MARINE ARCTIC ECOREGIONS THAT
ARE THE FOCUS OF RACER ASSESSMENTS.

Source: WWF, adapted from Spalding et al. 2007.

MARINE STUDY UNITS

- | | |
|---|--|
| 24. Arctic Ocean - Atlantic Basin | 37. Iceland Shelf |
| 25. Arctic Ocean - Pacific Basin | 38. Kara Sea |
| 26. Baffin Bay - Canadian Shelf | 39. Labrador Sea Basin |
| 27. Beaufort Sea - continental coast & shelf | 40. Lancaster Dound |
| 28. Beaufort - Amundsen -
Viscount Melville - Queen Maud | 41. Laptev Sea |
| 29. Chukchi Sea | 42. North Greenland |
| 30. Baffin Bay | 43. North and East Barents Sea |
| 31. East Greenland Shelf | 44. Northern Grand Banks - Southern Labrador |
| 32. East Siberian Sea | 45. Northern Labrador |
| 33. Eastern Bering Sea | 46. Northern Norway and Finnmark |
| 34. Fram Strait | 47. Norwegian Sea |
| 35. High Arctic Archipelago | 48. West Greenland Shelf |
| 36. Hudson complex | 49. Western Bering Sea |
| | 50. White Sea |

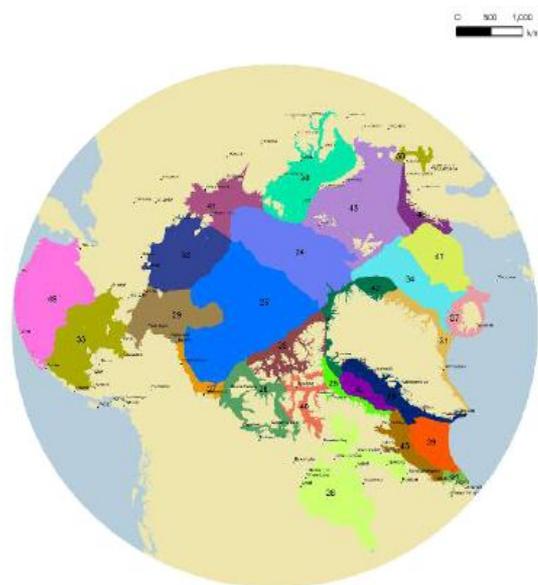


Fig. A1. Terrestrial (A) and marine ecoregions (B) that are the focus of RACER assessments. Source RACER: Rapid Assessment of Circum-Arctic Ecosystem Resilience – handbook, p. 18-19 (Christie and Sommerkorn 2012).

Appendix 2.

BIODIVERSITY

Terrestrial mammals

Caribou (*Rangifer tarandus*) is found almost throughout Western Greenland. They include both the indigenous wild caribou and the feral semi-domestic reindeer, the two are almost alike. The latter was introduced to Western Greenland in 1952 and again in 1963-65. Twelve separate populations of caribou exist in the region (Fig. A2). The total number of individuals is not known for all 12 populations, however, the largest concentrations exist within the areas Kangerlussuaq-Sisimiut (estimated at 98,300 individuals in 2010) and Akia-Maniitsoq (estimated at 24,000 individuals in 2010) (Cuyler et al. 2011).

Caribou tend to move to areas above 300 m elevation to calve (Cuyler and Linnell 2004). May-June is considered to be the peak calving period. During this period, the animals are very sensitive to human activities and, if disturbed, the mother might abandon her calf (Boertmann 2004). Only a few studies on Greenland caribou calving grounds are available, and the areas used are more extensive than the currently confirmed calving grounds (Cuyler pers. comm., 2013). Currently given calving areas are near the ice sheet by Sisimiut and Maniitsoq with two smaller areas located south of Nuuk (NunaGIS, 2012). Caribou feed on grasses, sedges and lichens, some individuals travel distances of up to 170 kilometers between summer and winter habitats, while others are more stationary (Jensen 2003, Cuyler and Linnell 2004).



Fig. A2. Locations and names of the 12 caribou/reindeer populations in Western Greenland. Source: The Greenland Institute of Natural Resources, www.natur.gl.

- (1) Inglefield/Pruhø Land
- (2) Olrik Fjord
- (3) Nuussuaq Halvø
- (4) Naternaq
- (5) Kangerlussuaq-Sisimiut
- (6) Akia-Maniitsoq
- (7) Ameralik
- (8) Qeqertarsuatsiaat
- (9) Qassit
- (10) Neria
- (11) Ivittuut
- (12) Isortoq

Muskoxen (*Ovibos moschatus*) are indigenous to the northern and eastern parts of Greenland and were originally absent from Western Greenland. In the 1960s, 27 individuals were transferred from Eastern Greenland to the inner Kangerlussuaq area, northeast of Maniitsoq. The population grew and the 2005 population estimate was 5,000-10,000 animals (Cuyler and Witting 2004, Johansen et al. 2008). Since the 1960s, muskoxen have been introduced to other parts of Western Greenland including Kap Atholl (Qaanaaq) and Sigguk/Svartenhuk (Upernavik/Uummannaq) in the north of Greenland, Naternaq in the north-central part, and Ivittuut in the south. The population status of these areas is unknown⁴.

Muskoxen require areas with variable terrain to thrive. In the summer months they prefer low valleys where they graze on grasses, sedges and young shoots of birch and willow, and in the winter they move to mountain areas with shallow snow cover (Johansen et al. 2008).

Polar bears are regarded as marine mammals but are regularly seen on land from south to the north of Greenland. Few polar bear breeds in Northwest Greenland⁵.

The Arctic hare and the Arctic fox are common throughout the entire Western Greenland ecoregion (Johansen 2008).

Birds

The two most abundant species of geese in the Western Greenland ecoregion are the Greenland White-fronted goose (*Anser albifrons flavirostris*) and the Canada goose (*Branta canadensis*). The Greenland White-fronted goose is indigenous to the region, whereas the Canada goose made its first appearance in the 1990s. The Greenland White-fronted goose arrives in Western Greenland in the beginning of May, where they breed during May-June and only in this area, and leave to fly south in September. The most important spring staging and moulting areas are located between Maniitsoq and Upernavik. Current status of the Greenland White-fronted goose in Greenland is 'endangered' and declining in numbers. This is believed to be partly due to dramatic increases in population numbers of the Canada goose. The two species are similar in both biology and choice of habitat.

Detailed knowledge about location of spring staging and moulting areas for the Canada goose is lacking. However, they are believed to use roughly the same areas as the Greenland White-fronted goose (65-72°N). Their total population number is unknown but is assumed to be increasing (Johansen et al. 2008, Jensen 2003).

The gallinaceous bird, the Rock Ptarmigan (*Lagopus muta*) is common and breeds in the entire region although the population is known to fluctuate from year to year (Boertmann 2002).

⁴ <http://www.natur.gl/en/birds-and-mammals/terrestrial-mammals/muskoxen/>.

⁵ <http://www.natur.gl/pattedyr-og-fugle/havpattedyr/isbjoern/>.

The Arctic char and other freshwater fish species

The Arctic char (*Salvelinus alpinus*) is common in streams and fresh water lakes throughout the Western Greenland ecoregion, where it functions as a top predator, and it is often the only fish present in the relatively simple ecosystems of Arctic lakes and streams. The Arctic char exists in two forms: an anadromous form that spends the summer in the sea and migrates to fresh water streams in the winter to breed, and a landlocked form that spends all its life in freshwater. The anadromous form has a faster growth rate and is therefore most important in relation to fishing activities (Johansen et al. 2008). To spawn successfully the anadromous form requires deep pools that do not freeze in winter and streams with enough water flow to supply the eggs with sufficient amounts of oxygen (Boertmann 2004).

The three-spined stickleback (*Gasterosteus aculeatus*) is common in both fresh and salt water within the ecoregion.

There is only one spawning-ground for salmon in Greenland. It is located in the river near Kapisillit in south-western Greenland (Johansen et al. 2008).

The American eel (*Anguilla rostrata*) is rare in Greenland but can be found in the lakes of south-western Greenland.

Appendix 3

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. 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. A3A). 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. A3B). The details of this method are described in Huard 2010.

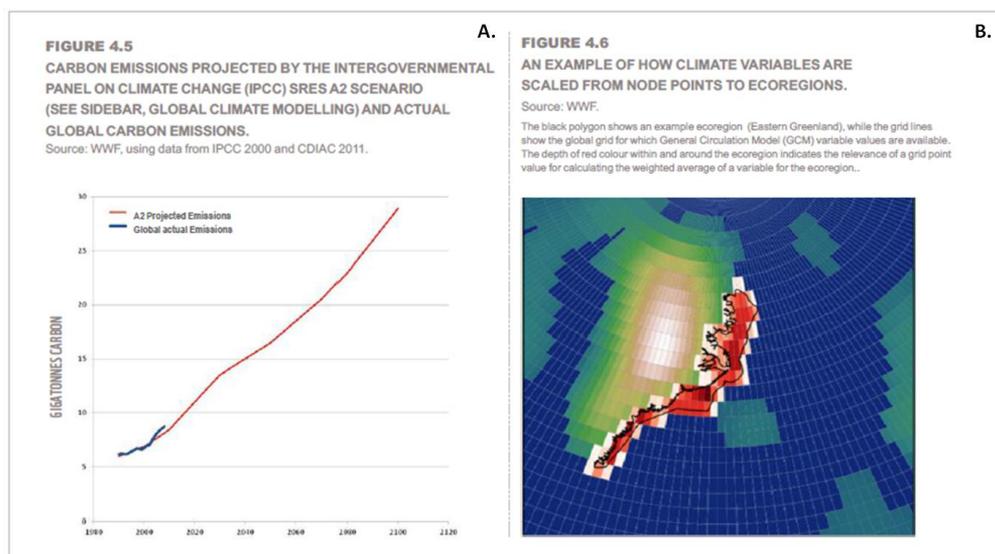
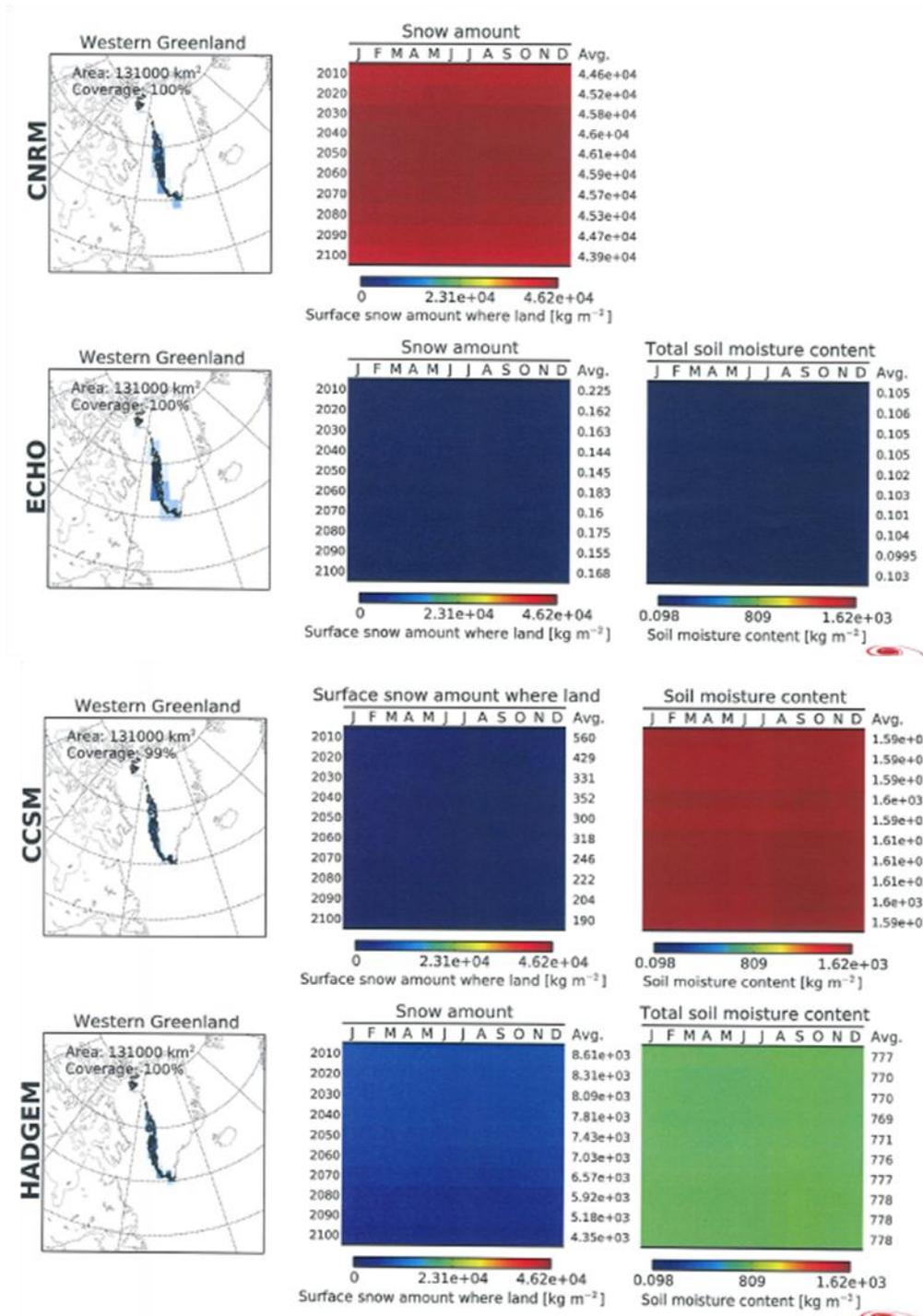
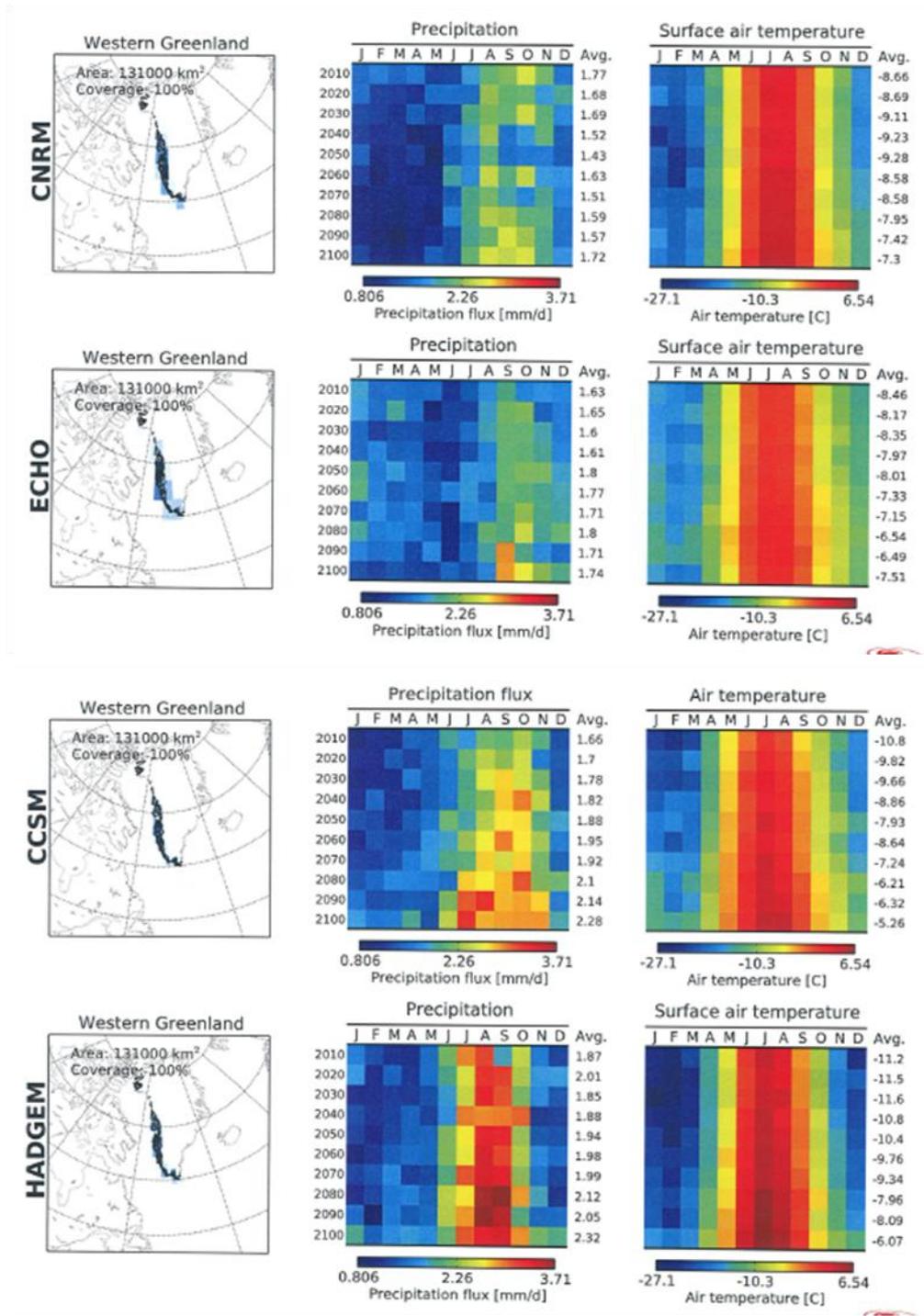


Fig. A3. A. Carbon emissions projected by IPCC SRES A2 scenario and actual global carbon emissions. B. example of how climate variables are scaled from node points to ecoregions (See also RACER: Rapid Assessment of Circum-Arctic Ecosystem Resilience – handbook (Christie and Sommerkorn 2012). Link to handbook: wwf.panda.org/arctic/racer).

GENERAL CIRCULATION MODELS (GCM'S) FOR WESTERN GREENLAND

Projections for Snow amount, Soil moisture, Precipitation, and Air temperature based on GCM's for the Western Greenland ecoregion through to the 21st century.





Trend: Snow amount – decreasing; Soil moisture - stable; Precipitation – increasing; Air temperature – increasing.

Taxon	Taxon continued	Taxon continued
Agrostis mertensii	Draba sp.	Poa alpina
Alnus crispa	Dryas integrifolia	Poa glauca
Alopecurus aequalis	Dryopteris assimilis	Poa pratensis
Angelica archangelica ssp. norvegica	Empetrum nigrum ssp. Hermaphroditum	Polygonum viviparum
Antennaria angustata	Epilobium anagallidifolium	Potamogeton alpinus ssp. tenuifolia
Antennaria canescens	Epilobium palustre	Potentilla crantzii
Antennaria glabrata	Equisetum arvense	Potentilla egedii
Armeria scabra ssp. sibirica	Equisetum sylvaticum	Potentilla hookeriana
Artemisia borealis	Equisetum variegatum	Potentilla nivea
Bartsia alpina	Erigeron humilis	Potentilla tridentata
Betula glandulosa	Erigeron uniflorus	Primula stricta
Betula nana	Eriophorum angustifolium ssp. subarcticum	Puccinellia phryganodes
Botrychium lunaria	Eriophorum scheuchzeri	Puccinellia cfr. coarctata
Calamagrostis langsdorffii	Euphrasia frigida	Puccinellia sp.
Calamagrostis neglecta	Festuca brachyphylla	Pyrola grandiflora
Calamagrostis hyperborea	Festuca rubra	Pyrola minor
Callitriche palustris	Festuca vivipara	Ranunculus confervoides
Campanula gieseckiana	Gentiana nivalis	Ranunculus hyperboreus
Campanula uniflora	Gnaphalium norvegicum	Ranunculus pygmaeus
Cardamine bellidifolia	Gnaphalium supinum	Ranunculus reptans
Cardamine pratensis	Gymnocarpium dryopteris	Rhododendron lapponicum
Carex bigelowii	Harrimanella hypnoides	Rhodiola rosea
Carex brunnescens	Hieracium hyparcticum	Rumex acetosella
Carex canescens	Hierochloë alpina	Sagina caespitosa
Carex capillaris	Hippuris vulgaris	Salix arctophila
Carex capitata ssp. arctogena	Huperzia selago	Salix glauca
Carex deflexa	Isoëtes echinospora ssp. muricata	Salix herbacea
Carex glacialis	Juncus arcticus	Salix uva-ursi
Carex glareosa	Juncus biglumis	Saxifraga aizoides
Carex gynocrates	Juncus castaneus	Saxifraga caespitosa
Carex lachenalii	Juncus trifidus	Saxifraga cernua
Carex macloviana	Juncus triglumis	Saxifraga foliolosa
Carex misandra	Juniperus communis ssp. alpina	Saxifraga hyperborea
Carex nardina	Kobresia myosuroides	Saxifraga nivalis
Carex norvegica	Koenigia islandica	Saxifraga paniculata
Carex rariflora	Ledum groenlandicum	Saxifraga oppositifolia
Carex rufina	Ledum palustre ssp. decumbens	Saxifraga tenuis
Carex rupestris	Leymus mollis	Saxifraga sp. (tenuis/nivalis)
Carex saxatilis	Limosella aquatica	Saxifraga tricuspidata
Carex scirpoidea	Loiseleuria procumbens	Scirpus caespitosus
Carex subspathacea	Lomatogonium rotatum	Sibbaldia procumbens
Carex supina ssp. spaniocarpa	Luzula arctica	Silene acaulis
Cassiope tetragona	Luzula confusa	Sparganium hyperboreum
Cerastium alpinum	Luzula groenlandica	Stellaria calycantha
Cerastium cerastoides	Luzula multiflora	Stellaria crassipes
Chamaenerion angustifolium	Luzula parviflora	Stellaria humifusa
Chamaenerion latifolium	Luzula spicata	Stellaria longipes
Cochlearia groenlandica	Lycopodium annotinum	Stellaria sp.
Comarus palustre	Menyanthes trifoliata	Taraxacum lacerum
Coptis trifolia	Minuartia biflora	Taraxacum sp.
Corallorhiza trifida	Minuartia groenlandica	Thalictrum alpinum
Cystopteris fragilis	Minuartia rubella	Thymus praecox ssp. arcticus
Deschampsia flexuosa	Montia fontana ssp. fontana	Tofieldia pusilla
Deschampsia pumila	Oxycoccus palustris ssp. microphyllus	Triglochin palustre
Diapensia lapponica ssp. lapponica	Oxyria digyna	Trisetum spicatum
Diphasiastrum alpinum	Papaver radiculatum	Trisetum triflorum
Diphasiastrum complanatum	Pedicularis flammea	Vaccinium uliginosum
Draba aurea	Pedicularis hirsuta	Vahlodea atropurpurea
Draba cana	Pedicularis labradorica	Veronica alpina
Draba cinerea	Pedicularis lapponica	Veronica wormskjoldii
Draba crassifolia	Phegopteris connectilis	Viola sp.
Draba glabella	Phippisia algida	Viscaria alpina
Draba nivalis	Phyllodoce coerulea	Woodsia ilvensis
Draba norvegica	Plantago maritima ssp. borealis	

Appendix 4.

Flora list of the study areas, 2011-2012, related to the Isua mining project. Modified from Bay and Simonsen 2013.

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