DISKO ISLAND AND NUUSSUAQ PENINSULA, WEST GREENLAND

A strategic environmental impact assessment of petroleum exploration and exploitation

Scientific Report from DCE – Danish Centre for Environment and Energy No. 199 2016

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Preface

Disko Island and parts of Nuussuaq Peninsula have petroleum potential and exploration activities took place until 1996 when a dry exploration well was drilled. When the Greenland government issued a new oil and mineral strategy in 2014 (Naalakkersuisut 2014a), a licencing round was announced in late 2016 (Naalakkersuisut 2014b). This round includes three licence blocks covering western Nuussuaq (1 block) and entire Disko Island (two blocks) (Figure 1).

It is statutory that a strategic environmental impact assessment of exploration and exploitation activities shall be carried out before an area is opened for petroleum exploration, and the Environmental Agency for Mineral Resource Activities (EAMRA) has commissioned DCE – Danish Center for Environment and Energy, Aarhus University and Greenland Institute of Natural Resources (GINR) to compile a Strategic Environmental Impact Assessment (SEIA) of petroleum activities in the licence blocks.

This SEIA gives an overview of the environment of the Disko/Nuussuaq area, presents important information gaps in relation to future activities in the areas and gives an assessment and risk evaluation of expected environmental impacts from petroleum exploration and exploitation activities in the three proposed licence blocks.

In 2015, some background studies were carried out in the assessment area, in order to update the information on vegetation and occurrence on birds (Wegeberg et al. 2016, Boertmann & Petersen 2016). These are described in the text Boxes 2 and 5).

Summary

The Environmental Agency for Mineral Resource Activities (EAMRA) of the Greenland government has commissioned DCE – Danish Centre for Environment and Energy, Aarhus University and Greenland Institute of Natural Resources (GINR) to compile a strategic environmental impact assessment (SEIA) of petroleum activities in the licence blocks of the forthcoming licencing round covering the western part of Nuussuaq Peninsula and Disko Island.

Three licence blocks cover the western part of Nuussuaq and entire Disko, and licence applications shall be submitted by 15 December 2016.

This SEIA gives an overview of the environment of the Disko/Nuussuaq area, presents important information gaps in relation to future activities in the areas and gives an assessment and risk evaluation of expected environmental impacts from petroleum exploration and exploitation activities in the three proposed licence blocks.

The assessment area covers the terrestrial parts of Disko and Nuussuaq including the coastal environment, while the waters off the assessment area are treated by a previous SEIA.

The environment

The climate of the assessment area is arctic and permafrost is widespread. The topography is dominated by alpine areas intersected by long valleys and a characteristic feature of Disko Island is the many homeothermic springs.

The most significant elements of the biological environment, in this assessment context, are the caribou of Nuussuaq (a discrete population and red listed as vulnerable (VU)), the geese (Greenland white-fronted goose) and their breeding and moulting areas, seabird breeding colonies along the coasts and Arctic char in some of the freshwater systems.

The population of white-fronted geese is endemic to Greenland; it is very small and in decrease and therefore red listed as endangered (EN). There are several areas in the assessment area, which are of international importance to this population (Ramsar sites).

The flora is very rich including several rare species. The very high biodiversity especially in the Disko area can be explained by the variation in the geology and soils, the presence of homeothermic springs and by the fact that the area is in the transition zone between the low Arctic and high Arctic and that both oceanic and continental areas are included in the area.

Some of the homeothermic springs moreover support a unique micro fauna.

The human use of the terrestrial habitats includes hunting for caribou (on Nussuaq only) and ptarmigan. In the coastal environment fisheries for lumpsucker, capelin and Arctic char are common and widespread and the local tourist industry arranges trips and hikes there.

Impact assessment

Impact of exploration activities in the Disko/Nuussuaq area

Seismic surveys typically cover large areas in an exploration phase and have the potential to cause widespread physical impacts on terrain and vegetation primarily in the form of tracks along the seismic lines. These impacts can largely be mitigated by carrying out the surveys in winter when terrain and vegetation is covered by a protective cover of snow. However, physical impacts may still occur at mobilization areas and locally along the seismic lines for example at steep slopes. The experience from winter seismic activities in Jameson Land, East Greenland in the 1980s show that even in level terrain damages occurred, and these are still visible. But careful regulation of activities will contribute to mitigate impacts, for example by ensuring that snow cover is sufficient and that transportation routes avoid steep slopes.

Disturbance from seismic surveys will mainly be local and temporal, and in the assessment area especially geese and caribou will be sensitive. By carrying out seismic surveys in winter the disturbance impacts will also be reduced, as the geese have left the area and only caribou will be exposed. Planning based on knowledge on the distribution patterns of the caribou can contribute to further reduce the disturbance impacts. As seismic activities are limited in time to a single or a few seasons, no long term impacts on the caribou population will be expected if the activities are carefully planned and regulated.

Physical impacts from exploration drilling in the assessment area will depend on the actual drill site and the season in which the drilling is carried out. Drill sites far from the coast for example will require longs access roads from a staging area on the coast. The least physical and visual impacts would be expected from winter drilling, when access roads can be constructed from snow and ice. Summer activities would cause more widespread terrain and vegetation damages, which can be very pronounced in especially moist habitats if gravel pads and embankments are required or if the permafrost layer is impacted. The physical impacts from the well drilled in 1996, were small and remediated, and today primarily tracks from off-road driving with ATVs are still visible. The physical impacts from an access road constructed in 2007 are still conspicuous, in part because the tracks were not remediated as requested.

Disturbance impacts from drilling activities are more localized than from seismic surveys, and they can also be mitigated by limiting the activities to the winter. The vulnerable goose and seabird species winters outside the assessment area and only caribou is present in winter. Exploration drilling has potential to displace caribou from critical winter habitats, but precise background knowledge of the caribou distribution and migration followed by careful planning may contribute to avoid such situations.

Other activities related to exploration drilling have disturbance potential as well. Especially helicopters commuting between drill sites and airports can disturb wildlife.

Exploration drilling produces large amounts of waste and atmospheric emissions. From the drilling process drilling mud and cuttings are produced and from the energy production large amounts of greenhouse gasses and other air pollutants are emitted. These wastes have the potential to cause local pollution and in case of greenhouse gases they contribute to the global warming. The other air pollutants may cause Arctic haze, which may accumulate in the long and deep valleys of the assessment area.

It is recommended that environmental impacts from these wastes and emissions shall be mitigated by strict regulation of the activities and by applying the Best Available Techniques (BAT) and Best Environmental Practice (BEP) principles in combination with the highest international standards such as those dictated by the OSPAR convention for related off shore activities.

The best way to handle drilling mud and cuttings is usually to dispose it to controlled sites, but other ways may be feasible depending on the environmental properties of the wastes.

There will be other potential impacts, such as consumption of fresh water, but these can be mitigated by careful planning and applying BAT and BEP.

Impacts of exploitation activities in the Disko/Nuussuaq area

The impacts from oil producing activities are more long-term. The physical environmental impacts will encompass habitat loss and fragmentation, and the most vulnerable species in this respect will, as in case of exploration activities, be caribou, geese, seabirds, Arctic char and rare plants.

Disturbance from exploitation activities will mainly impact caribou and geese, but also breeding and moulting seabirds along the coasts of the assessment area are vulnerable. Disturbed caribou may change their habitat use and there will be a risk of changed availability of caribou to the hunters.

Apart from accidental oil spills, the most severe environmental issue related to production wells is the produced water which contains many different pollutants. Produced water has to be cleaned to high standards or reinjected. Untreated produced water cannot be released to the environment.

As drilling continues during the production phase drilling mud and cuttings is produced and has to be disposed of as during the exploration phase.

Production of oil generates huge amounts of greenhouse gasses and other air pollutants. The greenhouse gas emissions from a large oil field may increase the Greenland greenhouse gas contribution many fold, and another risk from the emissions to the air is the generation of Arctic haze, if air emissions are not cleaned to a high standard.

Finally, production of oil requires large amounts of water, which usually has to be taken from rivers and lakes nearby, and potentially threatening limnic habitats and species.

The human use of the environment may be affected by establishment of infrastructure, for instance by disturbance and displacement of hunted species and by pollution of coastal habitats.

Impacts of accidental oil spills in the Disko/Nuussuaq assessment area

Oil spills from land-based exploration or production have the potential to be a severe threat to the environment. This will be the case if the spilt oil enters water courses and particularly if it by rivers ends up along the coasts of the assessment area. If spilt oil can be contained and prevented from moving into rivers, the environmental impacts will be much more localized and limited compared to a spill in the coastal marine areas.

The most significant impact from an oil spill restricted to the land areas will be destroyed vegetation in the affected area.

During production oil shall be shipped from the area and there is during this process also a risk for spilling large quantities of oil into the marine environment. This will impact the sensitive, coastal environment with potential for long-term impacts for example, on the human use, in a large area. This issue has been further dealt with in the Disko West SEIA (Boertmann et al. 2013).

Sammenfatning

I 2016 åbnes landområderne på den vestlige halvdel af Nuussuaq-halvøen og hele Disko-øen for olieefterforskning, hvor tre efterforskningsblokke bliver udbudt (Figur 1). I forbindelse hermed er denne strategiske miljøvurdering af forventede aktiviteter i de tre blokke udarbejdet. Miljøvurderingen skal dels bidrage til grundlaget for politiske beslutninger, dels til identifikation af manglende viden, der skal bruges ved regulering af kommende aktiviteter. Endvidere kan denne viden udnyttes af de selskaber, der opnår tilladelse til at efterforske og udnytte olie/gasforekomster, når de skal udarbejde miljøvurderinger af deres specifikke aktiviteter.

Miljøet i vurderingsområdet Disko/Nuususaq

Klimaet i området er arktisk, og en væsentlig faktor i forbindelse med olieefterforskning på land er forekomsten af permafrost.

Topografien er præget af høje fjelde, og lavlandsområder findes primært langs kysterne og i dale, der skærer sig langt ind i landområderne.

Et særligt element er de talrige ensvarme kilder på Disko. Disse er ofte omgivet af en meget rig vegetation og mange huser et særligt og unikt liv af mikroskopiske dyr.

Vegetationen i landområderne er mange steder rig og med mange forskellige, herunder sjældne plantearter. Dette hænger sammen med den varierede geologi, der giver mange forskellige jordtyper, med et varietet klima med både oceaniske og kontinentale områder og med at overgangen mellem den lavarktisk og højarktisk zone falder gennem området, sådan at både sydligt og nordligt udbredte plantearter findes her.

Dyrelivet på land er sparsomt, og de vigtigste arter i denne sammenhæng er rensdyr og grønlandsk blisgås. Rensdyr findes på Nuussuaq, hvor der er en lille lokal bestand (rødlistet som 'sårbar' (VU)). Blisgæssene findes i hele området, og flere områder på Disko er udpeget som Ramsar-områder, fordi der her forekommer internationalt vigtige antal af denne art. Denne gås yngler kun i Vestgrønland, bestanden er lille og i tilbagegang, hvorfor den betragtes som truet; på den grønlandske rødliste er den vurderet som 'moderat truet' (EN).

De ferske vande huser kun to fiskearter, hvoraf fjeldørred er vigtig i denne sammenhæng.

Landområderne udnyttes mest til jagt på rensdyr (kun på Nuussuaq) og ryper, mens der foregår fiskeri efter ammassat (lodde), stenbider og fjeldørred langs kysterne. Desuden har forskellige turistoperatører aktiviteter i landområderne især på Disko.

Miljøvurdering af landbaserede olieaktiviteter i Disko/ Nuussuaq-området

Efterforskning

De efterforskningsaktiviteter som vil medføre de væsentligste miljøpåvirkninger i området er seismiske undersøgelser og efterforskningsboringer.

Seismiske undersøgelser foretages først langs lange linier i landskabet, som fordeles i et netværk med flere km i mellem linierne (betegnet som 2D-seismik). Langs disse linier kører tungt materiel, som genererer et lydsignal, hvis reflektioner fra undergrundens forskellige lag opfanges af mikrofoner på landjorden. Lyden frembringes af en stor vibrator, eller i særlige tilfælde med sprængstof. Når et boremål siden skal udpeges, foretages nye seismiske undersøgelser, men med meget tættere linier og i et meget mindre område (betegnet som 3D-seismik).

Efterforskningsboringer foretages for at undersøge om der er olie eller gas til stede i de boremål, som er fundet ved de seismiske undersøgelser. De foretages med en borerig. I tørre landområder kan en borerig placeres direkte på undergrunden, på fugtig jord placeres den som regel på en stabil grusopfyldning. Transporten af boreudstyr og anden infrastruktur mellem et landgangssted på kysten og et borested inde i land omfatter mange tusind tons; i 1996 blev 3700 tons udstyr sat i land på kysten af Nuussuaq i forbindelse med en enkelt efterforskningsboring.

Miljøpåvirkningerne fra efterforskning skyldes først og fremmest:

- fysiske påvirkninger
- forstyrrelser af dyreliv
- affald og udledninger til luft og vand
  - boremudder og -spåner
- forbrug af vand

De *fysiske påvirkninger* omfatter ødelæggelse af terræn og vegetation, hvor der køres med tungt udstyr og hvor infrastruktur som for eksempel borerigge og beboelseslejre opføres. Især i forbindelse med seismiske undersøgelser er der risiko for omfattende påvirkninger af vegetation og terræn langs de seismiske linier, i form af kørespor, nedslidt vegetation og påvirkning af permafrostlaget. En efterforskningsboring forgår derimod i et begrænset område, hvor de fysiske påvirkninger bliver koncentreret. Foregår en boring langt fra kysten vil anlæggelse af kørespor bidrage til at øge det fysisk påvirkede område. Påvirkningerne kan medføre at levesteder for særligt planter ødelægges eller fragmenteres, og i vurderingsområdet vil sjældne planter med begrænsede voksesteder være sårbare i denne sammenhæng.

Store synlige skader udbredt i terrænet er også en risiko, særligt ved de seismiske undersøgelser.

Disse påvirkninger forebygges bedst ved at udføre aktiviteterne om vinteren, idet et snelag vil virke beskyttende på vegetation og terræn. Der kan desuden benyttes særlige skånsomme køretøjer med lavt hjultryk (såkaldt 'low impact seismics'), som er kendt fra Canada.

Erfaringerne fra tidligere seismiske undersøgelser foretaget om vinteren i Jameson Land i 1980erne viser, at man alligevel skal være opmærksom på fysiske påvirkninger, da der her stadig kan ses kørespor og andre skader i terrænet. Derfor skal undersøgelserne planlægges grundigt og der skal være regulering på plads, som bygger på indgående baggrundsviden om miljøet.

Erfaringerne fra en efterforskningsboring på Nuussuaq i 1996, viser at man skal være særligt påpasselig overfor ukontrolleret kørsel i terrænet med små ATV-køretøjer. Der står i dag mange spor fra disse i det omkringliggende terræn. De fysiske påvirkninger fra de øvrige aktiviteter blev reetableret efter forskrifterne og de fremstår kun utydeligt i dag.

En større transportoperation i 2007 i forbindelse med mineralefterforskning medførte anlæggelsen af et ca. 30 km langt kørespor på Nuussuaq. Dette blev ikke retableret nær så godt som efter aktiviteterne i 1996, og det fremstår meget tydligt i dag. Der blev desuden i 2015 konstateret mindre skader på permafrostlaget ('thermokarst') omkring dette kørespor.

Forstyrrelser af dyreliv omfatter bortskræmning og adfærdsændringer. Seismiske undersøgelser, som bevæger sig gennem vurderingsområdet, vil påvirke dyrelivet på denne måde i et meget stort areal, men kortvarigt det enkelte sted, mens en efterforskningsboring påvirker lokalt i betydeligt længere tid (det varer gerne flere måneder at foretage en boring).

Transport med helikopter i forbindelse med efterforskningsaktiviteter kan også have stor forstyrrelseseffekt.

I vurderingsområdet er særligt rensdyr og gæs sårbare overfor forstyrrelser, og der er risiko for at skræmme disse væk fra vigtige levesteder i den periode aktiviteterne varer. Dette kan for eksempel medføre at rensdyr skræmmes væk fra steder, hvor man traditionelt fanger dem i jagtsæsonen. Men generelt vil påvirkningerne være af kort varighed – dvs. en enkelt sæson.

Denne type påvirkninger forebygges bedst ved nøje planlægning og regulering, der mindsker konflikterne i tid og rum og som er baseret på indgående baggrundsviden. Som eksempel kan nævnes råstofforvaltningens feltregler om 'vigtige områder for dyrelivet', som regulerer aktiviteter med henblik på at reducere forstyrrelser af f.eks. gæssene, fældende dykænder og rensdyr. Ligesom for de fysiske påvirkninger vil vinteraktiviteter forstyrre mindre, fordi de særligt følsomme gæs er trukket bort for vinteren.

De mest omfattende affaldsmængder, der skal håndteres i forbindelse med efterforskning, er de *borespåner* der dannes ved boring og det *boremudder* der anvendes. Boring af en 3000 m dyb brønd vil kunne producere 850 tons spåner og forbruge 600 tons boremudder, og begge dele skal bortskaffes efter endt operation. I Alaska er boremudderet og spånerne tidligere blevet gravet ned i nærheden af borestedet (såkaldte 'sumps'), hvilket også skete i 1996 på Nuussuaq. I dag anbefales at det transporteres til kontrollerede deponier eller pumpes tilbage i brønden for at undgå evt. miljøpåvirkninger som forurening fra udsivende materiale fra det nedgravede affald. Andre steder i Arktis graves det stadig ned. I vurderingsområdet bør kun miljøvenlige kemikalier, der er på de internationale godkendelseslister (OSPAR, HOCNF) benyttes (ligesom i de grønlandske offshore områder) og boremudder og spåner bør transporteres væk eller om muligt pumpes tilbage i brønden.

Den anden store udledning fra efterforskningsaktiviteter stammer fra maskinernes udstødning, idet der benyttes store mængder brændstof for at gennemføre aktiviteterne. Det drejer sig om drivhusgasser og andre forurenende stoffer som SO_2 og NO_x. Drivhusgasserne bidrager til den globale opvarmning og de andre til forsuring af nedbør og dannelse af 'Arctic haze', som er et særligt luftforureningsfænomen, der kan opstå ved udledning af udstødning i dale med kold stillestående luft.

Efterforskning kan medføre *yderligere miljøpåvirkninger,* som for eksempel et stort forbrug af ferskvand, hvor der i tørre egne er risiko for at tørlægge vandløb og søer. Der kan desuden forekomme mere trivielle påvirkninger, som fra anden mere normal aktivitet i arktis. Sådanne påvirkninger forebygges med god planlægning og gennem myndighedesregulering.

Produktion

Produktions/udnyttelsesfasen varer i mange år; ofte årtier og miljøpåvirkningerne er derfor også af lang varighed.

Miljøpåvirkningerne ved produktion af olie kan ligesom dem afledt af efterforskning opdeles i:

- fysiske påvirkninger
- forstyrrelser af dyreliv
- affald og udledninger til luft og vand
  - boremudder og -spåner
  - produceret vand
- forbrug af vand

De fysiske påvirkninger stammer fra placeringen af den mangeartede infrastruktur, der etableres i forbindelse med et oliefelt. Et enkelt oliefelt kan hurtigt dække 20 ha, og hvis der tillige skal etableres lange veje og olieledninger fra en havnefacilitet på kysten eller landingsbaner til fly kan det samlede påvirkede areal blive væsentligt større. Disse fysiske påvirkninger kan medføre at levesteder bliver ødelagt eller fragmenteret, vandringsveje for trækkende dyr bliver blokkeret, afstrømningsforhold for vand (især i forårsperioden) ændres og permafrosten nedbrydes.

Da undergrunden mange steder i vurderingsområdet er mere eller mindre tør, er terrænet dog ikke så sårbart overfor placering af infrastruktur, som det ses på 'North Slope' i Alaska eller i Sibirien.

Støvdannelse og efterfølgende afsætning i omegnen kan også medregnes til fysiske påvirkninger.

Endelig kan infrastrukturen give en visuel påvirkning af de landskabelige værdier i et udnyttelsesområde.

I vurderingsområdet er særligt sjældne planter med begrænset udbredelse sårbare, men også rensdyr, der skal vandre mellem sommerområder og vinterområder kan blive påvirket ved at vandringsveje bliver spærret. Fjeldørreds vandring op i elvene, kan ligeledes blive afspærret.

Mange af de fysiske påvirkninger kan forebygges gennem grundig planlægning baseret på indgående baggrundsviden om det miljø der arbejdes i, ligesom anvendelse af de nyeste teknikker kan bidrage til at reducere det areal der arbejdes på og forbruget af vand.

Forstyrrelserne af dyreliv stammer fra infrastrukturen (tilstedeværelsen af mennesker) og fra de mange aktiviteter, der udføres i terrænet - herunder kørsel på veje, helikopterflyvning og mennesker, der færdes i terrænet.

I vurderingsområdet er især gæssene sårbare over for forstyrrelser, og der er risiko for permanent at skræmme gæs bort fra vigtige levesteder, hvis der placeres infrastruktur nær sådanne. Ynglende havfugle og fældende dykænder langs kysterne er også sårbare over for forstyrrelser og vil kunne fordrives fra deres ynglekolonier og fældeområder.

Rensdyr vil kunne blive fortrængt fra vigtige levesteder af forstyrrende aktiviteter, og her kan også jagten blive påvirket.

En særlig påvirkning i denne sammenhæng, er at en borelejr vil kunne virke tiltrækkende på visse dyr, som kan finde fødemuligheder i det affald der samles. Det er særligt ravne og ræve, der optræder ved sådanne lejre og de vil kunne påvirke anden fauna i omegnen af en lejr ved øget prædation.

Forstyrrelser kan i vis udstrækning forebygges gennem planlægning og regulering, for eksempel ved at lade helikoptere flyve langs faste ruter og i en vis minimumshøjde, som angivet i de grønlandske myndigheders feltregler.

Den væsentligste udledning til miljøet fra olieproduktion er det vand, som pumpes op sammen med olien, betegnet som *'produceret vand'*. Dette vand indeholder, ud over olierester, mange forskellige forurenende stoffer, som kan være akut giftige, radioaktive, have hormon- eller gødningseffekt eller de kan indeholde tungmetaller. Der er tale om meget store mængder vand (lige så meget som den olie der pumpes op eller mere), som skal bortskaffes. I andre arktiske områder har man tidligere pumpet det ud i floder efter mere eller mindre rensning, men i Alaska pumpes det i dag tilbage i de olieførende lag ('re-injection'). Tilbagepumpning er miljømæssigt den bedste løsning, men kan det ikke lade sig gøre af tekniske grunde, anbefales det, at der gennemføres en meget grundig rensning før udledning efterfulgt af kemisk og biologisk monitering, der sikrer, at effekter holdes på et acceptabelt niveau.

Da boringer fortsætter under produktionen, skal der tillige bortskaffes både *boremudder og -spåner*, ligesom ved efterforskningen, men nu i større mængder, da der kan bores mange brønde.

Udledningerne til luften er ligeledes meget store, og et oliefelt vil producere mange gange det nuværende grønlandske bidrag af drivhusgasser. Også ved produktion vil der være risiko for dannelsen af 'Arctic haze'.

Udledningerne og affald fra produktionen kan reduceres noget ved brug af den bedst tilgængelige teknik og den bedste miljøpraksis (BAT og BEP principperne, jvf. OSPAR). Men der bliver under alle omstændigheder tale om store mængder af produceret vand, boremudder og -spåner som skal håndteres miljømæssigt forsvarligt. Det kan gøres ved at pumpe vandet og boremudder tilbage i undergrunden, ved at deponere boremudder og spåner på sikrede deponier eller ved at transportere det til modtagefaciliteter til videre behandling.

Luftforureningen kan begrænses noget ved at benytte svovlfattige olier og allerbedst ved at benytte andre energikilder som vandkraft, vind- og solenergi.

Det må forventes at etableringen af et oliefelt vil påvirke jagt og fiskeri i omgivelserne. Der er risiko for at jagtbare arter vil blive skræmt væk fra traditionelle fangstpladser og forurening af nærområder vil også være en risiko.

Andre påvirkninger. Et producerende oliefelt medfører tillige en række mere trivielle miljøpåvirkninger, som svarer til dem fra andre beboede steder i Grønland. Disse kan og skal reduceres ved anvendelse af BAT og BEP principperne og gennem god planlægning og regulering af myndighederne.

Ferskvandsforbruget ved olieproduktion kan være meget højt, og her skal indvinding foretages sådan at der ikke er risiko for ændrede forløb eller ligefrem udtørring af vandløb og søer hvor der for eksempel lever fjeldørred.

Afvikling

Når et oliefelt er udtømt, skal infrastruktur fjernes, terræn retableres og alle brønde forsegles. Dette kan vare flere år og indledes allerede inden produktionen er helt afsluttet. Der er herunder igen risiko for forstyrrelser af dyreliv fra den intensive transport mellem oliefeltet og et udskibningssted. Der er også risiko for spredning af ophobede forurenende stoffer.

Problemerne kan imødegås ved god planlægning og ved anvendelse af BAT og BEP-principperne, herunder ved at indtænke nedrivning og fjernelse allerede i konstruktionsfasen.

En 'cost-benefit'-analyse af de miljørelaterede problemer ved nedlæggelsen af et oliefelt i vurderingsområdet skal også udføres.

Oliespild

Et stort oliespild i forbindelse med olieaktiviteter på Nuussuaq eller Disko kan enten stamme fra en udblæsning ("blow out") i forbindelse med boring af en efterforsknings- eller produktionsbrønd eller være en følge af brud på en pipeline. Uheld i forbindelse med lastning af tankskibe ved en havn på kysten er også en risiko for oliespild. Erfaringerne fra andre steder i Arktis (særligt Rusland) viser, at brud på pipelines har givet de største spild på land. Risikoen for et spild er dog lille, men spild kan ikke udelukkes.

Oliespild på land vil normalt ikke få samme store udbredelse som spild til havs. Men rammer olien et vandløb, er der risiko for at olien kan spredes til større områder og evt. nå ud i det marine miljø. Det er desuden meget svært at forudsige et oliespilds udbredelse, hvis det synker ned i jorden.

Oliespild på land ødelægger især vegetationen, og olien vil opsuges i jordlagene, hvor den kan ligge i mange år, hvis ikke den graves op. Når olien ud i ferskvandsystemer, vil fisk kunne påvirkes og forgiftes og vandfugle vil kunne påvirkes af olien.

Landdyr og -fugle vil undgå områder med olieforurening, og vil påvirkes ved at blive fortrængt fra levesteder. Men det vil næppe påvirke bestande, hvis det lykkes at inddæmme spildet til et begrænset landområde.

Oliespild forbygges ved at følge BAT og BEP-principperne, ligesom der skal være krav til at anvende de højeste sundheds-, sikkerheds- og miljøstandarter (HSE). Planlægning, regulering og beredskab skal tage højde for oliespild, for eksempel ved at forebygge, at olie når ud i de nærliggende vandmiljøer med risiko for at nå havet.

Oliespild i vurderingsområdet vil primært påvirke vegetationen. Men hvis olie spildes i eller føres til havet, vil der være en risiko for, at spildt olie også kan nå de meget mere følsomme kystområder og her påvirke et væsentligt større område, da olie spredes hurtigere og lettere på vandoverfladen.

Naalisagag kalaallisooq

2016-imi Nuussuup kitaata tungaa Qeqertarsuarlu tamarmi uuliaqarneranik misissueqqissaarfissatut ammaanneqarput, tassanilu misissueqqissaarfissat pingasut neqeroorutigineqarlutik (Titartagaq 1). Tassungalu atatillugu misissueqqissaarfissani pingasuni suliarineqartussat pillugit avatangiisitigut periusissiorfiusumik nalilersuineq manna suliarineqarpoq. Avatangiisinik naliliineq ilaatigut politikkikkut aalajangiinernut toqqammavissioqataassaaq, ilaatigullu suliat ingerlanneqartussat malittarisassiorneqarnerini ilisimasanik amigaatigineqartunik pissarsiniarfiussalluni. Aammattaaq ilisimalikkat tamakku ingerlatseqatigiiffiit uuliamik / gassimik misissueqqissaarnissamut qalluinissamullu akuersissutinik pissarsisut suliaminnut atasumik avatangiisit pillugit naliliineranni atorneqarsinnaassapput.

Piffimmi naliliivimmi Qeqertarsuarmi / Nuussuarmi avatangiisit

Tamatuma silaa issittup silaannaraa, aammalu nunamilu uuliaqarneranik misissueqqissaarnermi sunniutilerujussuaq tassaavoq nunap qeriuaannartuunera.

Nuna qaqqartuujuvoq, taavalu sineriak qooqqullu timmut atasut pukkinnersaapput.

Immikkuullarissullu tassaapput Qeqertarsuarmi puilasut allanngujaatsumik kissarnillit. Taakku naasorpassuarnik avatangerneqarsimakkajuttarput immikkuullarilluinnartunillu uumasuaraqartarlutik.

Nuna amerlaqisutigut assut naasoqartarpoq assigiinngissitaaqisunik ilaatigut qaqutigoortuusunik. Nunap sananeqaataata assigiinngissitaarnera, taamalu issup assigiinngissitaartunik amerlaqisunik akoqarnera tamatumunnga pissutaavoq, aamma sila immap nunaviullu silaannaanik sunnigaavoq, portussuserlu apeqqutaalluni issittup kujasinnerusortaatut avannarpasinnerusortaatullu kiassuseqartarluni, taamaammallu naasut kujasinnerusumi avannarpasinnerusumilu nassaasaasartut tamaaniittarlutik.

Nuna uumasoqarluanngilaq, pingaarnerpaallu tassaapput tuttut nerlerillu Nuussuarmi tuttoqarpoq navianartorsiortitaasutut isigineqartunik. Tamanna tamarmi nerleqarpoq, Qeqertarsuarmilu piffiit arlallit Ramsarikkut timmissanik illersuiffittut toqqagaasimapput nunanut tamalaanut pingaaruteqartumik nerlerit tamaanittartut amerlassuseqartarmata. Nerlerit taakku Kitaaniinnaq piaqqiortarput, ikittunnguupput ikiliartorlutillu, taamaammat navianartorsiortitaasutut isigineqarput; Kalaallit Nunaannilu navianartorsiortunik nalunaarsuiffimmi ingasanngitsumik navianartorsiortitaasutut nalunaarsimallutik.

Nunap erngini marluinnarnik aalisagaqarpoq, eqaluk pingaarnersaralugu.

Nuna tuttunniarfiunerusarpoq (taamaallaat Nuussuarmi) aqisserniarfiunerusarlunilu, sinerialli ammassannik, nipisannik aammalu eqalunnik piniarfiusarluni. Aammattaaq pingaartumik Qeqertarsuarmi nunami takornariartitsisoqartarluni.

Qeqertarsuarmi / Nuussuarmi nunami uuliasiornernut atatillugu avatangiisinik naliliinerit

Mississueqqissaarneq

Mississueqqissaarnermi suliat tamaani avatangiisinut annerpaamik sunniuteqartussat tassaapput sajuppillatsitsisarluni mississuinerit qillerinerillu.

Sajuppillatsitsisarluni mississuinerit nunami titarnerit takisuut atuarlugit ingerlanneqartarput, titarnerillu kilometerinik arlalinnik akunnilersorneqartarlutik (tassa 2D-mi mississsuinertut taaneqartartut). Titarnerit taakku atuarlugit atortut oqimaatsut nipiliortartut angallanneqartarput, nipillu nunap iluaniit utertarneri nunami nipinik tigooraassutit atorlugit tigooqqarneqartarlutik. Nipit sajuppillattartorsuarnit, imaluunniit qaqutikkut qaartartunit pilersinneqartarput. Qilleriffissamik toqqaasoqartussanngoraangat nutaamik sajuppillatsitsisarluni mississuisoqartarpoq, kisiannili taava titarnerit mississuiffissat assorsuaq akulikinnerusarput piffimmilu annikinneerarsuarmi pisarlutik (3D-imik mississuinertut taaneqartarput).

Mississueqqissaarluni qillernikkut sajuppillatsitsisarluni mississuinermi qilleriffissatut nassaarineqartuni uuliaqarnersoq gasseqarnersorluunniit mississorneqartarpoq. Qilleriviit atorlugit qillerisoqartarpoq. Nunami panertumi qillerivik nunap qaaginnaanut inissinneqarsinnaasarpoq, nunami isugutasumi inissaa ujaraaqqanik patajaallisarneqaqqaartarpoq. Sinerissami niusivimmiit nunami qilleriffissamut qillerutinik angallassissutinillu allanik assartuinermi atortut 1000 tonserpassuarnik oqimaassusillit assartorneqartarput; 1996-imi ataasiarluni mississueqqissaarluni qillerinermi atortut 3700 tonsit Nuussuarmut nunnigunneqarput.

Avatangiisinut sunniutit annermik makkunannga aallaaveqarput:

- nunap allanngortinneqarneri
- uumasut akornusersorneqarneri
- eqqakkat aammalu silaannarmut immamullu aniatitat
  - marraq qillerinermi perrassaat qillernerlukullu
- imermik atuineq

Nunap allanngortinneqarneri tassaapput atortut oqimaatsut angallassigineqarneranni aammalu soorlu qilleriviit najugaqarfiillu suliarineqarnerini nunap naasullu aserorneqartarneri. Pingaartumik sajuppillatsitsisarluni mississuisoqartillugu titarnerni mississuiffiusuni naasut nunalu assorujussuaq sunnerneqarsinnaapput, soorlu tassaallutik qamutit illerngi, naasut nungullarneri aammalu nunap qeriuaannartup sunnerneqarneri. Mississueqqissaarlunili qillerinerit piffimmi killilimmi sunniisarput. Qillerivit timerpasissumiippat qamutit illerngi nunap allanngortinneqarneranut ilapittuutaassapput. Allanngortinneqarnerat pissutigalugu naasut immikkuullarissut naasarfii aserorneqarsinnaapput imaluunniit aggulunneqarsinnaallutik, piffimmilu naliliiviusumi naasut qasutigoortut piffimmi killilimmi naasartut navianartorsioqqajaanerussallutik. Aamma pingaartumik sajuppillatsitsisarluni mississuiffiusuni nunap ersitsumik innarligaaffii siammasissinnaapput.

Sunniutit tamakku ukiumi mississuinikkut pitsaanerpaamik killilersimaneqarsinnaapput nunammi apummit saassimanera naasunut nunamullu illersuutaassammat. Aamma Canadami ilisimaneqartut qamutit naqinnikitsunik assakaasullit atorneqarsinnaapput.

Jameson Landimi 1990-ikkunni ukiuunerani sajuppillatsisisarluni ukiukkut ingerlanneqaraluarpataluunniit nunap allanngortinneqarnissaa eqqumaffigisariaqarpoq tassami tappavani qamutit aqqutaat nunallu innarlerneri allat suli takussaammata. Taamaammat misissuinerit pilersaarusioqqissaarneqartariaqarput avatangiisillu pillugit ilisimasat sukumiisut aallaavigalugit malittarisassanik aallaaveqartariaqarlutik.

1996-imi Nuussuarmi misissueqqissaarluni qillerinermit misilittakkat naapertorlugit qamutit nunakkooruteeqqat killeqanngitsumik angalanerat mianersorfigilluarneqartariaqartoq. Suli ullumimut nunami tamaani angallavii takussaapput. Suliat allat sunniutaat malittarisassat malillugit iluarsaqqinneqarput ullumikkullu ersigunnaangajassimallutik.

2007-mi aatsitassaqarneranik misissueqqissaarnermi annertuumik assartuisoqarneratigut Nuussuarmi 30 km-iusunik illinersuaqalersimavoq. Allanngortitanik iluarsaaqqinnerit 1996-imi misissueqqissaarnerit kingorna iluarsaaqqinnertulli iluatsitsigisimanngillat, ullumikkullu suli erseqqeqalutik. 2015-imissaaq paasineqarpoq illinerni taakkunani nuna qeriuaannartoq annertunngitsumik innarligaasimasoq (itersarsuaqalersimasoq).

Uumasut akornusersugaaneri tassaapput nujoqqatitsinerit pissusilersuutinillu allannguinerit. Sajuppillatsitsisarluni misissuinerit piffimmi annertoorujussuarmi uumasunut sunniuteqassapput, piffimmili ataatsimi sivikittuinnaasassallutik, misissueqqissaarlunili qillerinerit piffimmi aalajangersimasumi sunniutaat piffissami sivisunerusumi atuuttassallutik (qillerinerit qaammatinik arlalinnik sivisussuseqarsinnaasarput.

Misissueqqissaarnerit ingerlaneranni qulimiguullit atorlugit assartuinerit aamma assorsuaq akornusersuiffiusarput.

Piffimmi naliliiffiusumi pingaartumik tuttut nerlerillu akornusersorneqaqqajaassapput piffissallu suliaqarfiusup ingerlanerani taakku uumaffimminnit pingaarutilinnit nujoqqatsinneqarnissaat ulorianaateqarsinnaavoq. Assersuutigalugu tuttut piniarnerup nalaani qangaanerusoq pisarineqarfigisartakkaminniit nujoqqatsinneqarsinnaapput. Amerlanertigulli sunniutit sivikitsuinnaasassapput – tassa ukiup ingerlanerani piffissaq ataaseq.

Sunniutit taama ittut ilisimasat pitsaasut tunngavigalugit sukumiisumik pilersaarusiornikkut malittarisassaqartitsinikkullu piffissaq sumiiffillu eqqarsaatigalugit akornusersuinerit annikinnerpaaffianiitsineqarsinnaapput. Assersuutigalugu aatsitassaqarnermik ingerlatsiviup 'uumasoqarfiit pingaarutillit' pillugit misissuivinni malittarisassai taaneqarsinnaapput, taakkunuunalu assersuutigalugu qeerlutuut alluumasartut isasut akornusersorneqarnissaat annikillisarniarneqartarpoq. Aamma nipitigut nunamullu sunniutit eqqarsaatigalugit suliat ukiuunerani ingerlanneratigut akornusersuineq annikinnerussaqaaq pingaartumik nerlerit sunnertiaqisut ukiuunerani aallarsimasussaanerat pissutigalugu.

Eqqagassat misissueqqissaarnerup ingerlanerani isumagineqartussat annersaat tassaapput *qillernerlukut* qillerinermi pinngortartut aammalu *marraq qillerinermi* perrassaatigineqartartoq. 3000 meteriusumik qillerinikkut qillernerlukut 850 tons pilersinneqassapput marrarlu perrassaat 600 tons atorneqassalluni, taakkulu qillerineq naamasseriarpat iginneqartussaassallutik. Alaskami marraq perrassaat qillernerlukullu qilleriffiup eqqaanut iginneqartarsimagaluarput ('sumpsinut') 1996-imilu Nuussuarmi taamaaliortoqarsimavoq. Ullumikkut kaammattuutigineqarpoq eqqaavissuarnut nakkutigisanut ingerlanneqartassasut imaluunniit qillerivimmut maqeqqinneqassasut eqqagassanit assaanneqarsimasunit seerinikkut avatangiisinut sunniisoqaqqunagu. Issittumi piffinni allani eqqagassat taama ittut suli assaanneqartarput. Piffimmi naliliiffiusumi akuutissat avatangiisinut uloriananngitsut kisimik nunat tamalaat akuerisanik allattuiffiiniittut OSPAR, HOCNF) atorneqartariaqarput (soorlu nunatta imartaani qillerinermi akuerisatut ittut), aammalu marraq qillerinermi perrassaat qillernerlukullu aallarunneqartariaqarput imaluunniit ajornanngippat qillikkamut maqeqqinneqartarlutik.

Misissueqqissaarnerni aniatitsineq annertooq alla tassaavoq maskinat aniatitsinerat, tassami misissueqqissaarnerit ingerlanneqarneranni orsussarujussuaq atorneqartarpoq. Taakku tassaapput silaannaat kiatsinnartut aammalu mingutsitsisuusut soorlu SO_2 og NO_x. Siulliit taaneqartut nunarsuup kiatsikkiartorneranut ilapittuutaapput kingulliillu sialummik seernartunngortitsisarput aammalu issittup pujoraanik mingutsitsinermit pissuteqartumik, issitsillugu qatsungasumi pinngortartumik pilersitsisinnaasarlutik.

Misissueqqissaarnerit allatigut *avatangiisinut sunniuteqarsinnaapput*, soorlu imermik assorsuaq atuiffiusarput, piffinnilu panikuluttuni kuuit tatsillu imaarunnerinik kinguneqarsinnaallutik. Aammattaaq sunniutit nalinginnaanerusut pisinnaapput, soorlu issittumi sulianit nalinginnaanerusunit pisut. Sunniutit taama ittut pitsaasumik pilersaarusiornikkut aammalu oqartussat malittarisassaqartitsinerisigut pinaveersaartinneqarsinnaapput.

Qalluineq

Qalluineq ukiorpassuarni ingerlassaaq; amerlasuutigut ukiut qulikkaat arlallit ingerlanneqartarpoq taamaammallu aamma avatangiisit sivisuumik sunnersimaneqartarlutik.

Uuliamik qalluinermit avangiisit sunnigaaneri misissueqqissaarnermisulli arlalinngorlugit avinneqarsinnaapput:
- nunap allanngortinneqarneri
- uumasut akornusersorneqarnerat
- eqqakkat aammalu silaannarmut immamullu aniatitat
  - marraq qillerinermi perrassaat qillernerlukullu
- imermik atuineq

Nunap allanngortinneqarneri atortorissaaruterpassuit uuliamik qillerivimmut atatillugit pilersinneqartut inissinneqarnerinit pisarput. Uuliamik qillerivik 20 hektarinik angissuseqalertorsinnaasarpoq, aammalu sinerissami umiarsualivimmiit aqquserniortoqassappat imaluunniit timmisartunut mittarfiliortoqassappat nuna allanngortitaq annerujussuusinnaavoq. Nunap allanngortitaanerisa tamakku kingunerisaannik uumaffiit aserorneqarsinnaapput imaluunniit aggulunneqarsinnaallutik, uumasut ingerlaartarfiit asserneqarsinnaallutik, erngup ingerlaarfii (pingaartumik upernaakkut) allanngortinneqarsinnaallutik aammalu nuna qeriuaannartoq qeriunnaarsinneqarsinnaalluni.

Nunamili naliliiffiusumi nunap ilua Alaskami North Slopemisut Siberiamisulli masattuunngimmat atortorissaaruteqarfinnik inissiinermi nuna taakkunanisulli sunnigaatiginavianngilaq.

Pujoralatsitsineq taakku piffiup eqqaanut unerarnerat nunamik allannguinertut aamma oqaatigineqarsinnaapput.

Aammattaaq atortorissaaruteqarfiit piffimmi qalluffiusumi nunap takujuminassusianut sunniuteqarsinnaapput.

Nunami naliliiffiusumi pingaartumik naasut qaqutigoortut killilimmik siammarsimaffillit sunnertiasussaassapput, aammali tuttut aasisarfimmik ukiisarfimmillu akornanni angalasartussat aqqutinnaamik asserneqarneratigut sunnerneqarsinnaapput. Aamma eqaluit majortarfii asserneqarsinnaapput.

Nunap sunnigaaneri amerlasuut avatangiisit suliffigineqartut pillugit ilisimasat pitsaasut tunngavigalugit sukumiisumik pilersaarusiornikkut pinaveersimatinneqarsinnaapput, aamma periaatsinik atortunillu nutaanik atuinikkut piffik sunnigaq imermillu atuineq annikillineqarsinnaapput.

Uumasut akornusersorneqarnerat atortorissaaruteqarfinnit (inoqarneranit) aallaaveqarpoq aammalu nunami suliarpassuarnit aallaaveqarluni – soorlu aqqusinertigut angallannermit, qulimiguullit ingerlasarnerinit inuillu nunami angallannerannit.

Nunami naliliiviusumi pingaartumik nerlerit akornusersoqqajaaneqassapput, nerlerillu najugannaaminnit nujutsinneqarsinnaapput piffiit taama ittut eqqaanni atavissunik atortorissaaruteqarfiliortoqarpat. Aamma timmissat imarmiut piaqqiortut kiisalu sinerissami qeerlutuukkut akornusersorneqarsinnaapput kiisalu ineqarfimminnit isassarfimminnillu nujutsinneqarsinnaassallutik.

Tuttut najugannaaminnit aamma akornusersorneqarlutik ingalatsinneqarsinnaapput, tamatumanilu aamma piniarneq sunnerneqarsinnaalluni.

Tamatumani sunniut immikkut ittoq tassaavoq uumasut eqqakkani nerisassarsiortartut qillerivimmut kajungilersinnaammata. Pingaartumik tulukkat terianniallu najugaqarfinnut taama ittunut qaninniartarput najugaqarfiullu eqqaani uumasunut sunniuteqarsinnaapput uumasoqatiminnik piniarnerusalerunik.

Akornusersuinerit pilersaarusiornikkut malittarisassaqartitsinikkullu pinaveersaartinneqakannersinnaapput, soorlu qulimiguullit aalajangersimasumik pukkinnerpaaffeqartillugillu ingerlaartinneqartarpata, soorlu nunami suliaqarneq pillugu Kalaallit Nunaanni oqartussat malittarisassiaanni oqaatigineqartutut.

Uuliamik qalluisoqartillugu avatangiisinut aniatinneqartartut annersaat tassaavoq imeq uuliamut ilanngullugu qallorneqartoq. Imeq taanna uuliap sinnikuinik akoqassutsimi saniatigut aamma mingutsitsisartunik assigiingitsorpassuarnik, aamma toqunartoqarsinnaasunik, qinngorneqarsinnaasunik, hormoninut sunniuteqartartunik imaluunniit naggorissaataasunik imaluunniillu saffiugassanik oqimaatsunik akoqarsinnaapput. Tamatumani pineqartoq tassaavoq imerujussuaq (uuliatut qallorneqartutut annertutigisoq annerusorluunniit) arlaatigut iginneqartariaqartussaq. Issittumi piffinni allani qangaanerusoq imeq taama ittoq annerusumik minnerusumilluunniit saleriarlugu kuunnut aniatinneqartarsimagaluarpoq, massakkulli Alaskami nunap iluani uuliaqarfinnut maqeqqinneqartalerpoq. Nunap iluanut maqitseqqittarneq avatangiisit eqqarsaatigalugit pitsaanerpaajuvoq, teknikkikkulli pissuteqartumik ajornarpat kaammattuutigineqarpoq imeq aniatinneqartigani salilluaqqissaarneqassasoq aammalu aniatinneqartup akoqassusia uumassusilinnullu sunniutaa malinnaavigeqqissaarneqassasoq akui akuerineqarsinnaanngitsumik qaffasissuseqaleqqunagit.

Qalluinerup nalaani qillerinerit ingerlaqqittartussaammata aamma *marraq qillerinermi perrassaat qillernerlukullu* misissueqqissaarnermisulli iginneqartariaqarput, taakkuli annertunerulersimassapput qillerinerit amerlasinnaaqimmata.

Aamma silaannarmut aniatitsineq annertussaqaaq, uuliasiorfillu ataaseq nunatsinni silaannarnik kiatsikkiartortitsisartunik aniatitsinermit qasseeriaaterpassuarmik aniatitsisassalluni. Aamma qalluisoqarnerata nalaani issittup iseriaa pilersinneqarsinnaavoq.

Qalluinermit aniatitsinerit eqqagassallu annikillisarneqarsinnaapput periaatsinik atortorissaarutinillu pitsaanerpaanik aammalu avatangiisitigut iliuutsinik pitsaanerpaanik atuinikkut (OSPAR takuuk). Tamatigulli imerujussuaq, marraq qillerinermi perrassaat qillernerlukullu annertoqisut pilersinneqassapput avatangiisitigullu isumannaatsumik isumaginiarneqartariaqassallutik. Taama iliortoqarsinnaavoq erngup marraallu perrassaatip nunap iluanut maqeqqinneqarneratigut, marraap perrassaatip qillernerlukullu isumannaatsunut matoorunneqarneratigut imaluunniit tigooraavinnut suliareqqitassanngorlugu assartorneqarneratigut.

Silaannarmik mingutsitsineq killilersimakannerneqarsinnaavoq uulianik svovleqarluanngitsunik atuinikkut pingaarnerpaamilli nukissiutinik allanik soorlu imermik, anorimik seqinermillu nukissiuteqarnikkut.

Sunniutit allat. Uuliasiorfik aamma nalinginnaanerusunik avatangiisitigut sunniuteqarsinnaavoq Kalaallit Nunaanni inoqarfinni allani takussaasartunik. Taakkuli periaatsinik atortorissaarutinillu pitsaanerpaanik avatangiisitigullu periaatsinik pitsaanerpaanik atuinikkut kiisalu pilersaarusiorluarnikkut oqartussaniillu malittarisassaqartitsinikkut annikillisarneqarsinnaallutillu annikillisarneqassapput.

Uuliasiornermi imermik atuineq annertoorujussuusinnaavoq, tamatumanilu assersuutigalugu eqaloqarfinni kuuit allanngortinneqannginnissaat imaluunniit paqqertoortinneqannginnissaat eqqarsaatigalugu imermik pissarsisoqartassalluni.

Atorunnaarsitsineq

Uuliaqarfik imaaruppat atortorissaaruteqarfiit piiarneqassapput, nuna iluarsaqqinneqarluni aammalu qilleriviusimasut simitsitsinerneqassallutik. Tamanna ukiunik qassiinik sivisussuseqarsinnaavoq qalluinerlu suli unitsivinneqartinnagu aallarnisareerneqartariaqarluni. Tamatumanissaaq aamma uuliaqarfimmiit aallarussuiffiusumut assartuinerujussuakkut uumasut akornusersorneqarsinnaapput. Aamma minguit katersorsimasut siammarneqarsinnaapput.

Ajornartorsiutit pilersaarusiorluarnikkut aammalu periaatsinik atortorissaarutinillu pitsaanerpaanik avatangiisitigullu periaatsinik pitsaanerpaanik atuinikkut pakkersimaarneqarsinnaallutik, taamaammallu sanaartornerup ingerlanerani ingutserinissap qimagussuinissallu eqqarsaatigineqareertariaqarpoq.

Aamma uuliamik qalluiffiup atorunnaarsinneqarnerani avatangiisinut ajornartorsiutit eqqarsaatigalugit akilersinnaassutsimik misisissuinerit ingerlanneqassapput.

Uuliamik maqisoorneq

Nuussuarmi Qeqertarsuarmiluunniit uuliasiortoqartillugu annertuumik uuliamik aniasoorneq pisinnaavoq qillerinermi uuliaqarfimmik eqquinikkut tissaluttoornikkut imaluunniit sullulimmik alittoornikkut. Aamma umiarsualivimmi uuliamik assartuussuarnut maqitsinermi aniasoortoqarsinnaavoq. Issittumi piffinni allani misilittakkat (pingaartumik Ruslandimi) takutipaa sullulinnik alittoornerit nunami annerpaamik aniasoorutaasartut. Aniasoornissarli ilimanaatikeqaaq, aniasuunngilluinnarnissarli oqaatigineqarsinnaanngilaq.

Nunami uuliamik aniasoorneq imaani aniasoornertulli siammartitsiviutigineq ajorpoq. Uuliali kuummut piguni piffimmut annerusumut siammarsinnaavoq, aamma imaanut taamaalilluni pisinnaavoq.

Nunami uuliamik aniasoorneq pingaartumik naasunik aseruisarpoq, aammalu uulia issumit, sioqqanit, marrarmillu millunneqassaaq qaqinneqanngikkunilu ukiorpassuarni uninngasinnaalluni. Uulialu imermut pippat aalisakkat sunnerneqarsinnaassapput toqunartumillu sunnigaallutik aammalu timmissat imermiittartut uuliamit sunnerneqarsinnaassallutik.

Nersutit timmissallu uuliamik mingutsitsivik ingalassimassavaat, najugannaamminnillu nujutsitaanermikkut sunnigaassallutik. Ataatsimoortulli tamarmiullutik sunnigaajunnanngillat aniasoorfik nunami killilimmi unitsinneqarsinnaassappat.

Periaatsinik atortorissaarutinillu pitsaanerpaanik aammalu avatangiisit eqqarsaatigalugit periaatsinik pitsaanerpaanik atuinikkut uuliamik maqisoornissaq pinaveersaartinneqassaaq, aammattaaq peqqissutsikkut, isumannaallisaanikkut avatangiisitigullu piumasaqaatit qaffasinnerpaat atortinneqassapput. Pilersaarusiornermi, malittarisassiornermi upalungaarsimanermilu uuliamik maqisoorsinnaaneq piareersimaffigineqassaaq, assersuutigalugu uulia kuunnut tatsinullu pinaveersimatinneqassaaq imaanut pisinnaaqqunagu.

Nunami naliliiviusumi uuliamik maaqisoorneq annermik naasunut sunniuteqassaaq. Uuliali imaani aniappat immamullu ingerlappat aamma uulia maqisuugaq sinerissami piffinnut sunnertianerujussuarnut siammaasiinnaavoq, uulialu immap qaaniilluni siammalertornerusaqimmat piffik annerujussuaq tamaani sunnerneqarsinnaassalluni.

1 Introduction

This report is a strategic environmental impact assessment (SEIA) of onshore petroleum activities in Disko Island and Nuussuaq Peninsula of West Greenland. The area has both petroleum and mineral potential, and exploration activities for these resources are expected to increase in the coming years. Two companies presently hold mineral exploration licences in the area: Avannaa Exploration Ltd. (2012/29) and Coastal Ventures A/S (2013/09). Petroleum exploration has been halted since 1996 when a dry well (named GRO#3) was drilled in western Nuussuaq. The hitherto only active mine in the assessment area was a coal mine at Qullissat on Disko, and that was closed in 1971.

The report replaces a preliminary SEIA covering only Nuussuaq Peninsula and issued in 2008 (Boertmann et al. 2008).

The descriptions of the environment are based on the present information supplemented with new information collected during a baseline study in July-August 2015. Other important sources of information include the Arctic Council's working group's (AMAP) Oil and Gas Assessment (AMAP 2010) available on the AMAP homepage (www.amap.no) and the compilation of cumulative impacts of oil and gas activities in Alaska (NAS 2003).

It shall be stressed that a SEIA does not replace the need for site- and activity specific Environmental Impact Assessments (EIAs). The SEIA provides an overview of the environment in the licence areas as well as in adjacent areas which can be impacted by the activities. It identifies major potential environmental effects associated with petroleum exploration and exploitation activities. These effects shall be considered both by the authorities e.g. in a regulation context, and by the companies to be assessed when developing their EIA(s). Hence, the SEIA highlights issues of concern, and recommend mitigation and planning actions as well as it identify missing knowledge and information needs.

The SEIA describes the environment and the potential impact of oil activities at a generic and regional level, as the precise location of potential activities is not known.

The potential impacts are in principle described in relation to a zero-oil activity scenario. However, as climate change and development in fisheries and hunting and other human activities may cause ecological changes that are hard to predict, the zero-oil activity scenario is somewhat hypothetic.

An important issue in this context is climate changes. These affect both the physical and the biological environment, and according to CAFF (2013): *Climate change is by far the most serious threat to biodiversity in the Arctic*. In a region such as the area covered by this report significant changes include increases in temperature and winter precipitation and in the surrounding marine areas winter sea ice cover will decrease, and these changes will impact e.g. on growth period, occurrence of migratory animals, distribution of permafrost and snow cover (Christensen et al. 2016).

The SEIA is solely an assessment of impacts on the biological environment and the use of the biological resources. Aspects on socioeconomics, archaeology and cultural history are not dealt with in this report, and will be dealt with in other contexts.

This SEIA was funded by EAMRA and prepared by DCE – Danish Center for Environment and Energy together with the Greenland Institute of Natural Resources (GINR).

1.1 Coverage of the SEIA

This SEIA covers the onshore areas of Disko Island (Qeqertarsuaq) and the western part of Nuussuaq Peninsula (Figure 1). This area is generally referred to as 'the assessment area' or the 'Disko/Nuussuaq area'. The islands of Qeqertarsuatsiaq/Hareø and Qeqertat are not included in the proposed license blocks, although Qeqertat is inside the assessment area.

Potential impacts on marine environment in the assessment area due to shipping in connection with onshore oil exploration and exploitation is not covered in present SEIA, but can be extracted from the SEIA for offshore oil exploration and exploitation activities in the Disko West Area (Boertmann et al. 2013).

The assessment area includes one town (Qeqertarsuaq, with 430 inhabitants in 2015) and three villages: Kangerluk (15), Niaqornat (52) and Qaarsut (85) (Figure 1). Just east of the assessment area is the village Saqqaq (92) situated (Figure 1). Further away are the towns Ilulissat (4500) and Uummannaq (1250).

The Sections 1 to 8 comprise the descriptive part of the report, while Section 9 is the assessment and risk evaluation and the final Section (11) is an identification of missing knowledge and proposals how to acquire such knowledge.

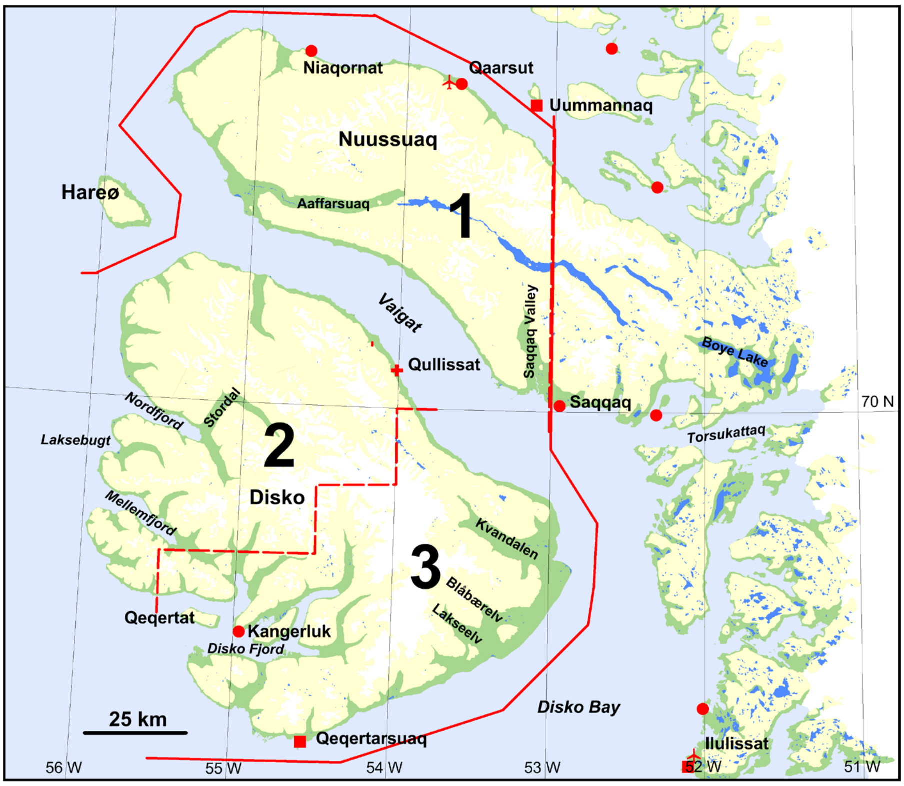


Figure 1. The assessment area (red solid border), proposed licence blocks (hatched red line and numbers) and towns (red squares) and villages (red dots) near and inside the assessment area. Airports indicated with aircraft symbol. The red cross shows the abandoned coal mine at Qullissat.

1.2 Abbreviations and acronyms

AMAP	=	Arctic Monitoring and Assessment Programme
APNN	=	Ministry of Fisheries, Hunting and Agriculture, Greenland Government
a.s.l.	=	above sea limit
AU	=	Aarhus University, Denmark
ATV	=	All-terrain vehicle
BAT	=	Best Available Technology
bbl	=	barrel of oil
BC	=	black carbon
BEP	=	Best Environmental Practice
BMP	=	Bureau of Minerals and Petroleum (today EAMRA and MLSA)
CAFF	=	Conservation of Arctic Flora and Fauna
CI	=	Confidence Interval
CITES	=	Convention on International Trade in Endangered Species of Wild Fauna and Flora (the Washington Convention)
CRI	=	Cuttings Re-Injecting
CV	=	Coefficient of Variance
DCE	=	Danish Centre for Environment and Energy, Aarhus University
DDT	=	dichlorodiphenyltrichloroethane
DMI	=	Danish Meteorological Institute
EAMRA	=	Environmental Agency for Mineral Resource Activities, Greenland Government
EIA	=	Environmental Impact Assessment
FDD	=	freezing degree days
GEUS	=	Geological Survey of Denmark and Greenland
GDD	=	growing degree days
GINR	=	Greenland Institute of Natural Resources
HSE	=	Health, Safety and Environment
HOCNF	=	Harmonized Offshore Chemical Notification Format (OSPAR)
IBA	=	International Bird Area
IUCN	=	International Union for Conservation of Nature
LRTAB	=	Convention on Long-Range Transboundary Air Pollution (UNECE)
MLSA	=	Mineral Licence and Safety Authority, Greenland Government
NEBA	=	Net Environmental Benefit Analysis
NERI	=	National Environmental Research Institute, now DCE
NGO	=	Non-Governmental Organisation
NORM	=	Naturally-Occurring Radioactive Materials
OBM	=	Oil based drilling mud
OSPAR	=	Oslo-Paris Convention for the protection of the marine environment of the Northeast Atlantic
PAH	=	Polycyclic Aromatic Hydrocarbons
PDBE	=	Polybrominated diphenyl ether
PFAS	=	Perfluorinated alkylated substances
PFOS	=	Perfluorooctane sulphonate
PLONOR	=	OSPARs list over substances which *Pose Little or No Risk to the Environment*
POP	=	Persistent Organic Pollutants
SBM	=	Synthetic based drilling mud
SEIA	=	Strategic Environmental Impact Assessment
SD	=	Standard deviation

SM	=	Synthetic drilling mud
TDD	=	thawing degree days
ULSD	=	Ultra low sulphur diesel
UNECE	=	United Nations Economic Commission for Europe
UNEP	=	United Nations Environment Programme
UTC	=	Coordinated Universal Time
VEC	=	Valued Ecosystem Components
VOC	=	Volatile Organic Compounds
WBM	=	Water based drilling mud

2 Summary of petroleum exploration and exploitation activities

Janne Fritt-Rasmussen, Wendy Loya and David Boertmann

Onshore exploration activities comprise different steps including seismic surveys to define the prospect, construction of the exploration site and conduction the exploration drilling. Each step will be described in the following with focus on general technical principles, derived overall impacts and also possible mitigations techniques. A deeper assessment of the impacts can be found in Section 9. Further also the required logistics/infrastructure for performing the exploration activities are touched upon. At the end of this section production and decommission activities are briefly mentioned.

In general, it is expected that the principles of Best Available Technique (BAT) and Best Environmental Practice (BEP) (OSPAR convention, Appendix 1, Link) are applied in connection with all activities related to petroleum exploration and exploitation in Greenland. This is to ensure the least environmental impact, as well as to ensure that any possible mitigation shall be implemented.

2.1 Routine petroleum exploration activities

Petroleum exploration activities include primarily geophysical surveys and drilling, and the primary conflicts with the environment relate to the physical impacts from facilities and activities, disturbances of wildlife and discharges to air and land/water. In general all activities related to petroleum exploration are temporary and will be terminated after a few years if no commercial discoveries are made and production initiated.

2.1.1 Geophysical surveys

Geophysical surveys are an integrated part of the petroleum exploration with the overall purpose to gain knowledge about the prospect and target the areas for further exploration. Geophysical exploration surveys include primarily reflection seismology and gravimetric surveys, while other methods are sometimes also used. Gravimetric surveys are usually carried out from low level flying aircrafts covering large areas with a densely spaced network. The major risk of impact from such activities is short time disturbance of wildlife, most severe if helicopters are used.

Reflection seismology (or just seismics) is the most widely used ground-based geophysical method to identify oil and gas structures in the underground prior to exploration drilling. Seismic surveys on land are typically carried out with two different sound sources: Either as vibrating seismic, where the sound source is a large vibrating devise usually carried by a large truck, or by use of explosives with the energy source placed in shot holes in the ground. Seismic surveys require usually extensive equipment in form of accommodation (trailer camp) and support vehicles to bring fuel, supplies and staff. Thus, seismic surveys have a high potential for environmental impacts mainly in form of disturbance of animals and damage of terrain and vegetation. More technical details about the seismic surveys are given in the following.

2D/3D Seismic
There are two main types of seismic exploration on land: 2D and 3D seismics.

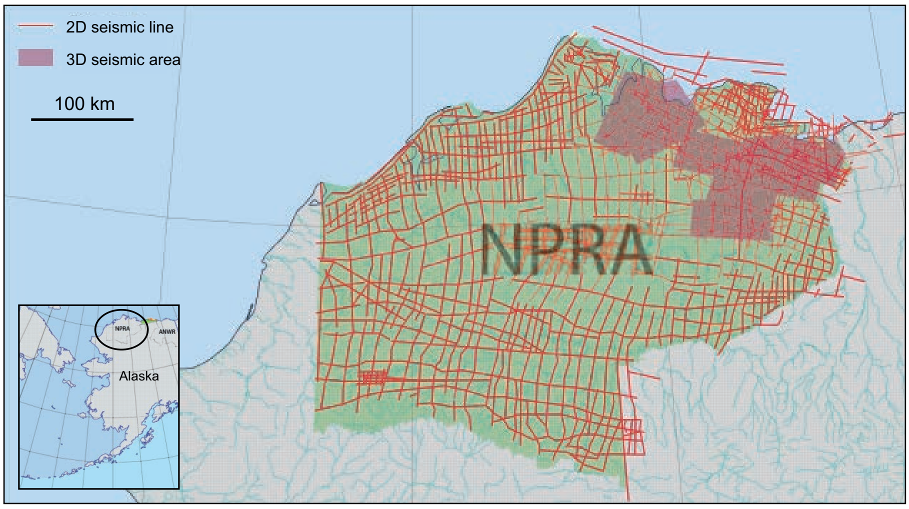


Figure 2. 2D seismic (red lines) and 3D seismic (red shaded areas) for which seismic data have been collected for NPRA area in Norther Alaska. From AMAP (2010).

2D seismic surveys are traditionally carried out in an extensive grid consisting of long widely spaced survey lines (up to 10 km) and a sampling area may cover thousands of square kilometers. 2D surveys are useful for regional reconnaissance surveys and initial data collection (NPR-A 2012). Each survey requires at least 10 vehicles/trailers. *3D seismic* surveys are usually carried out when a drill site shall be identified. Therefore it covers a restricted area, but with the lines much closer together (Yukon Government 2006). Thus, 3D seismic surveys potentially cause greater impacts in soil and vegetation than 2D seismics although in a smaller area (Winter et al. 2014). A typically 3D seismic survey includes a grid-pattern with a line spacing much smaller than for 2D seismic and data will be sampled in a smaller area. The increased use of 3D seismic and complex geological models in recent years has resulted in a decrease in the need for exploratory drilling (AMAP 2010).

For both 2D and 3D seismic operations, survey vehicles and support camp modular units are needed. The camp modular units consist of fuel trucks and trailers pulled by bulldozers (AMAP 2010). Fuel trucks will go back and forth to fuel-depots to fill up the tanks.

Figure 2 shows an example of 2D and 3D lines for the National Petroleum Reserve in the Northern Alaska.

Sound source

In seismic surveys an elastic wave motion is excited by an active source. For onshore seismic surveys dynamite or a vibrator seismic sound source are usually applied. This was also the case in Jameson Land in 1986-1989 when 80% of the seismic lines were surveyed with vibrators. Many other sources (e.g., airgun, weight drop, p-shooter) are available when explosives or vibrators cannot be used. Unusual surface conditions or geophysical requirements are usually the driving force toward considering nonstandard sources (Cordsen et al. 2000), and for example airguns may be used to generate the sound in lakes.

From the source, energy is radiated into the earth, where the different layers reflect the signal which is recorded by geophones placed on the surface. The recorded signal is subsequently used to deduce the structure of the subsurface.

Explosives/Dynamite

To conduct a seismic survey with explosives, shot holes must be drilled in the ground, typically at a depth of 5-8 meters. These shot holes are drilled by portable rigs, either moved by ATVs or helicopters (Cordsen et al. 2000). The type of drill used will depend on the access to the area. E.g. is heli-portable operations preferred in mountainous regions (Cordsen et al. 2010). A minor part the seismic surveys carried out in Jameson Land in 1986-1989s was summer activities using helicopters and dynamite as sound source.

The advantage of using explosives is that a survey can be e.g. supported by helicopters and light vehicles. Another advantage is that it can be the most economical solution if the drilling of the shot holes is fast and efficient (Cordsen et al. 2010). Generally the cost of using explosives may be less compared with vibrators, and the availability of explosives is also better in some parts of the world. Under certain conditions, explosives may also be a better sound source, as they give a broader frequency spectrum. In the National Petroleum Reserve – Alaska (NRP-A 2012) explosives are generally dismissed due to the environmental impacts.

The explosives may also be detonated above ground - "surface shots", for instance when access is limited (Cordsen et al. 2000).

Vibrators

In level and dry terrain vibrators will usually be the preferred geophysical survey method.

The vibrator is a mechanical devise with a plate placed in contact with the ground and mounted on a vehicle. Electronics control a hydraulic system that transmits vibrations through the base plate on the ground (NPR-A 2012). Geophones collect the reflected signals and could be installed by hand on the frozen ground of the tundra or on/in frozen water bodies (lowered to the floor of e.g. a lake through PVC pipes set through ice) (NPR-A 2012). Vibrator techniques works best on a hard and solid ground, thus not during summer on wet tundra (Trupp et al. 2009). Several vibrators can be used concurrently to produce the needed sound (AMAP 2010). Even though the sound produced is relatively modest, the modern acquisition and processing technique allows for the use of this method as a practical and environmentally acceptable substitute of dynamite (AMAP 2010). On the Arctic North Slope there has been a gradually replacement of explosives with vibrators. However, explosives are still being used since they can be more effective under certain circumstances.

The required width of the seismic survey line (area to be cleared due to access) differs between vibrator sizes and also between 2D (6.5 m line width) and 3D (around 4.5 m width line). The smallest vibrators require around 3 m wide survey lines.

2.1.2 Exploration drilling

Exploration drilling is conducted to obtain detailed information about the ground below the surface, and it is the only way to ascertain if petroleum is present. Drilling for deep prospects requires large rigs and heavy equipment, while shallow geology can be explored with much lighter equipment – "slim hole drilling", leaving much less environmental impact than a large rig. The main purpose of the drill rig is the hosting, circulating and rotation systems backed-up by the pressure-control equipment (Khan and Islam 2008). Thus, onshore and offshore drilling are essential similar processes. Alternative, non-conventional drilling techniques such as laser and water jet drilling is beginning to receive attention (Khan and Islam 2008).

An exploration well is drilled in sections with decreasing radius and for each section the well bore is lined with casing tubes securing the wall. On top of this casing a blow-out-preventer is placed, which in case of a blow-out can seal off the well and contain the pressure. An essential component here is the drilling mud. This is circulated between the rig and the button of the well. The mud lubricates and cools the drill bit, transports rock cuttings (the material removed from the borehole by the drill bit) to the surface, prevents sloughing from the sides of the well bore and provides a weighting medium to counteract the pressure in the well.

Drilling mud is either based on water (water based mud – WBM) or on oil (oil based mud – OBM) mixed with different chemicals. Oil based mud is generally much more environmentally hazardous than water based, and the use of OBM was not allowed in Greenland until 2015, when a new strategy opened for the use of OBM drill systems provided that cuttings and mud will be transported to safe deposits or to treatment plants (Gustavson et al. 2013). Other types of drilling mud are occasionally used, among these is synthetic based mud (SBM) based on synthetic oil, which is less hazardous to the environment than mineral oil. A 3,000 m well could use 600 tons of drilling mud and produce 850 tons of rock cuttings (BLM 2012).

Exploration wells in the assessment area will likely exceed 3,000 m depth, based on the experience from GRO#3 (Box 3). At such depths, most exploration wells could be drilled, logged, and tested within a single winter season. Exploration and delineation wells are normally drilled straight down, though directional drilling techniques have allowed an offset of about 500 m. (BLM 2012). To define the limits of reservoirs after a discovery is made, several delineation/confirmation wells would likely be drilled before making a commitment to full project development. Additional delineation wells, surrounding the discovery well, would likely be planned for the following winter or two, and would require new ice pads.

Exploration drilling activities consume large amounts of fresh water to create drilling fluid (in case it is water based) and according to NPR-A (2012) a 10,000 foot well could require approximately 420,000 to 1.9 million gallons (1.5-7.2 million of L) of water for drilling. The camp facilities are also dependent on a large freshwater supply (e.g. 1.4 million l during a single season (NAS 2003)). This would have to be taken from nearby lakes or rivers, and might in case of a restricted supply, dry out these sources and destroy them as habitat for freshwater fauna. Melted snow could be used as a supplement (NPR-A 2012). During the 1996-exploration drilling on Nuussuaq, fresh water was taken from an artificial lake created by damming a small creek.

After a well has been drilled, it may be tested for the presence of hydrocarbons. The well can be tested using drill-stem testing equipment, where samples are collected in the wellbore, or by flowing fluids to the surface and through a production separator to measure the amount of fluid and the respective fractions of oil, gas, condensate, and water. Often exploration/delineation wells are plugged and abandoned during the same season in which they were drilled because it is more cost-efficient to complete activities in a single season (BLM 2012). Cement plugs would be placed throughout the abandoned well bore to prevent migration of fluids and gases and to protect subsurface resources (BMP 2011).

Potentially-producing petroleum wells can be suspended and shut in with plugs and wellhead gauges to monitor the well. Such successful wells can be re-entered for use as production wells at a later time by drilling out the cement plugs.

Drill rigs are placed on dry stable ground, and in case of wet tundra, gravel pads are constructed as a solid base. In winter, access roads and drill pads can be made from ice, which usually leave a very slight impact when they thaw. An alternative to using water from lakes/rivers is to use ice chips taken from solid ice on a lake and aggregate them with water. It takes less time to build an ice road or pad in this way if large amounts of solid ice are at hand close by.

Heavy equipment (drilling rigs, drill pipes, camps etc.) and large amounts of materials (steel casing, drilling mud, cement, and fuel) have to be transported in connection with a drilling operation, and for example required the drilling of the GRO#3 well in 1996 3700 tons of equipment and material (Box 3) brought in by ship and unloaded on the nearby beach.

Environmental impacts related to exploration drilling on land are:

1/ physical impacts from placement of structures, movement of heavy equipment e.g. drilling rigs, drill pipes, from camp sites and from large amount of materials including steel casing, drilling mud, cement and fuel.

2/ emissions and discharges. Large amounts of greenhouse gasses are emitted and other air pollutants from combustion of fuel in machinery and for heating. Well testing also contributes to the emissions by burning often large quantities of oil and gas. The off-shore drillings in West Greenland in 2010/11 increased the Greenland greenhouse gas budget significantly in those years. The emissions also include NO_x and SO_2, which contribute to formation of Arctic haze, and which may impact local vegetation by acidic precipitation, especially if the buffer capacity of the soil is low. Arctic haze is an air pollution phenomenon observed especially in valleys in mountainous areas and both Nuussuaq and Disko have many of such sites.

Various hazardous materials are being used during petroleum exploration/exploitation operations and should be stored and transported with outmost care. Drilling operations will produce waste of run-off, wash water, process water and other fluids associated with the well operation (OGP 2013). Other effluent from the process including oil, sludge and other solids are potential contaminants that should also be handled carefully.

The most significant waste products to be discharged are drill cuttings and drilling mud. This and other waste from the drilling activities must be disposed of safely. Depending on the materials and their toxicity, disposal options can include re-injection into an abandoned well, transfer offsite in tanks to hazardous waste facility, or deposit into a sump with an impermeable synthetic liner.

Finally, accidents and unforeseen incidents potentially pose a risk to the environment. The most severe accident will be a blow-out resulting in a large oil spill. But many other hazardous substances can be spilt.

3/ disturbance of wildlife and vegetation. The infrastructure may prevent wildlife from using important habitats or prohibit migrating populations from following their traditional routes in the terrain. During exploration these impacts will be temporary, but shall nevertheless be considered when planning the operations. Again winter activities will generally cause less impact than summer activities. Sensitive vegetation is also at risk in this context.

4/ water consumption. Drilling operations require large amounts of water to create drilling fluid. A 3,000 m well could require from 2000 to 8000 m^3 of water for drilling, in addition to approximately 375 l per day for each person in the drilling crew for camp use (BLM 2012). These amounts of water may potentially dry out water courses and ponds near a drill site.

2.2 Production

If petroleum discoveries are made, appraisal and preproduction phases will follow.

Preproduction development activities, including field delineation, for any particular discovery could take four or more years prior to production start-up. After a commercial discovery of oil or gas has been confirmed by delineation wells and seismic surveys, a number of construction activities are required to develop a permanent production operation. The limits of the reservoir must be determined before the full project development and production. The appraisal phase can last for several years and include further seismic surveys, drilling and well testing. Rock cuttings from exploration and delineation wells could be backhauled to existing disposal wells (NPR-A 2012). If the appraisal shows a commercial discovery, development may follow and production will start.

The number of production wells is determined by the unique characteristics of the oil and gas reservoir, such as thickness, permeability, lateral continuity, oil and gas qualities, and, most importantly, the reservoir recover mechanism. Well drainage areas vary for conventional wells, but generally do not exceed 60 hectares for oil (Ballem 2008). In addition to production wells, other wells are drilled to inject water or gas into the field to maximize oil recovery.

Exploitation of hydrocarbons is, compared to the exploration phase long lasting, and oil fields may produce for decades, why impacts from exploitation will be of long-term. The major conflicts with environment derive from more or less the same type of activities as exploration drilling, but in a much larger scale and longer perspective. Additional impacts should be considered from e.g. processing facilities, accommodation/camps, access roads and pipelines, airstrip, multiple well sites, gravel mines, shipment facilities, waste disposal facilities and tank farms and additional seismic surveys. Pipelines and roads could block or disturb important migration routes for the animals in the area. In addition the most extensive environmental impacts may derive from a large accidental oil spill. Impacts of oil spills and oil spill response on land will be described in Section 9. The infrastructure may also impact the permafrost layer by heating from facilities or by altering the insulation properties of the surface layers, e.g. by removal of vegetation or by piling of snow. Moreover, the drainage patterns of surface and subsurface waters may be altered by the infrastructure.

A production operation would require an all-year production gravel pad (gravel is the preferred material for the construction) that could support many wells and processing facilities in addition to the logistics facilities (airstrip, camps and storage etc.) as well as oil/gas pipelines (NPR-A 2012). As drilling continues during the production phase, drilling mud and cuttings will be produced and have to be disposed of. As described in Section 9.2.3, disposal in sumps is problematic seen from an environmental point of view. However, reinjection in old wells is an option in the production phase. New technologies are developing in the search for methods to extract even more oil and gas. Such methods are for instance coiled tubing drilling that allows for the drilling of new well bores from existing wells (AMAP 2010). Another additional technology is the extended-reach drilling that could allow for wells drilled beyond 12 km from the reservoir on e.g. an onshore surface location to a distant offshore reservoir location (AMAP 2010). Satellite stations and cluster well sites should be considered to minimize the number of flowlines. This technical development has in recent decades reduced the footprint from production sites.

Emissions to air are mainly combustion gases from the energy producing machinery (for drilling, production, pumping, transport, etc.). But also flaring of gas, trans-loading of produced oil and de-pressurizing of produced water contribute to emissions. The emissions consist mainly of greenhouse gases (CO_2, CH_4), NO_x, VOC and SO_2.

By volume the largest discharge from a production well is the produced water. The overall ratio of water to oil is 2.9 in Alaska (Clark & Veil 2009), but this ratio shows a considerable variation between wells and through the life time of a well.

Water flooding is a process that can increase oil recovery from production wells. To maintain reservoir pressure, the volume of oil withdrawn from the reservoir must be replaced with an equivalent or greater volume of water. Water is injected into selected areas of the reservoir to maintain subsurface pressure and promote fluid flow up to the surface. This process requires vast amounts of water that may overwhelm local freshwater sources. Industry must instead rely on seawater and produced water. Water flooding systems consist of seawater intake and treatment plants located on the coast, and an insulated pipeline that carries the seawater from the plant to production wells in the field (BLM 2012).

The impacts from discharges should be mitigated by reducing discharges applying the principles of BAT and BEP. They encompass for example re-injecting produced water, disposal of drilling waste at controlled sites and exclusively use of ultra-low sulphur diesel (ULSD, < 15 ppm) in all vehicles and machinery.

2.3 Decommissioning

Decommissioning include removal of all constructions and infrastructure and remediation of terrain and vegetation damages. A significant impact on the environment can be remobilization and spreading of accumulated contaminants, which can be spread by wind (dust) and watercourses.

The Qullissat coal mine site was not decommissioned when the activities stopped in 1971, and today the mine site is a mess of ruined buildings, coal, dump sites and damaged rail roads and with many potential sources of pollution.

Decommissioning activities also include intensive transport with the risk of disturbing wildlife along transport corridors and at shipment facilities. The impacts shall be mitigated by careful planning, applying the BEP and BAT principles. It is moreover important to make the different constructions in a way facilitating future removal and a comparison of environmental impacts from the removal activities should be considered as they may cause more impacts on the environment than just leaving them in place.

3 Physical environment

Wendy Loya and David Boertmann

3.1 Climate

Climate is monitored at some sites in the area, and these data are available through technical reports on the Danish Meteorological Institute Portal. Reports are updated annually and contain all available data (Link). Data since 1993 from a weather station near Qeqertarsuaq (69° 14′ 38′′ N, 53° 31′ 44′′ W, 12 meter above sea level) including temperature, wind, relative humidity and precipitation are also available by request from Asiaq (official holder of data from the physical environment in Greenland, Link). Other sources of climate data include air, land and sea measurements taken at the University of Copenhagen's Arctic Station on Disko Island near Qeqertarsuaq, are available through the station's administration.

The data from Arctic Station have recently been summarized by Hansen et al. (2006) and Hollesen et al. (2015). The researchers compared monthly air temperatures for Arctic Station and Ilulissat, and found strong similarity between the data (Hollesen et al. 2015). Together, they provide a contemporary summary of climatic conditions for the area. The mean annual air temperature was -3.0 °C ± 1.8 °C for the period of 1991-2011. The coldest mean monthly temperature was found for March (-14.0 °C ± 5.0 °C) and warmest mean monthly temperature was for July (7.9 °C ± 1.6 °C). Temperature trends suggest an overall increase of 0.2 °C per year, with greater increases in winter (0.4 °C per year) compared to summer and fall (0.1 °C per year).

Hollesen et al. (2015) also found significant increase in the length of the growing season by comparing the first 10 years (1991–2000) with the most recent 10 years (2002–2011). The mean annual number of freezing degree-days (FDD) decreased from 2240 to 1585 FDD and the number of thawing (TDD) and growing degree-days (GDD) increased from 680 to 912 TDD and from 160 to 284 GDD. While the overall temperature regime for Arctic Station, which is on the southern edge of the study area, is likely to maintain mean annual temperatures below freezing for at least the next 15 years, the increase in TDD and GDD will have implications for the stability of the soils in the landscape, especially in lower, wetter areas over permafrost.

Accurate and consistent measurements of precipitation are difficult in remote and/or snowy places, and so there is an incomplete record of precipitation at Arctic Station (Hollesen et al. 2015). The mean annual rainfall from 1994-2006 was 273 mm ± 100 mm, with September being the wettest (63 mm) and March the driest (15 mm) months. At Arctic Station, approximately 60 % of the total precipitation is estimated to fall as rain (Hansen et al. 2006) and the mean annual total precipitation (rain and snow) is estimated to be around 400 mm. Hollesen et al. (2015) also report large year-to-year variation in snow cover, with an average of 16 cm between October and May. An overall decrease in the duration of snow cover has implications for industrial activities if impacts are to be minimized by allowing transportation overland when soils are frozen and protected by adequate snow cover as required for oil exploration in Arctic (DNR 2015).

Sea ice in the area has implications for access by boat and barge. On average, sea ice cover of more than 50% was observed for 95 days each winter for the period 1991–2011 (Hollesen et al. 2015). However, over that period, the sea ice cover was reduced by approximately 50 %, with a tendency of the sea ice being formed later and disappearing earlier in the season. Sea ice charts and satellite images of Disko Bay are available through DMI to aid in navigational planning (Link).

DMI has estimated the expected climate change in Greenland based on the latest Danish and international scenario calculations focusing on climate change within this century (Christensen et al. 2015). The assessment of future climate change is based on the emission scenarios used by the Intergovernmental Panel on Climate Change (IPCC). Climate variability and change are expected to increase towards 2100 in terms of higher temperatures, more winter precipitation, more frequent and extreme weather events and a continuing loss of sea ice. Continued increases in temperature in the spring and especially the autumn could cause an increase in mean temperatures from below freezing to above freezing. This could have both positive and negative implications for both natural processes and human activity in the area and should be considered in long-term environmental planning.

3.2 Topography

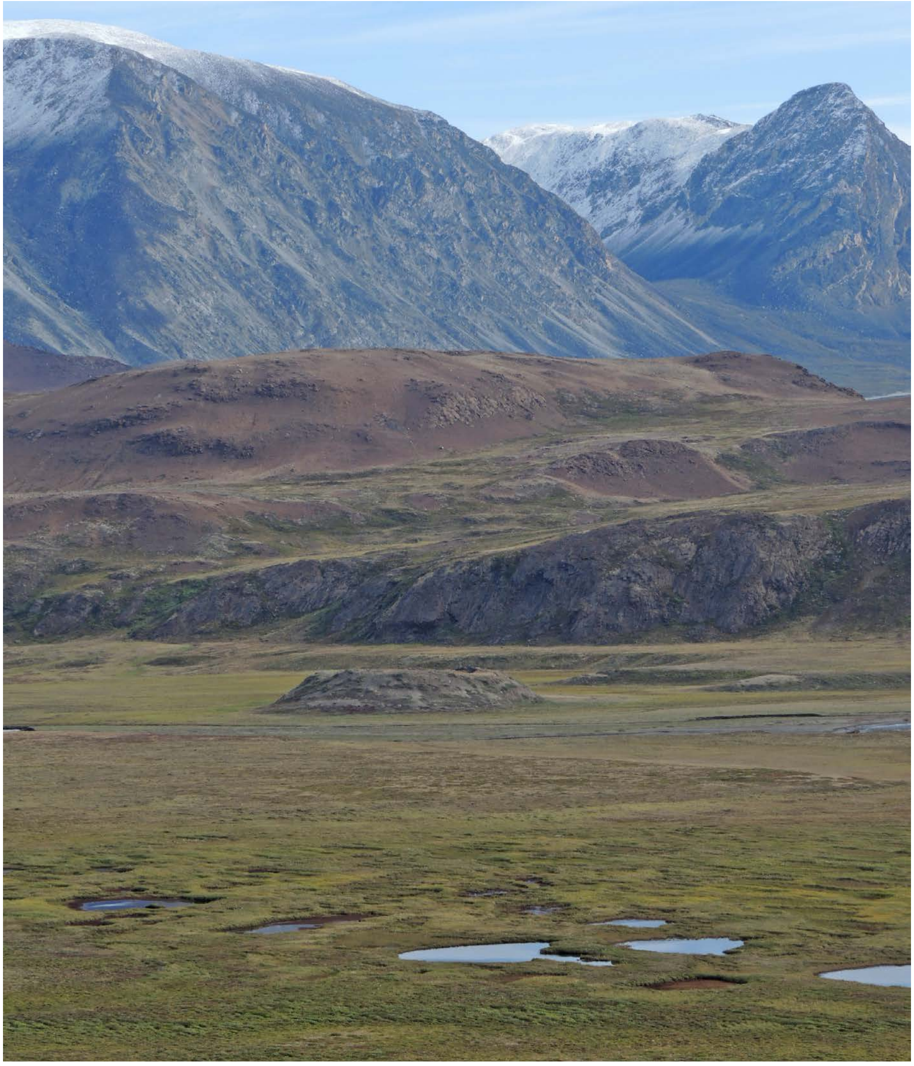
The Nuussuaq peninsula is about 175 km long and 50 km wide, encompassing approximately 7150 km^2. It is a mountainous landscape, with the highest peaks reaching 2,144 m. Lowlands are found in the coastal forelands and in the river valleys (Figure 1). The most prominent valleys are the central Aaffarsuaq valley, the Saqqaq valley and the Boyes Lake valley. Most of the coastlines are steep with only narrow forelands, but wider, gently sloping forelands are found especially at the western tip of the peninsula. Lakes are few in numbers, and large lakes are found only in the central valley and in the eastern part of the peninsula (outside the assessment area). The coasts are generally rocky or with narrow sediment beaches. Salt marshes are found at a few sites, e.g. at the mouth of the Aaffarsuaq valley. Extensive glaciers cover the highest parts of the area and turbid meltwater flows from these to the rivers and lakes of the central Aaffarsuaq valley. A special landscape feature – linked to the permafrost – is represented by the small distinct hills in the floor of the main valleys, the pingos (Figure 3)

Disko Island, called Qeqertarsuaq in Greenlandic, lies south of the Nuussuaq Peninsula. They are separated by Vaigat (Sullorsuaq) Strait. Disko Island is approximately 8,578 km^2. Disko Island has similar topography with steep glacier capped mountains cut by steep U-shaped valleys and surrounded in general by steep coastlines. Peaks gradually increase from about 800 m in the southwestern part of the island to more than 1900 m in the northeastern part. Disko Island does not have any large lakes, but several of the rivers have significant lowland areas with wetlands. Water sources include direct runoff from rainfall and annual snowmelt, groundwater sources in the basalt benches and loose sediments and flow from glacial and perennial snowpatch melt (Christiansen et al. 1995). The island has been described as being situated within the zone of continuous permafrost, and periglacial landforms including rock glaciers (Humlum 1996) and solifuction lobes are found, as well as pingos (Christiansen 1995). Salt marshes are found at the mouth of many of the large valleys.

3.3 Geology

The assessment area covered in this SEIA includes the western portion of the Nuussuaq and the entirety of Disko Island. A general description of the geology of this area is given by Henriksen (2008), from which following account is derived. The eastern section of the Nuussuaq Peninsula is excluded from the

Figure 3. The partly eroded pingo in outer Saqqaq Valley, Aug. 2015.



proposed licence blocks as the underground primarily is shallow or exposed continental bedrock. To the west and on Disko Island, thick deposits (up to 6 km thick) of sediments that could contain oil and gas are found. Palaeogene basalts overlie the sediments in many areas and therefore little is known about the deeper-lying successions in the Disko-Nuussuaq area. Development of faults in the late Tertiary resulted in uplift of the basalt and sediments approximately 1 km from the level of the Cretaceous-Tertiary boundary.

Subsequent quaternary glaciers dissected the basalt plateaus, in some cases exposing sediments, with the highest plateaus remaining glaciated at present. The volcanic basalt makes it difficult to conduct seismic surveys of the subsurface sediments where hydrocarbons would exist (Henderson et al. 1981), if present, and which has slowed hydrocarbon exploration in the area since it was initiated in the 1970's. A 2,996 meter deep well (GRO#3) drilled on the southwestern coast of the Nuussuaq Peninsula in 1996 by grønArctic Energy did not reveal commercially recoverable oil, nor has offshore drilling in the Disko West licence blocks (Christiansen et al. 1997). Limited offshore seismic work near the coast has provided some context for understanding the geology of the Nuussuaq Peninsula and Disko Island.

However, oil has been located in numerous seeps in the assessment area, primarily on the coast of western Nuussuaq and on north Disko (Bojensen-Koefoed et al. 1999).

There are a number of interpretations of the geology with regards to hydrocarbons. In 2009, the Geologic Survey of Denmark and Greenland (GEUS) published a report on the Cretaceous-Paleocene lithostratigraphy including the assessment area (Dam et al. 2009) to create a common reference for geoscientists working in the region.

3.4 Permafrost

Permafrost is an important issue to consider, when dealing with infrastructure in the assessment area. Permafrost denotes that soils are more or less frozen throughout the year. The ground remains at or below 0 °C, although the topmost layers usually thaw and is termed the active layer. The thickness of this varies from several meters to few centimeters, depending on soil type, moisture and vegetation cover (see International Permafrost Association, Link). The assessment area is situated in a region where both discontinuous and continuous permafrost is found (Christiansen & Humlum 2000). Discontinuous means that permafrost underlays 50-90 % of the terrestrial habitats (Brown et al. 2002).

The permafrost layer is under pressure from climate change and increased temperatures (AMAP 2011), and thawing permafrost has a high potential to alter landscapes, especially by changes in the hydrology.

Land impacted by degraded permafrost is termed thermokarst - the melting layer creates ponds, hummocks, cracks and especially clefts which by erosion may develop into deep clefts. Large land areas may slide downwards. Activities related to hydrocarbon exploration and exploitation has the potential to induce thermokarst for example at roads, pipelines and other infrastructure (AMAP 2011). Figure 4 shows an example of impacted permafrost and there is another example in Box 1.

Infrastructure (buildings, roads, pipelines, runways etc.) placed in such areas with melting permafrost becomes unstable, are deformed or damaged, sinks into the ground or is simply destroyed (AMAP 2011).

Permafrost must be expected in most of the land areas of the assessment areas and the presence of pingos (Figure 3) in some of the valleys of Disko and Nuussuaq is a clear indicator of permafrost.

Figure 4. The permafrost is thawing due to driving. It continued to develop despite filling in with gravel and caused the track to be transposed to the sides – inducing more and wider impacts on the terrain, Nuussusaq Sept. 2007.

BOX 1

TRACKS FROM DRIVING OPERATIONS IN NUUSSUAQ

David Boertmann

The Marraat area and the central valley of Nuussuaq, Aaffarsuaq, has been the focus area for both petroleum and mineral exploration activities since the mid-1990s. The most extensive activities encompassed the drilling of an oil exploration well near the coast in 1996 by grønArctic and exploration for nickel in 2007 by Green Mining, 20 km inside the valley. Both these activities included extensive transportation jobs from the coast to the exploration sites and numerous tracks, ruts, creek crossings etc. was constructed and to some degree remediated after the completion of the exploration activities.

Figure 1. Satellite image (Google earth) showing the outer part of Aaffarsuaq valley, with the access road constructed in 2007 clearly visible in 2012. Arrow to the left points at the track over a dry Dryas-heath and the left arrow at the crossing of a creek.

The 1996 activities included driving with heavy equipment from the coast and up to 2.5 km inland, while the 2007 activities included the construction of a 31 km long access road. The operating companies were instructed to remediate the tracks and scars in the terrain as far as possible, however, there are still very obvious signs of the transportation activities in the area – the access road is for example clearly seen in satellite images (Figure 1).

The tracks near the coast and other signs of the transportation jobs were inspected in August 2015 (Wegeberg et al. 2016) and photo documented (Figure 2).

The results of the photo documentation in 2015 were that:

- in many areas, especially dry and vegetation less flats and in the river bed, the tracks and other signs of the activities were remediated as required (Figure 2),
- the access road in more moist areas was not really restored; geo grid and fibre cloth were not removed (Figure 3),
- thermokarst had developed in connection to the road in at least two sites (Figure 4),
- some of the culverts were not removed from creek crossings,
- in ruts created in 1996 and filled in with gravel, vegetation was slowly reestablishing,
- some deep holes in wet soil, created by a stock bulldozer in 1996 and filled in with gravel, appeared restoring with reestablishing vegetation,
- there are many tracks from driving with different kinds of vehicles in the terrain outside approved tracks.

Figure 2. The two images show the same part of the access road constructed in 2007. Upper image from 23 August 2007 during the operation and lower image showing how the remediated area looks like, 8 years later on 4 August 2015.

From the photo documentation, 2007 and 2015, DCE concluded that

- the tracks and many of the other terrain damages will be visible for many decades ahead based on the limited reestablishment and development of vegetation in 8 years (2007-2015),
- the companies did not follow the regulation of no driving outside the marked tracks,
- the company operating in 1996 restored and remediated their working areas as required,
- the company operating in 2007 missed to remediate the access road; there are some culverts still in place, fiber cloth and geo grid has not been removed and are exposed in some places,
- if the recommendation in 2007 from DCE (then NERI), to do the transportation jobs in winter when the terrain was snow covered and frozen, was followed, it is assessed that most of the resulting impacts from the activities could have been avoided. This is in accordance with the requirements for oil exploration transport activities in Arctic Alaska (DNR 2015).

Figure 3. The two images show the same part of the access road constructed constricted in 2007 in a moist area. Gravel is placed on fibre cloth and geogrid to prevent the track to sink into the wet soil. Lower image during the operation on 28 August 2007 and upper image 8 years later on 4 Aug. 2015. The track was not remediated, only leveled slightly along the edges. Note that some vegetation has established in 2015.

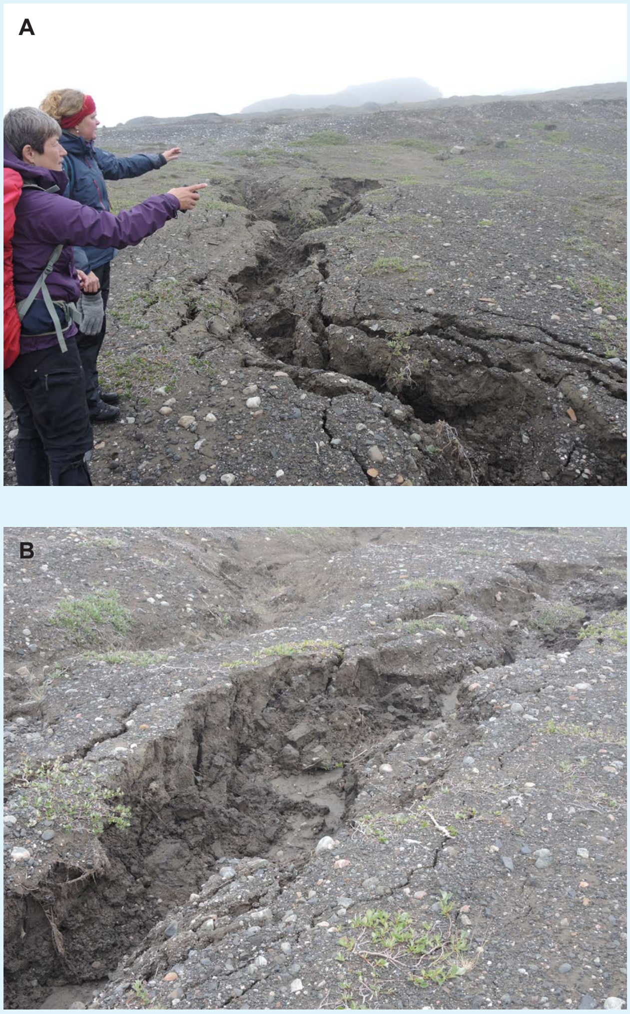


Figure 4. Two examples of thermokarst development along the access road constructed in 2007. Images from 4 Aug. 2015.

When an access road was constructed in the central valley of Nuussuaq Peninsula in 2007, damage to the permafrost layer became an increasing problem several places along the road (Figure 4). It resulted in the need for either displacement of the track to the side or in more or less continuous filling in with gravel. During inspection in 2015 of that access road, it also became clear that thermokarst had developed at least at two locations in connection to the tracks (Box 1).

Permafrost is not an impermeable barrier to terrestrial oil spills (Biggar et al. 1998, Chuvelin & Miklyaeva 2003, Fritt-Rasmussen 2006). Pores, cracks and capillary forces will facilitate transportation both horizontally and vertically, but to a limited degree. Permafrost may also to some extent facilitate the orientation of seeping oil (R. Tatner pers. comm.) and the permeability will also depend on water/ice content. Another feature to consider in case that an oil spill moves to the permafrost, is that such oil may be remobilized if frozen soil melts.

3.5 Homeothermic springs

Disko Island is particularly rich in homeothermic springs (Figure 5). The water temperatures in these spring range from 1 °C to 18.5 °C (Kristensen 2006). A few springs hold radioactive and mineral rich waters, while the majority have almost pure waters with a little HCO_3^- (Kristensen 2006). The flora and fauna in and near these springs is rich, because the stable water temperature creates a protected environment in winter. Vascular plants with a southern distribution have their northern distribution limit at these springs and the vegetation can be very lush. Many springs have a unique fauna of invertebrates (Kristensen 2006), why their conservation value is high. They are actually specifically included in the Nature Protection Law as particular important and protected habitats, why exploration activities shall be planned to ensure that these springs are well outside potential impact radius.

The number of springs on Disko is estimated at 'thousands' (Kristensen 2006), and Figure 5 only shows those actually known.

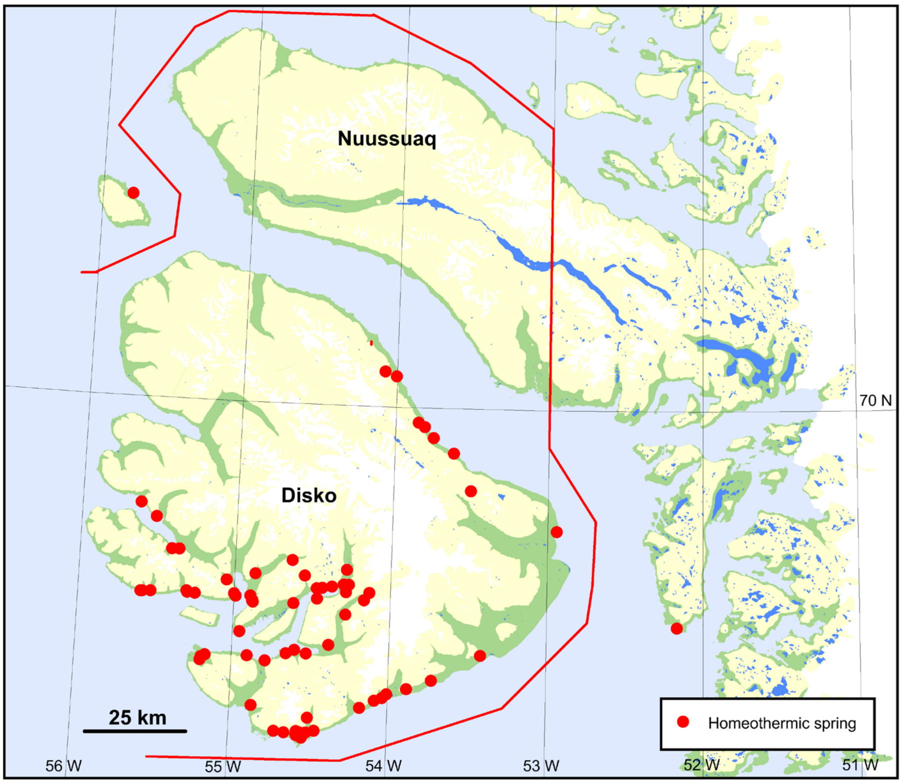


Figure 5. Distribution of homeothermic springs in the assessment area. Based on information from R.M. Kristensen (pers. comm.) and J. Feilberg (pers. comm.). Many more spring are not mapped.

4 Biological environment

4.1 Vegetation

Christian Bay and Caroline Ernberg Simonsen

4.1.1 Botanical exploration of the Disko-Nuussuaq area

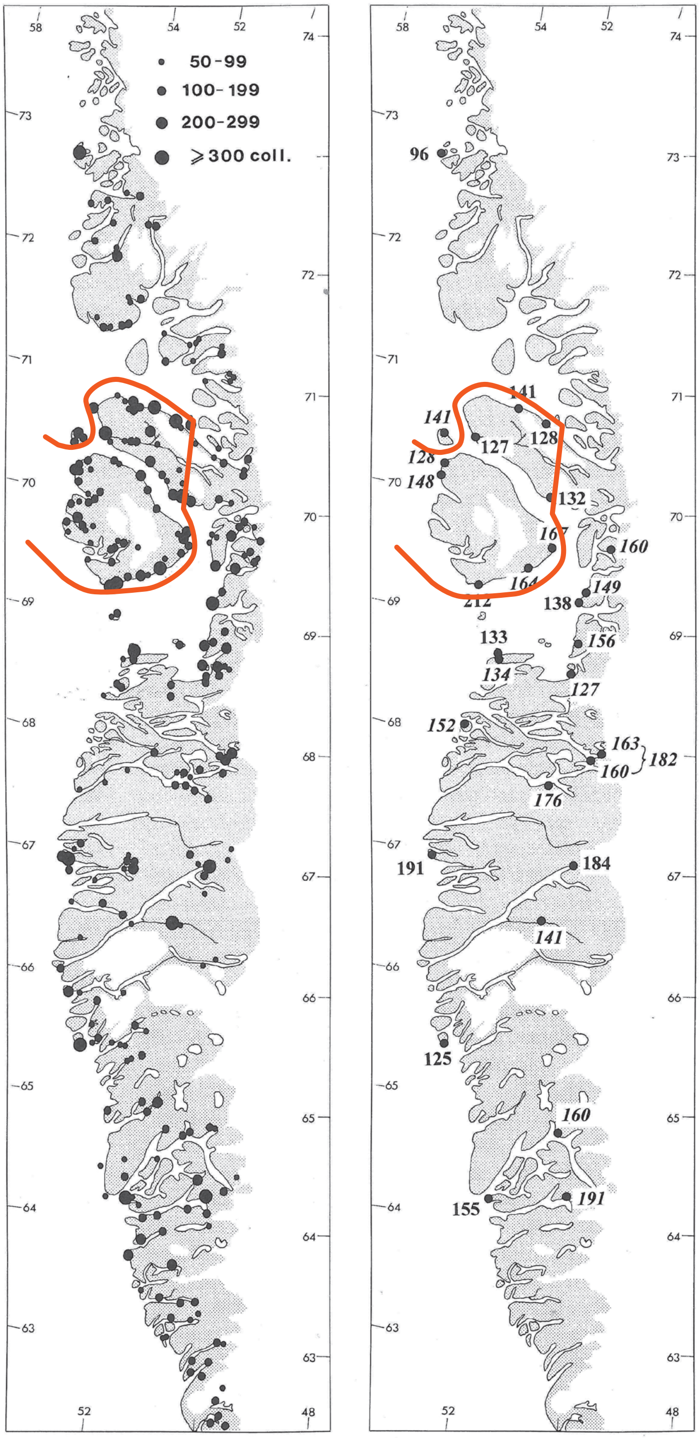


Figure 6. To the left a map showing the botanical study intensity expressed as collection sites. Only localities with at least 50 collections are shown. To the right the number of taxa at some of the richest localities. Red line delimit the assessment area.

The exploration of the flora of Disko Island and the Disko Bay area started after the establishment of the Arctic Station at Qeqertarsuaq/Godhavn in 1906 by the University of Copenhagen. The botanist M.P. Porsild was the founder and leader of the station for decades and carried out botanical work in the region from 1906. Böcher (1963) worked at two localities on Disko. Greenland Botanical Survey (GBS), University of Copenhagen, worked in the region in 1980-87 plus 1992 and collected hundreds of vascular plant specimens during the periods, where the botanists Jon Feilberg and Wilhelm Dalgaard were scientific leaders of the Arctic Station. Minor botanical studies in restricted areas have been carried out by Vestergaard (1978), Phillip (1978), and Post & Bøving (1993). The flora and phytogeography of the entire West Greenland area was studied by Fredskild (1996) based on 55,000 specimens in herbaria of vascular plants (see below).

In August 2015, a vegetation survey was conducted at four locations in the assessment area, two on Disko and two on Nuussuaq as part of the background studies conducted to support the present report (Box 5, Wegeberg et al. 2016).

4.1.2 Flora

Compared to many other regions of Greenland the Disko-Nuussuaq region is well studied in a botanical sense (Fredskild 1996, Figure 6). Several localities have been investigated and several collections of vascular plants are available in the herbaria. M.P. Porsild (1910a, 1910b, 1912, 1920) and A.E. Porsild (1926) were the first to publish studies from the region and e.g. 220 species were recorded on Disko Island. Since then several species have been added and Fredskild (1996) lists 212 species of vascular plants alone at the town of Qeqertarsuaq/Godhavn, making it the most diverse locality of vascular plants in Greenland. The number of vascular plant species on well-investigated localities in the Disko Bay varies between 128 and 167 (Fredskild 1996).

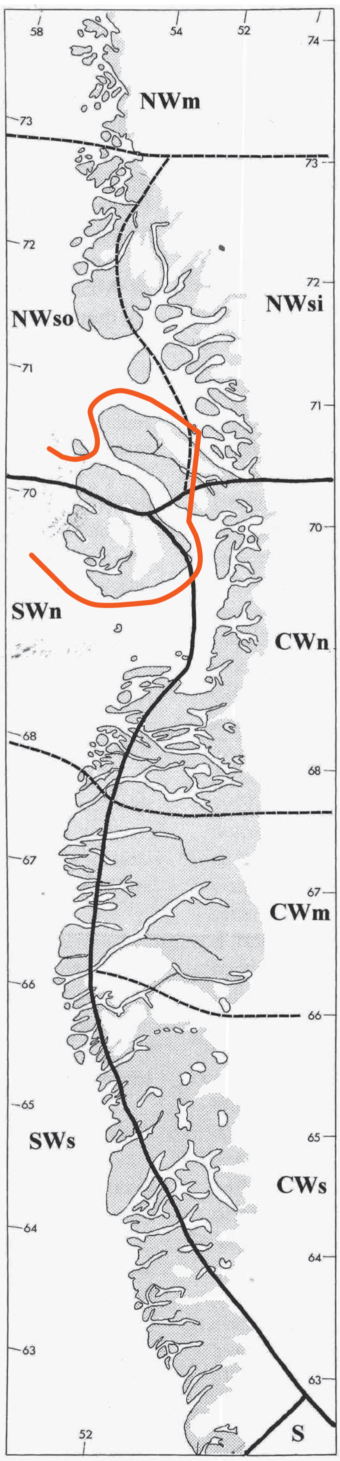


Figure 7. The boundaries between floristic provinces (solid lines) and districts (dashed lines). The line between NWso/NWsi, and SWn/CWn is considered the phytogeographical boundary between high and low Arctic Greenland. (From Fredskild 1996). Red line delimit the assessment area.

4.1.3 Phytogeography and diversity

The results of Fredskilds (1996) phytogeographical (the science dealing with the geographical relationships of plants) study were distribution maps of 379 vascular plant species and an account of the phytogeography. New boundaries between floristic provinces and districts were also proposed. The Disko-Nuussuaq area is in the transition zone between the low arctic and the high arctic in West Greenland. The line goes from northernmost Disko eastwards to the southern area of Nuussuaq (Figure 7). The floristic districts SWn and CWn comprise the oceanic and the continental areas, respectively. The latter comprises the mainland east of Disko, the southeast coast of Disko and the southernmost part of Nuussuaq.

The species diversity declines with increasing latitude but despite the location of the study area half way up the west coast of Greenland the very high biodiversity of the Disko area can be explained by the variation in the geology and soils, and mostly by the fact that the area is in the transition zone between the low Arctic and high Arctic and both oceanic and continental areas are included in the study area.

4.1.4 Vegetation

Fredskild (1969) describes the vegetation of the Disko-Nuussuaq and divides the vegetation into the following types:

1. Herb slopes are the most luxuriant vegetation type dominated by *Alchemilla glomerulans*. They occur on south facing slopes with many low arctic species e.g. *Leucorchis albida*, *Plantanthera hyperborea*, *Listera cordata* and *Epilobium hornemannii*.
2. willow shrubs with *Angelica archangelia* ssp. *norvegica* at homeothermic springs,
3. rich dwarf shrub heath,
4. *Cassiope* heath,
5. snow-patches and
6. many types of fell-field vegetation with several high arctic species.

This classification is used in the following account.

On the south side of the eastern part of Nuussuaq the vegetation is influenced by the low arctic continental conditions. *Betula nana* is the most common heath plant in the lowland followed by *Vaccinium uliginosum* ssp. *microphyllum*, *Ledum palustre* ssp. *decumbens*, and *Empetrum nigrum* ssp. *hermaphroditum* and in less dry heaths, *Salix glauca*. In the upland above 500 meter these heath types are replaced by *Cassiope tetragona* heath or *Loiseleuria-Salix herbacea* vegetation with *Phyllodoce coerulea* and *Silene acaulis*, and by fell-fields. Herb slopes are rare and no *Salix* scrubs are found. Many types of snow-patches, ranging from *Anthelia* dominated solifluction soil to *Salix herbacea-Stereocaulon canescens* vegetation with *Antennaria canescens*, *Polygonum viviparum*, *Luzula spicata*, *Trisetum spicatum*, and *Agrostis mertensii*, are frequent. Fens are few, whereas vegetation on frost boils with *Sagina intermedia, Juncus biglumis* and *Tofieldia pusilla* are common on shallow ground.

On the northeast coast of Disko the vegetation is high arctic continental. *Dryas integrifolia* heaths and *Dryas integrifolia-Carex rupestris* heaths are dominating, whereas *Cassiope tetragona* only occurs in the gorges. *Vaccinium uliginosum* ssp. *microphyllum* is fairly frequent, *Betula nana* is rare. On dry sites *Carex nardina* and *Kobresia myosuroides* are common, sometimes accompanied *by Potentilla pulchella* and *Lesquerella arctica*. Snow-patches and frost boils vegetation are sparse and small, and fens, ponds and herb slopes are absent.

High arctic maritime vegetation is found on the northwest coast of Disko. Mossy *Cassiope tetragona-Salix arctica* heaths cover vast areas and solifluction soil and frost boils with open vegetation dominating by *Juncus biglumis*, *Polygonum viviparum*, and *Equisetum arvense*, are frequent. *Salix arctica* heaths with *Vaccinium uliginosum* ssp. *microphyllum* are frequent on south-facing slopes. *Empetrum nigrum* ssp. *hermaphroditum* occurs only at protected sites. No *Betula nana* and only few *Salix glauca* are seen. Only exceptionally dry slope plant communities are seen with *Carex nardina*, *C. glacialis*, *Potentilla vahliana*, and *Antennaria ekmanniana*. Only a few areas of species-poor snow-patch and herb slope-like vegetation are seen. *Carex stans* fens occur along rivulets, but neither *Eriophorum scheuchzeri* fens nor ponds occur.

4.1.5 Rare species

Rare species are defined as species occurring within less than 20 localities in the region (Talbot et al. 1999). Tables 1-3 lists species considered as rare in the assessment area.

Twenty high arctic and middle arctic species have their southern distribution limit in the area and are considered rare in the region (Table 1).

Several low arctic species (n = 76) have their northern distribution limit in the area and are considered rare in the region (Table 2).

Table 1. High arctic and middle arctic species considered as rare in the assessment area. Figures in brackets indicate number of localities in the assessment area.

Braya purpurescens	(15)
Braya thorild-wulffii	(6)
Carex atrofusca	(8)
Carex marina ssp. *pseudolagopina*	(12)
Draba adamsii	(4)
Draba fladnizensis	(2)
Draba subcapitata	(17)
Dryopteris fragrans	(6)
Eutrema edwardsii	(12)
Festuca hyperborea	(13)
Halimolobus mollis	(7)
Minuartia rossii	(1)
Phippsia algida ssp. algidiformis	(11)
Poa abbreviata	(10)
Poa hartzii	(13)
Poa pratensis var. colpodea	(7)
Potentilla rubricaulis	(5)
Puccinellia andersonii	(10)
Ranunculus affinis	(4)
Tofieldia coccinea	(2)

Table 2. low arctic species (n = 76) have their northern distribution limit in the assessment area and are considered rare in the assessment area. Figures in brackets indicate number of localities in the assessment area.

Alchemilla glomerulans	(17)	*Epilobium hornemannii*	(17)	*Phleum commutatum*	(12)
Alopecurus aequalis	(14)	*Epilobium lactiflorum*	(9)	*Pinguicula vulgaris*	(17)
Angelica arcangelica ssp. *norvegica*	(16)	*Epilobium palustre*	(4)	*Plantago maritima* ssp. *borealis*	(15)
Antennaria affinis	(11)	*Equisetum scirpoides*	(10)	*Plathantera hyperborea*	(13)
Antennaria hansii	(9)	*Equisetum sylvaticum*	(1)	*Poa flexuosa*	(2)
Antennaria intermedia	(17)	*Erigeron uniflorus*	(1)	*Polysticum lonchitis*	(5)
Arabis holboellii	(18)	*Festuca saximontana*	(6)	*Potamogeton filiformis*	(15)
Botrychium lanceolatum	(5)	*Festuca groenlandica*	(7)	*Potamogeton pusillus* ssp. *groenlandicus*	(15)
Botrychium lunaria	(15)	*Gentiana aurea*	(2)	*Potentilla egedii*	(18)
Calamagrostis langsdorffii	(6)	*Gentiana nivalis*	(7)	*Potentilla ranunculus*	(13)
Callitriche anceps	(3)	*Gnaphalium norvegicum*	(8)	*Potentilla tridentata*	(12)
Callitriche palustris	(4)	*Gnaphalium supinum*	(18)	*Puccinellia coarctata*	(11)
Carex brunnescens	(7)	*Gymnocarpium dryopteris*	(5)	*Pyrola minor*	(15)
Carex canescens	(3)	*Hieracium alpinum*	(1)	*Ranunculus reptans*	(6)
Carex deflexa	(1)	*Hieracium groenlandicum*	(2)	*Rhodiola rosea*	(1)
Carex microglochin	(9)	*Hieracium subarcticum*	(1)	*Rumex acetosella*	(6)
Carex rufina	(14)	*Juncus subtilis*	(3)	*Sagina saginoides*	(19)
Carex subspathacea	(16)	*Juniperus communis* ssp. *alpina*	(1)	*Scirpus caespitosus*	(15)
Chamaenerion angsutifolium	(10)	*Leucorchis albida* ssp. *straminea*	(10)	*Sedum villosum*	(7)
Coptis trifolia	(1)	*Leymus arenarius*	(3)	*Sparganium hyperboreum*	(2)
Corallorhiza trifida	(6)	*Linnaea borealis* ssp. *americana*	(1)	*Stellaria calycantha*	(10)
Diphasiastrum complanatum	(10)	*Listera cordata*	(5)	*Trisetum triflorum*	(11)
Draba aurea	(13)	*Luzula parviflora*	(19)	*Veronica fruticans*	(12)
Draba incana	(1)	*Montia fontana* ssp. *fontana*	(11)	*Utricularia intermedia*	
Elymus violaceus	(1)	*Parnassia kotzebuei*	(6)	*Utricularia minor*	(1)
				Vaccinium vitis-idaea	

Table 3. Middle arctic species only occurring in central West and central East Greenland are rare in the Disko/Nuussuaq area. Figures in brackets indicate number of localities in the assessment area.

Antennaria porsildii	(3)	*Orthilia secunda* ssp. *obtusata*	(8)
Arctostaphylos alpina	(2)	*Primula stricta*	(4)
Braya linearis	(2)	*Puccinellia deschampsioides*	(19)
Carex capitata ssp. *capitata*	(1)	*Puccinellia groenlandica*	(2)
Draba cana	(6)	*Puccinellia langeana*	(8)
Draba cinerea	(8)	*Puccinellia rosenkrantzii*	(4)
Gentiana tenella	(4)	*Utricularia ochroleuca*	(1)
Luzula groenlandica	(2)		

Table 4. Endemic and rare species of vascular plants occurring in the assessment area.

Antennaria affinis	(11)	*Puccinellia groenlandica*	(6) **
Hieracium subarcticum	(1)	*Puccinellia porsildii*	(1)
Potamogeton pusillus ssp. *groenlandicus*	(14)	*Puccinellia rosenkranzii*	(4)***
Potentilla ranunculus	(12)*		

*Only known from the Disko/Nuussuaq region and during the field work only found at Mudderbugten with an estimated frequency at 3.
**During the field work the species was only found at Gro #3 and the frequency was estimated to 1.
*** Only known from four sites in Nuussuaq. This is the world distribution of the species which belongs to the rarest species in Greenland. During the field work the species was only found at Saqqaq and the frequency was estimated to 1.

Fifteen middle arctic species only occurring in central West and central East Greenland are rare in the Disko-Nuussuaq area (Table 3).

4.1.6 Endemic species

Seven of the species found in the assessment area are endemic to West Greenland (Fredskild 1996) and are also rare in the study area (Table 4).

4.2 Fish

Wendy Loya

Only two fish species occur in the freshwaters of the area: Arctic char (*Salvelinus alpinus*) and three-spined stickleback (*Gasterosteus aculeatus*). According to an interview study of local fishermen, Arctic char are found in five or six rivers of the Nuussuaq peninsula, including the large river in central part (Olsvig & Mosbech 2003). However, other sources state that there are no char in that river (D. Boertmann pers. com. 2007). The large lakes Boyes Sø and Amitsup Tasia are presumed to hold stationary stocks of Arctic char, but no information is available. Arctic char on Disko Island are reported to be abundant by rivers and inlets evenly spread over most of the Disko coast and in Disko Fjord. On the east side of the Disko Island, at the bay Aqajarua, the area is referred to as a good and very important Arctic Char fishing ground.

The stickleback is very common in coastal lagoons and in lakes in the assessment area.

Two marine fish species use the subtidal zone for spawning in the springtime. This is the capelin (*Mallotus villosus*) and the lumpsucker (*Cyclopterus lumpus*). The spawning and fishing sites for these species were also mapped during the interview study (Olsvig & Mosbech 2003). No fishery for lumpsucker takes place in the coastal waters of Nuussuaq; therefore, knowledge on the spatial distribution of spawning sites is limited. Fishermen from Qeqertarsuaq identified the entire coastline around the southwest tip of Disko Island as well as areas near Kangerluk (in a radius of about 20 km from the village) as important lumpsucker areas. Capelin is fished by local people and spawning takes place along several coastlines of the peninsula – mainly in the southeast and along the northern coast.

4.3 Birds

David Boertmann

4.3.1 Inland birds

The number of bird species breeding inland (this comprise terrestrial birds and birds associated with fresh water) in the assessment area is relatively low. Two diver (loon), five species of waterfowl (ducks and geese), three species of shorebirds, ptarmigan, two species of birds of prey and five species of passerines (songbirds). An additional few species occur as regular visitors (on migration) or as summer visitors.

The most important land bird species in a conservation context are the white-fronted goose and the gyr falcon. They are here treated in more detail than the other species.

White-fronted goose ***Anser albifrons flavirostris***
This species deserves special attention, because there is conservation concern for the population. The white-fronted goose breeding in West Greenland is a taxonomically separate form with status as subspecies. The breeding range of this subspecies is restricted to central West Greenland between c. 66° and 73° N, including the assessment area. The population numbered in spring 2014 20,797 individuals and in spring 2015 18,884 (Fox et al. 2014, 2015) and the population has been suffering from a continuous decrease since 1999 (Fox et al. 2006), resulting in the classification as having an unfavorable conservation status.

The geese arrive from wintering grounds in the British Isles in early May and leave again in September. Breeding pairs occur scattered in the moist lowlands. A large segment of the population comprises non-breeding birds, which assemble in large flocks in marshes and at lakes within the same range as the breeding birds. Here they perform feather moult and become flightless for a three-week period in July. These moulting birds are very sensitive to disturbance when flightless (Glahder & Walsh 2007, Madsen 2004).

The white-fronted geese in the assessment area have been surveyed at several occasions, both from the air and during land-based studies:

The aerial surveys include:
- Breeding geese in July 1999 (Malecki et al. 2000).
- Moulting geese July 1992, 1995 and 2003 (Glahder 1999, Glahder et al. 2002, Madsen 2004).
- Post-moulting geese in August 2007 (Fox & Glahder 2010).
- Moulting geese in 2016 (Box 2).

Land-based studies include:
- Breeding and moulting geese on Disko in July 1989 (Frimer & Nielsen 1990).
- Breeding and moulting geese on Disko in July 1994 (Heegaard et al. 1994).
- Breeding and moulting geese on Disko in July 2001 (Egevang & Boertmann 2001, Boertmann & Egevang 2002).
- Moulting geese in Disko in July and August 2004 (Levermann & Raundrup 2004, Raundrup et al. 2012).

BOX 2

GOOSE AND SEADUCK SURVEY IN THE ASSESSMENT AREA IN JULY 2015

David Boertmann

In the days 27-31 July, the valleys and coasts of the assessment area were surveyed from aircraft for moulting geese and seaducks (Figure 1A). The survey results are shown on the maps in Figure 1B, 1C and 1D and in Table 1.

Table 1. Number of geese counted during the survey in July 2015.

Site	White-fronted goose	Canada goose	Unidentified goose
Disko Island			
Blåbær- og Laksedal	88	75	113
Kvandalen	319	317	576
Kuannersuit Kuussaat	0	82	0
Stordal/Nordfjord	293	126	85
Laksebugt	0	129	1060
Mellemfjord	128	561	4
N of Qasigissat	50	0	0
Daugaard-Jensen Dal	30	42	0
Coast E of Godhavn	0	0	176
Aallaagissat	0	133	0
Disko NW coast	0	65	0
Nuussuaq			
Affarsuaq	201	789	81
Saqqaq Valley	122	369	0
Ubekendt Ejland*	40	110	65
Naternaq*	335	1469	1702

* outside assessment area

The survey confirmed that the areas designated as 'important areas for wildlife' still are valid, and that two of the three Ramsar sites still hold international important numbers of Greenland white-fronted geese, i.e. 1% of the total population numbers corresponding to 190 individuals (Figure 1B). See also Tables 5 and 6 in main text.

The survey also confirmed that the Canada geese are widespread in the assessment area and that the population continues to increase (Figure 1C).

The numbers of common eiders were three times higher along the West coast of Disko (Figure 1D) than observed during a similar survey in 1998. On 28 and 29 July 2015, 37,332 were counted and on 22 and 30 July 1998 12,992. This increase is in line with the general increase in the breeding population in West Greenland since 2001, when spring hunting was restricted.

Numbers of White-fronted geese were alarmingly lower than previous surveys have shown (see main text), while numbers of Canada geese were much higher.

Especially Nordfjord is known to be an important moulting habitat for king eiders. However, only relatively few king eiders were recorded (n = 3477 and of these 1814 in Nordfjord). Much higher numbers occur in the area later in August.

See also the report describing the survey results (Boertmann & Petersen 2016).

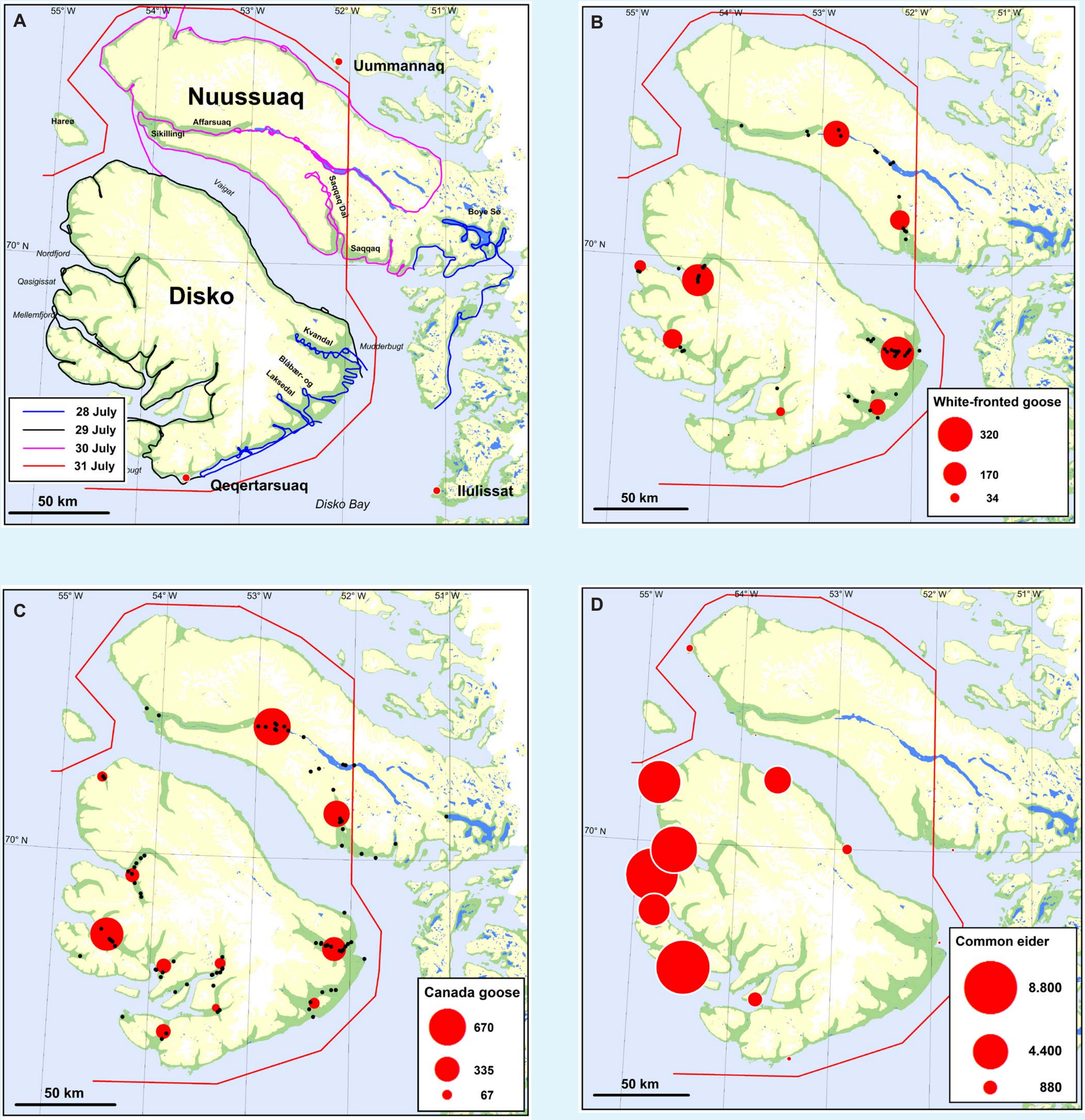


Figure 1. A) The tracks of the aerial survey for geese and seaducks in July 2015. **B)** Distribution of moulting Greenland white-fronted geese as observed during the aerial survey July 2015. Black dots shows position of single flocks and red dots aggregated numbers for larger localities. **C)** Distribution of moulting Canada geese as observed during the aerial survey July 2015. Black dots shows position of single flocks and red dots aggregated numbers for larger localities. **D)** Distribution of common eiders as observed during the aerial survey July 2015.

Table 5. Results of surveys for white-fronted goose on Disko Island in July. Shaded grey were aerial surveys.

Site	1989		1992		1994		1995		2001		2004		2015	
	Moulting indvs	Breeding pairs	Moulting indvs	Breeding pairs	Moulting indvs	Breeding pairs	Moulting indvs	Breeding pairs	Moulting indvs	Breeding pairs	Moulting indvs	Breeding pairs	Moulting indvs	Breeding pairs
Aqajarua-Sullorsuaq	254	5	397	0	450	13	372	5	637	34	201		319	0
Kangersooq – Kuussuaq			199	0			539	4	395	23			293	0
Kuannersuit Kuussuat			30	0			74	0	0	0			0	0
Blåbær- og Laksedal							230	0					88	0

Table 6. Results of aerial surveys for moulting geese in July 1992, 1995 and 2003 in Nuussuaq Peninsula. In 1992 and 1995 a fixed-wing aircraft was used; in 2003 a helicopter. For details see Glahder (1999) and Madsen (2004). The site Aaffarsuaq includes the entire valley and the delta area at the coast.

Site	1992		1995		2003		2015	
	Moulting indvs	Breeding pairs	Moulting indvs	Breeding pairs	Moulting indvs	Breeding pairs	Moulting indvs	Breeding pairs
Saqqaq Valley	17	0	105	0	0	0	122	0
Aaffarsuaq	683	10	877	3	203	13	201	0

These surveys document that there are a number of very important sites for the population. On Disko there are at least three such areas (Table 5) and two of these are designated as Ramsar sites and as "areas important to wildlife" (see Section 5). On Nuussuaq peninsula, there are two important areas - the long central valley Aaffarsuaq and the Saqqaq Valley (Table 6). None of these are Ramsar sites, while the central part of Affarsuaq is an "area important to wildlife".

Due to the unfavourable conservation status and the small population size, the Greenland white-fronted goose population is listed as endangered (EN) on the Greenland red-list. It is not listed separately on the international Red List of threatened species (IUCN 2016).

Gyr falcon *Falco rusticolus*

The gyr falcon breeding population size in the assessment area is very low with probably no more than 5 to 10 pairs in total. Active nests or recently fledged chicks have only been reported from a few sites e.g. in the Kuannersuit Kuussuat area on Disko (Egevang & Boertmann 2001) and in the Saqqaq Valley (Joensen & Preuss 1972). During the field work in 2015, a supposed nest was seen on the south coast of Nuussuaq near Sikillinge and two birds were observed in Aqajarua/Kvandal on 15 Aug.

Gyr falcons occur in the area throughout the year, and birds from further north and from Canada contribute to the population during winter.

The gyr falcon is listed as near threatened (NT) on the Greenland Red List because the total national population is very small.

Other birds from inland habitats

Two other inland birds of conservation concern may also occur in the area, but their status there is almost unknown. These are the great northern diver *Gavia immer* and the harlequin duck *Histrionicus histrionicus*, both listed as near threatened (NT) on the Greenland Red List.

A harlequin duck with a large chick was observed in Kangersooq/Nordfjord, Disko Island in Sept 2003 indicating a nesting site nearby.

Harlequin ducks place their nests at turbulent rivers and may be sensitive to activities in these habitats and to regulation of the water course (for instance by establishment of hydropower facilities).

Great northern divers breed at large lakes. There is only one such lake in the assessment area - in the Aaffarsuaq valley, and great northern diver most likely do not breed there due to the turbid melt water of that lake. The nearest suitable lakes (Boye Sø and nearby lakes) are found just east of the license block covering Nuussuaq Peninsula, where a pair with a chick was observed in July 2015 during the aerial survey. No great northern divers were observed inside the assessment area during that survey.

The other diver species occurring in the assessment area is the red-throated diver (loon) (*Gavia stellata*). It breeds here and there at small ponds and lakes near the coasts. There were for instance three active nests in the Kangersooq/Kuussuaq-area on Disko in 2001 and six in the Qaamassoq/Sullorsuaq area (Egevang & Boertmann 2001).

Canada goose *Branta canadensis*

This species immigrated to Greenland in the 1980s and 1990s and is now numerous and widespread throughout West Greenland (Fox et al. 2012). There are today large breeding and moulting populations in the Nuussuaq and Disko area, where they occur in the same habitats as the white-fronted geese. They behave in the same way, with scattered breeding pairs and large aggregations of moulting non-breeding birds. The decrease in the population of white-fronted goose may partly be related to this expansion (Kristiansen & Jarret 2002, Fox et al. 2006). Besides breeding and moulting at habitat like the habitats of white-fronted geese, they also occur on small islands, along coasts and at coastal lagoons and appear less particular in their habitat choice than the white-fronted geese. Numerous canada geese were recorded during the 2015 survey (Box 2).

Brent goose *Branta bernicla*

This species is a migrant visitor to the assessment area. In spring, late May to early June the major part of the flyway population "the eastern Canadian high arctic light-bellied brent goose" migrate through the assessment area (Boertmann et al. 1997). The population winters primarily in Ireland and breeds in the high arctic part of the Canadian archipelago and northwest Greenland. The spring migration is very rapid and the birds usually do not stage in the assessment area. In spring they are observed most frequently on SW and W Disko. The autumn migration takes place in late August and early September and flocks of geese stage along the coasts of the assessment area. The most important staging areas are found in the fjords of west Disko – Kangersooq/Nordfjord, Akullit/Mellemfjord – where they utilize the saltmarshes (Boertmann et al. 1997).

This separate population of brent goose have a favourable conservation status as it presently is increasing and it numbered in October 2012 41,465 individuals (Brides 2013).

At lakes, marshes and protected coasts are mallards (*Anas plathyrhynchos*), long-tailed ducks (*Clangula hyemalis*) and red-breasted mergansers (*Mergus serrator*) found, and red-necked phalaropes (*Phalaropus lobatus*) breed at small ponds. Other shorebirds breeding in the assessment area include purple sandpiper (*Calidris maritima*) and great ringed plover (*Charadrius hiaticula*).

The bay of Qasigissat on the west coast of Disko is an important site for moulting long-tailed ducks. Up to 758 have been observed there in early September (Boertmann & Petersen 2016).

The other bird of prey - peregrine falcon - is more numerous than the gyr falcon and nests are found here and there. In contrast to the gyr falcon, the peregrines are migratory and leave the assessment area for the winter.

In September 2007 a pair of white-tailed eagles (*Haliaeetus albicilla*) was observed at the Marrat area in the westernmost part of the Nuussuaq peninsula. They were subadult birds, but apparently territorial. However, no eagles were observed at the same site during three days of field work in 2015. The nearest regular breeding pairs are found near Ilulissat.

Species such as ptarmigan (*Lagopus mutus*), snow bunting (*Plectrophenax nivalis*), Lapland longspur (*Calcarius lapponicus*), redpoll (*Carduelis flammea*), wheatear (*Oenenthe oenanthe*) and raven (*Corvus corax*) are widespread breeders in the lowlands of the assessment area.

Arctic redpoll (*Carduelis hornemannii*), is a winter visitor, most frequently observed at feeding places in the towns and settlements.

4.3.2 Coastal birds

Along the coasts of the assessment area there are numerous breeding colonies for seabirds. These comprise: northern fulmar (*Fulmarus glacialis*), great cormorant (*Phalacrocorax carbo*), common eider (*Somateria mollissima*), glaucous gull (*Larus hyperboreus*), Iceland gull (*Larus glaucoides*), kittiwake (*Rissa tridactyla*), Arctic tern (*Sterna paradisaea*), razorbill (*Alca torda*) and black guillemot (*Cepphus grylle*). Approximately 80 sites in the assessment area can be termed as seabird breeding colonies, i.e. sites (usually a steep cliff or a small, low island) holding at least five breeding pairs of the species. Several species often breed at the same site. Most of the colonies in the assessment area are relatively small holding op to some hundred birds. However, there are a few very large colonies: The fulmar colonies on the southwest coast of Disko and the island of Qeqertaq (actually outside the licence blocks, but close enough to be impacted by activities) are the largest in Greenland with more than 20.000 pairs and the cormorant colony also on Qeqertaq is the largest in Greenland with almost 400 pairs in 2005.

Seabird breeding colonies are sensitive to disturbance and birds resting on the water are particularly sensitive to oil spills.

Below is an overview of colonial species and their breeding abundance (See also maps in Figure 8). This is based on the Greenland Seabird Colony Register (Boertmann et al. 2010):

- Northern fulmar: Three very large colonies with probably more than 20,000 pairs in each on SW Disko.
- Great cormorant: 30 colonies with 5-400 pairs (seven of these on Hareø outside assessment area).

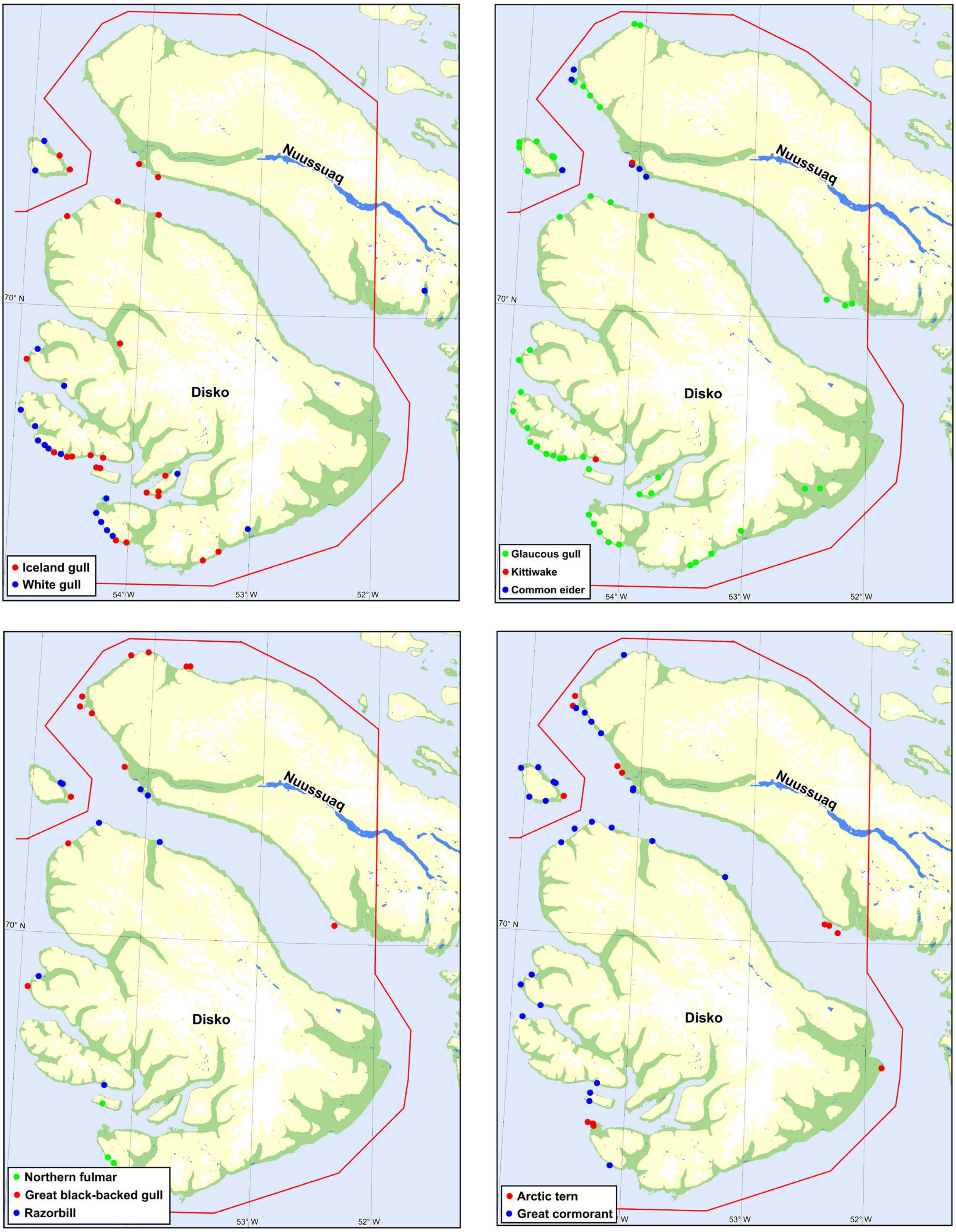


Figure 8. Distribution of selected seabird breeding colonies in the assessment area. 'White gulls'are unidentified Iceland or glaucous gulls.

- Common eider: Six breeding sites are known, where several nests (up to 56) have been found. However, common eiders also nest solitary along the coasts.
- Iceland gull: at least 22 colonies, with up to 200 pairs, Additionally 15 with undetermined glaucous or Iceland gulls. On Hareø two colonies with Iceland gulls and two with undetermined gulls.
- Glaucous gull: at least 45 colonies and additionally six on Hareø. Most are small with a max. of 10 pairs and a few with up to 200 pairs.
- Great black-backed gull: Thirteen breeding sites known with one to four pairs breeding. But there are probably more as single pairs are not recorded in the database.
- Kittiwake: Three colonies, with 10 to 100 nests at most recent survey. There are a couple of sites where colonies have been established for shorter periods. The Torsukattaq (NE part of Disko Bay) to the east of the assessment area is a very important area for breeding kittiwakes. Here are several very large colonies with up to 7000 pairs.
- Arctic tern: Eleven colonies, most on small islands, and relatively small, with 40 to 600 individuals.
- Razorbill: Twelve colonies with max.10 pairs in each.
- Black guillemot: at least 45 colonies and additionally seven on Hareø. They hold between 10 and 500 individuals.

4.3.3 Non-breeding season

A single species occur as a numerous summer visitor. Canadian king eiders (*Somateria spectabilis*) assemble in thousands in coastal waters of NW Greenland in August/September to perform feather moult. Males arrive from July after the mating season and females arrive later (failed breeders first and later supplemented with breeders) (Frimer 1993, Mosbech et al. 2006). There are at least two important moulting habitats for the species in the assessment area. These are Kangersooq/Nordfjord and Aqajarua/Mudderbugten, both on Disko Island. The highest numbers recorded in Kangersooq/Nordfjord were 7800 in September 1995 while Mudderbugten seems to have lost the status as an important site for this species (Mosbech & Boertmann 1999).

The west coast of Disko is also a very important site for moulting and wintering common eiders. The aerial survey in July 2015 resulted in a count of 34,000 where the majority was found in Qasigissat and along the Northwest coast (Box 2). This is three times more than counted on a similar survey in July 1998, reflecting the increase in the breeding population since 2001, when the spring hunt period was reduced (Merkel 2010).

Most of the land associated birds leave the assessment area for the winter, and only gyr falcon, raven, ptarmigan and Arctic redpoll can be found during winter.

Among the coastal birds, species such as the gulls, common eider and black guillemot winter as far north as open water occur. This means that they can be found along the coast in the winter when the ice conditions are light. During spring, open water increases along the west coast of Disko, and the coastal waters here are very important to migrating common eiders.

4.4 Mammals

Wendy Loya

Land mammal fauna of the Nuussuaq peninsula and Disko island is typical of that found throughout West Greenland, as only Arctic fox (*Alopex lagopus*), Arctic hare (*Lepus arcticus*) and caribou (*Rangifer tarandus*) occur. The fox and the hare are common and widespread.

The native caribou population on the Nuussuaq Peninsula was estimated to be at least 1200 animals in 2002 (Cuyler 2004, 2005). The animals inhabiting the peninsula are largely isolated by topography and distance from the other populations in West Greenland. In 1968, 10 semi-domestic reindeer were introduced to provide the region's hunters with animals to harvest at a time when the native population was estimated to be extremely low (Meldgaard 1986). When last surveyed in April 2002, it appeared that the native and introduced populations had remained largely separate, with the feral population occupying mainly the eastern third of the peninsula and the native population mainly the middle third (Cuyler 2004, 2005). The primary habitat occupied by the presumed native population was predominantly the valley floors, at elevations around 200 m a.s.l., but extending as high as 600 m a.s.l. Animals were found in groups that averaged 8 individuals. The caribou present on the eastern third of the peninsula, presumably the introduced population, were generally found at elevations below 200 m a.s.l. and were found in larger groups of in average 40 individuals.

Observations during goose surveys and caribou surveys (Boertmann et al. 2008, Boertmann & Petersen 2016, Cuyler 2004) indicated that in summer the caribou are at higher altitudes above 300 m a.s.l., while in winter they are mainly in the valley floors.

Hunters from Saqqaq and Niaqornat report fall (August) harvest of animals at higher elevations than are found in winter, and they are found often near glaciers and snowfields (Figure 9).

There are no caribou on Disko Island today, although it is possible that animals cross over from the Nuussuaq Peninsula.

Marine mammals occurring in the waters near the Nuussuaq peninsula and Disko Island include four species of seals, walrus (*Odobenus rosmarus*) as well as several species of whales. Polar bear (*Ursus maritimus*) is a rather rare winter visitor. In summer, the fin (*Balaenoptera physalus*), minke (*Balaenoptera acutorostrata*) and humpback (*Megaptera novaeangliae*) whales and the harp (*Phoca groenlandica*) and hooded (*Cystophora cristata*) seals are frequent. In winter, walrus, narwhal (*Monodon monoceros*), white whale (*Delphinaptera leucas*) and bowhead whales (*Balaena mysticetus*) occur in the waters close to the Nuussuaq peninsula. The Environmental Oil Spill Sensitivity Atlas for the West Greenland (68°-72° N) Coastal Zone and the Strategic Environmental Impacts Assessment of petroleum activities in the Disko West area should be consulted for a more complete description of marine mammals in the assessment area (Clausen et al. 2012, Boertmann et al. 2013).

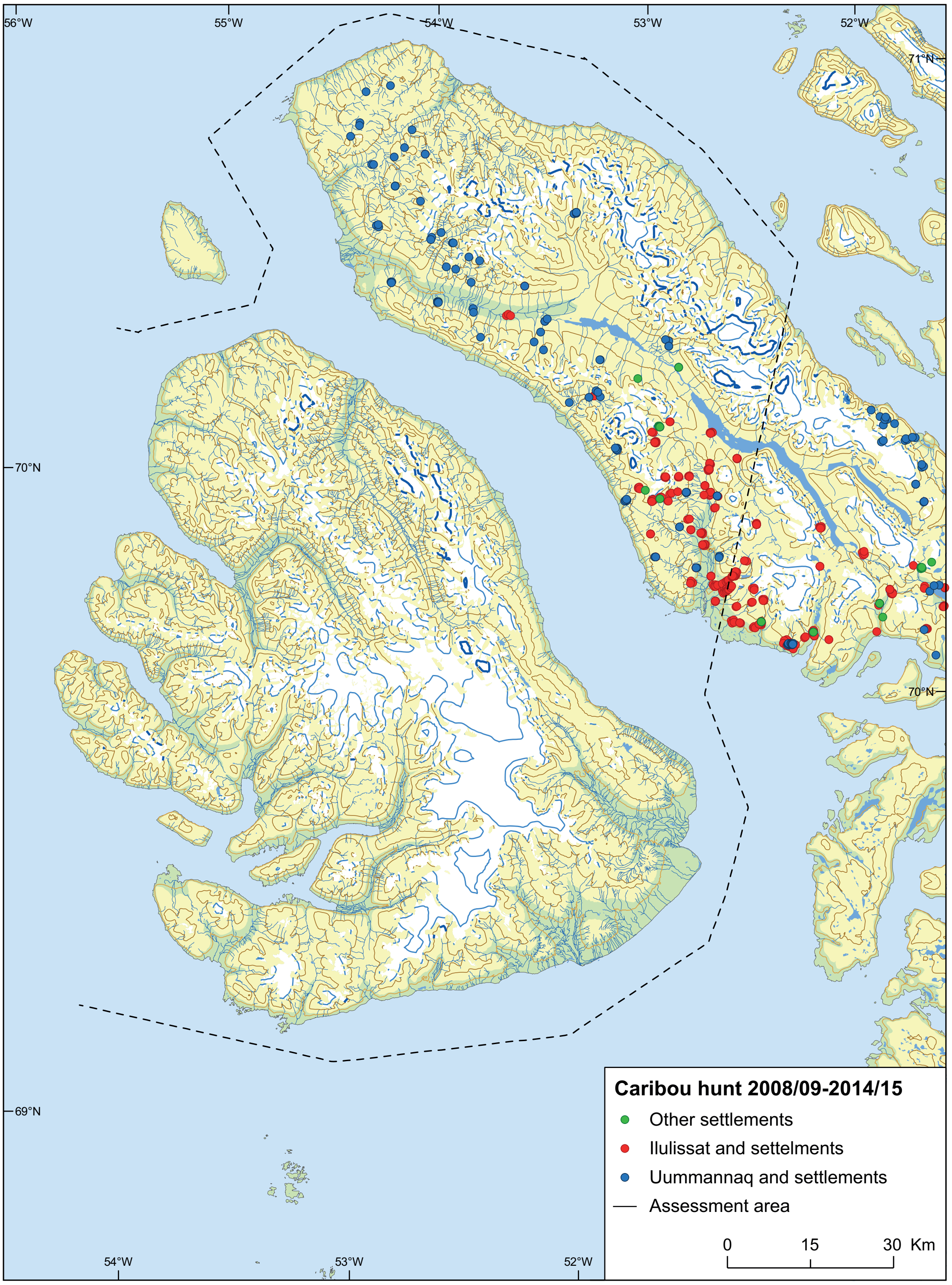


Figure 9. Caribou hunt in the seasons 2008/98 to 2014/15, distributed between the hunters hometowns. N = 218 of which 106 were taken inside the assessment area.

5 Protected areas and conservation

David Boertmann

5.1 International designations

According to the Convention on Wetlands (the Ramsar Convention, (Link), Greenland has designated twelve areas to be included in the Ramsar list of Wetlands of International Importance (Ramsar sites). These areas are to be conserved as wetlands and should be incorporated in the national conservation legislation; however, only one of the Greenland Ramsar sites has so far been protected by jurisdiction. Three of the Greenland Ramsar sites are found within the assessment area (Figure 10) (Egevang & Boertmann 2001).

5.2 National nature protection designation

The only land areas to be protected according to the national nature protection law within the assessment area are three small strips of land at Qeqertarsuaq (Figure 10). The special bird protection areas are not represented in the assessment area, but seabird breeding colonies are generally protected according to the bird protection order. In these areas activities are regulated in order to protect the conservation interest.

The MLSA and EAMRA have issued a set of field rules for exploration activites, and according to these a number of 'areas important to wildlife' are designated. Here, mineral (and hydrocarbon) exploration activities are regulated in order to protect wildlife. There are several of these areas important to wildlife within the assessment area and they also include the most important seabird breeding colonies (Figure 11). Several of these areas are designated because high numbers of moulting geese and seaducks occur.

Section 7 in the Greenland Nature Protection Law (Landstingslov nr. 29 af 18. dec 2003) mentions some specifically protected nature elements, and these include the homeothermic springs and lakes with salty waters.

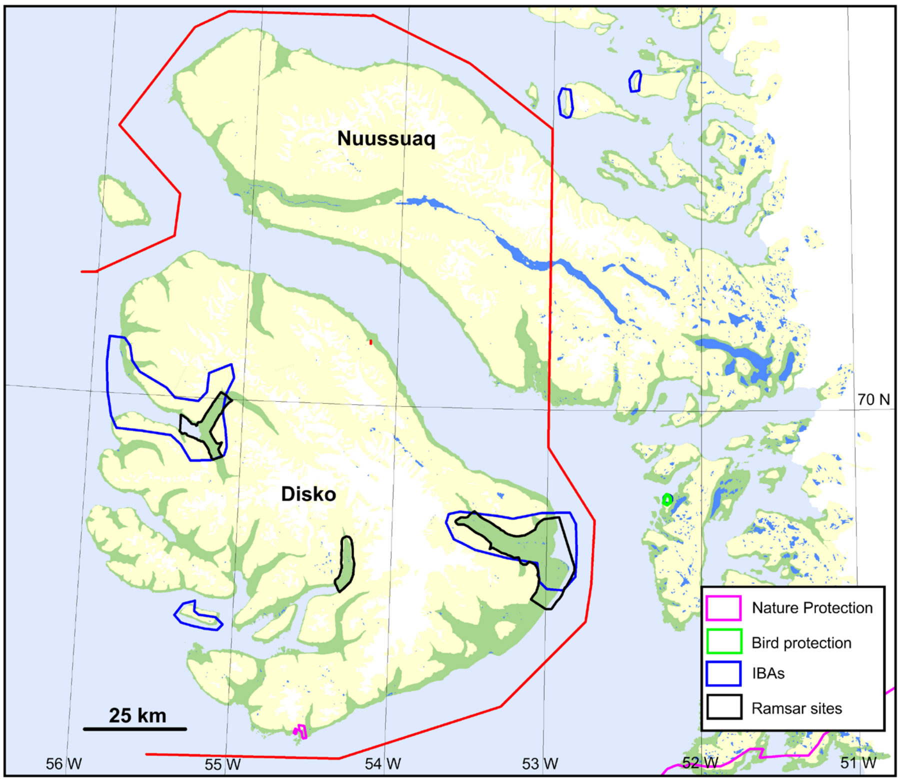
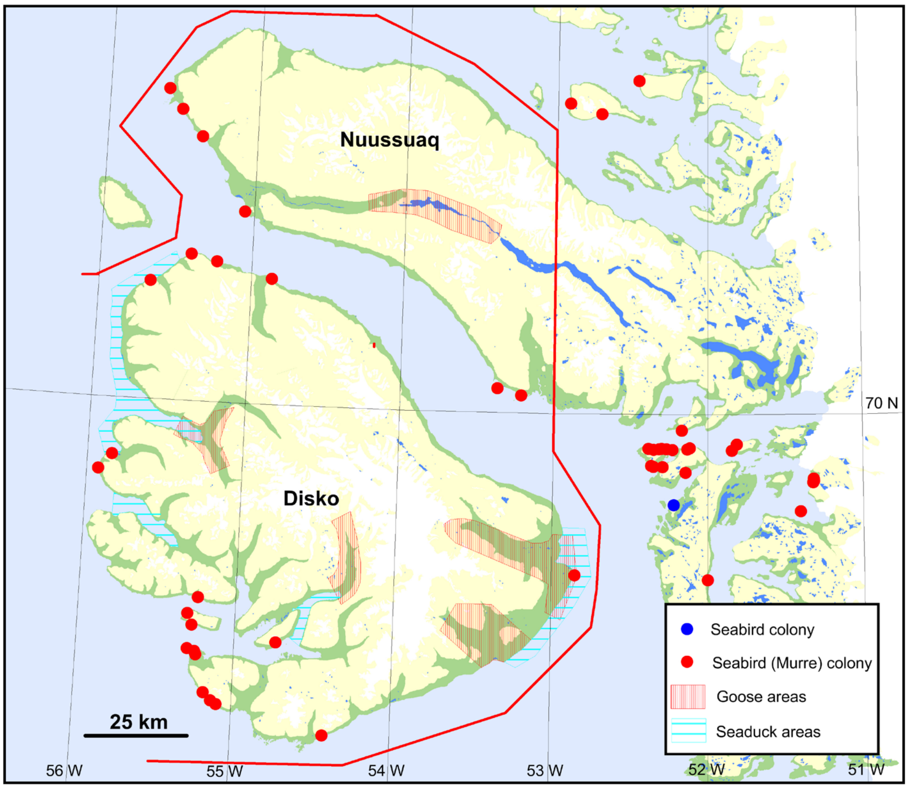


Figure 10. Areas protected according to national (Nature protection, Bird protection) laws, international conventions (Ramsar) and designated by BirdLife international (IBA).

Figure 11. The 'important areas for wildlife' as stated in the 'field rules' where disturbing activities are regulated in order to minimize impacts on sensitive wildlife. Goose areas are designated in order to protect moulting geese, seaduck areas in order to protect moulting seaducks, seabird colonies in order to protect breeding colonial seabirds.



5.3 NGO designated areas

The international bird protection organisation, BirdLife International, has designated a number of *Important Bird Areas* (IBAs) in Greenland (Heath & Evans 2000), of which three are located within the assessment area (Figure 10). They comprise the two Ramsar sites Nordfjord and Kvandalen and the large colony of breeding northern fulmars on the island of Qeqertaq in Disko Fjord (actually just outside the license blocks). For further information see the IBA website (Link).

5.4 Threatened species

Eight bird species and one mammal regularly found in the assessment area (see Table 7) are included in the national Red List of threatened species (designated according to risk of extinction).

Six bird species from the assessment area are categorized as *national responsibility species* (Table 8). This means that a significant part of the population occurs in Greenland and Greenland therefore have a particular responsibility for their protection.

The only vascular plants assessed in the Greenland Red List (Boertmann 2007) are the five members of the orchid family: *Amerorchis rotundifolia*, *Corallorhiza trifida*, *Listera cordata*, *Leuchorchis albida* and *Plathantera hyperborea*. Only *Amerorchis* do not occur in the assessment area. None of the remaining species are classified as threatened and of these *Corallorhiza trifida* is found both on Disko and Nuussuaq, while the further three species only are known from Disko.

Globally threatened (according to the IUCN Red List) species occurring in or near the assessment area include only species associated with the marine environment (Table 9).

Table 7. Nationally red-listed species occurring in the Disko/Nuussuaq assessment area.

Species	National Red List category
Great northern diver	Near threatened (NT)
Greenland white-fronted goose	Endangered (EN)
Common eider	Vulnerable (VU)
Harlequin duck	Near threatened (NT)
White-tailed eagle	Vulnerable (VU)
Gyr falcon	Near threatened (NT)
Black-legged kittiwake	Vulnerable (VU)
Arctic tern	Near threatened (NT)
Polar bear	Vulnerable (VU)
Caribou (Nuussuaq population)	Vulnerable (VU)

Table 8. National responsibility species (defined as more than 20 % of the global population in Greenland).

National responsibility species (only birds)	
Light-bellied brent goose	Common eider
Greenland white-fronted goose (endemic)	Iceland Gull
Mallard	Black guillemot

Table 9. Globally threatened species occurring in the marine areas close to the assessment area (IUCN 2016).

Species	Global Red List category	Species	Global Red List category
Ivory gull	Near Threatened (NT)	Fin whale	Endangered (EN)
Razorbill	Near Threatened (NT)	Sperm whale	Vulnerable (VU)
Polar bear	Vulnerable (VU)	Narwhal	Near Threatened (NT)
Blue whale	Endangered (EN)	White whale	Near Threatened (NT)

6 Human use of the environment

Wendy Loya

Human use of the coastal regions of the assessment area is described in Strategic Environmental Impact Assessment of petroleum activities in the Disko West region (Boertmann et al. 2013), and use of specific coastal fish (Arctic char, lumpsucker and capelin) were investigated by Olsvig & Mosbech (2003), and these reports are referred to if more detailed information is needed.

6.1 Fisheries

Commercial fisheries in deeper marine waters include northern shrimp (*Pandalus borealis*) and Greenland halibut (*Reinhardtius hippoglossoides*). The shrimp fisheries take place in the outer parts of the Vaigat and around Hareø and within Disko Bay. The Greenland halibut fisheries take place in the deep waters of the Torsukattak strait, off Ilulissat and off the north coast of the Nuussuaq peninsula. Many other species of fish are caught in offshore waters and used locally or sold to local processing plants. They include: spotted wolffish (*Anachias minor*), redfish (*Sebastes spp*.), Atlantic halibut (*Hippoglossus hippoglossus*), Greenland shark (*Somniosus microcephalus*) and rough-headed grenadier (*Macrourus berglax*).

In the coastal waters of the Nuussuaq Peninsula and Disko Island, two species are important for the fisheries (Olsvig and Mosbech, 2003). Capelin (*Mallotus villosus*) are fished mainly for private consumption in spring when capelin spawn in dense schools in the subtidal waters (Figure 12). Arctic char (*Salvelinus alpinus*) are fished both for private consumption and for sale at local markets. They are caught mainly with gill nets near the outlets of the rivers where they spawn (Figure 12).

6.2 Tourism

Tourist activities on the Nuussuaq peninsula are presently limited. Regular water taxi service occurs in summer between Ilulissat and Saqqaq. Hiking on the peninsula is possible, although not as an organized activity. From Uummannaq, there are also boat trips to selected sites along the north coast. On Disko Island, tours to Qerqertarsuaq can include coastal sailing excursions, hiking, dogsledding on the Lyngmark Glacier in summer or snowmachining (www.diskoline.dk, accessed 18/04/2016).

6.3 Hunting

The hunters of Greenland and in the assessment area focus on species from the marine environment, and only one terrestrial species – the caribou – is im-

Table 10. Hunting bag of Arctic fox, Arctic hare and ptarmigan recorded in the former municipalites Qeqertarsuaq, Uummannaq and Ilulissat, range over 2005-2014 (data from the Ministry of Fisheries, Hunting and Agriculture). An unknown part of the animals from Ilulissat and Uummannaq are taken in the assessment area.

Species	Municipality		
	Ilulissat	Uummnannaq	Qeqertarsuaq
Arctic hare	82-125	54-121	16-80
Arctic fox	20-130	13-51	10-177
Ptarmigan	1725-4196	408-3638	322-1688

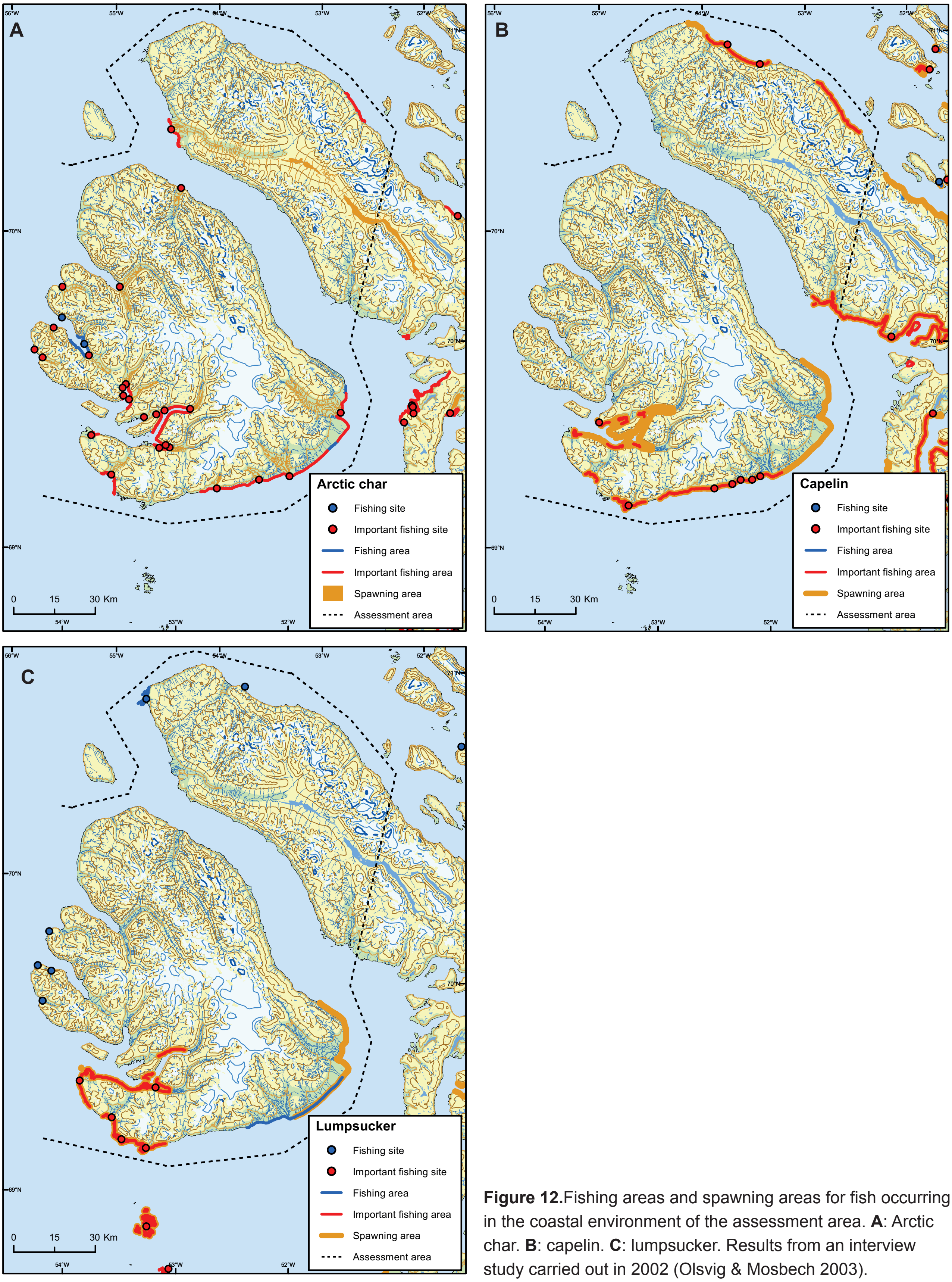


Figure 12. Fishing areas and spawning areas for fish occurring in the coastal environment of the assessment area. **A**: Arctic char. **B**: capelin. **C**: lumpsucker. Results from an interview study carried out in 2002 (Olsvig & Mosbech 2003).

portant to the hunters. The caribou hunt in Nuussuaq is regulated by open periods and quotas. The autumn quota (Aug. 1 - Oct. 15) is currently 474 animals and the winter quota (Feb. 18- Mar. 10) is 150 animals (Naalakkersuisut 2015).

Greenland Institute of Natural Resources collects information and interview local hunters on where caribou are observed and harvested. In fall, harvest of caribou occurs primarily in the mountains and valleys on the southern edge of the Nuussuaq Peninsula.

In winter, harvest is reported primarily in the peninsula valleys, which are accessible by dogsled or snowmobile. During the period from fall 2008 through early winter 2015, the majority of caribou harvests occurred near Saqqaq. Hunters from Saqqaq and Qeqertaq on the southern coast of the peninsula, and from settlements south of the peninsula are the predominant hunters in the Saqqaq Valley and within the southwestern quarter of the peninsula (Figure 11). Harvest on the western half and northeast quarter is generally reported by hunters from Uummannaq area, including the settlements of Niaqornat and Qaarsut that lie on the northern coastline of the peninsula (Figure 11).

Harvest of other terrestrial species – Arctic fox, ptarmigan and Arctic hare – is recorded in the official hunting bag record system (Piniarneq), but harvested numbers can only be broken down to the former municipalities, in this case Uummannaq and Ilulissat (Table 10).

Hunting in the marine areas is aimed at marine mammals and seabirds. This activity is regulated by open seasons and quotas for many species, although no limits apply to seal hunting. Harvest is dominated by harp seal (*Phoca groenlandica*) and hooded seal (*Cystophora cristata*) in the open water season and ringed seals (*Phoca hispida*) when ice is present. Walrus (*Odobenus rosmarus*) is hunted west of Hareø and Disko in winter. Whales are also important quarry for the hunters of the assessment area and there are quotas on white whales, narwhals, minke whales, fin whales, humpback whales and bowhead whales.

7 Summary of sensitive areas and species

The most sensitive areas with regards to oil exploration and exploitation activities in the assessment area are the lowlands with extensive vegetation, and the coastal areas with concentrations of breeding and moulting seabirds. In the lowlands especially the large, wide valleys will be sensitive. On Nuussuaq this applies to the long, central valley Aaffarsuaq and the Saqqaq Valley (to more than 400 m a.s.l. and on Disko at least Kvandalen, Lakse- and Blåbærelv, and the valleys of Nordfjord, Mellemfjord, Disko Fjord and Laksebugt. These valleys are also the most accessible areas and they are the obvious and natural approaches to the inlands. In these valleys there are important habitats for caribou, geese and rare plants and many homeothermic springs are located on the sides of the valleys.

The most disturbance sensitive species in the terrestrial environment are the caribou and the geese. The caribou population is relatively small and it constitutes an important hunting resource, and the goose has an unfavourable conservation status.

Sensitive to physical impacts, discharge of contaminants and oil are rare plants, spawning rivers for Arctic char and habitats for geese and caribou.

The marine coastal environment of the assessment area is particularly sensitive to noise disturbance and oil spills. Here are especially the seabird colonies and the concentrations of moulting and staging seaducks important. Oil spills in this environment have the potential to impact widespread areas with seabirds, spawning fish and hunting and fishing grounds for local people.

Figure 13 summarizes areas sensitive to activities related to petroleum exploration and exploitation based on presence of biological conservation interests (sensitive habitats and species).

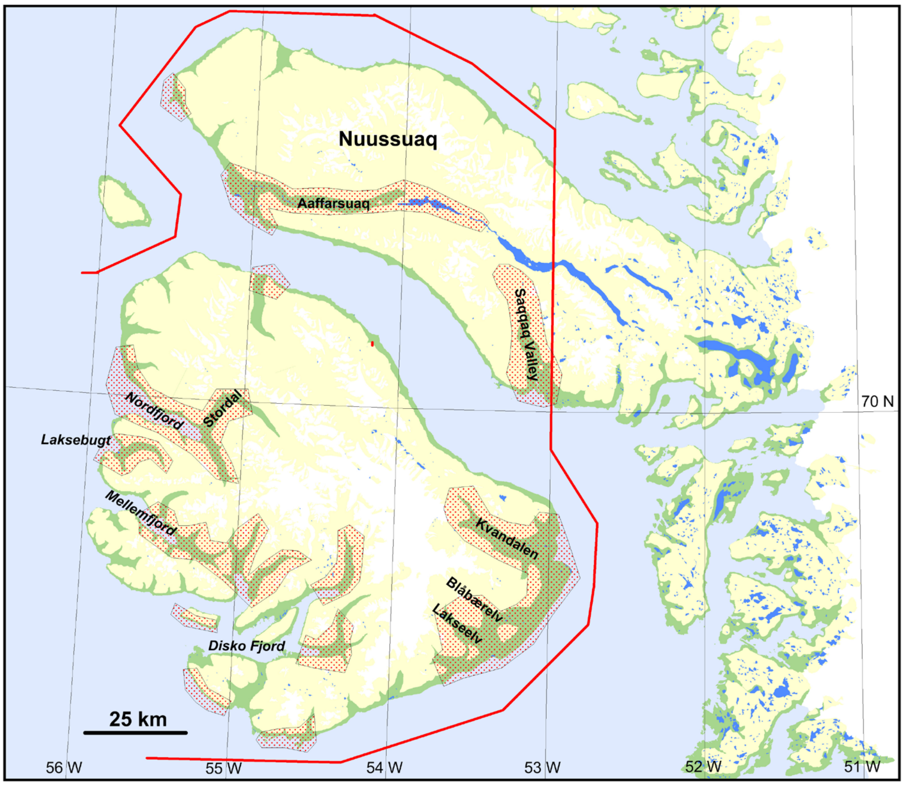


Figure 13. Dotted signature indicated areas sensitive to petroleum exploration and exploitation activities.

8 Background levels of contaminants

Frank Rigét

Knowledge on background levels of contaminants in areas with hydrocarbon exploration and exploitation is important, mainly as a baseline for monitoring the potential contamination of the environment from the activities.

There exists relative little knowledge on contaminants in the terrestrial and freshwater environment of the Disko/Nuussuaq area. No systematic monitoring has been performed but some scattered information exists derived from different investigations carried out through the years.

However, more systematic monitoring of contaminants in the marine environment in the Disko/Nuussuaq area have been performed and will be included in the following overview as proxy for the expected general level of contamination stress in the assessment area. Furthermore, increased activities related to petroleum and minerals in the assessment area may also impact the nearby marine environment.

The only active mine in the assessment area was the coal mine at Qullissat, and it was closed in 1971. However, the potential pollution from this site has never been surveyed, and in order to get an impression, a preliminary sampling of sediments and lichens were carried out by DCE in August 2015. The analyses of the samples were not finished when this report was prepared.

8.1 Heavy metals

Heavy metals, such as mercury (Hg), cadmium (Cd) and lead (Pb), in the environment are derived from both anthropogenic sources to the atmosphere (e.g. coal burning and mining) and from natural sources (e.g. volcanoes and weathering of rocks). The air provides a fast transport route – bringing contaminants from Europe to the Arctic within days. Ocean transport is slower, but more important for contaminants that partition into water and sediments rather than air and aerosols (AMAP 2004). Once in the Arctic, contaminants can be taken up in the food chains, in particular in the relative long marine food chains.

Hg profiles in dated marine sediment cores from Greenland including five cores from Disko Bay supported that Hg have increased in the environment during the last 100 years (Asmund & Nielsen, 2000), and Hg concentrations in surface sediment ranged between 0.024 and 0.1 mg/kg dry weight; highest closest to Ilulissat. According to OSPAR (2009) the level for background concentration of Hg in sediment is 50 µg/kg (0.05 mg/kg). This is in accordance with AMAP (2005) and below the threshold level at which the Hg concentration is considered as natural. Hence the surface sediment closest to Ilulissat must be considered as contaminated.

Baseline data on number of elements (Cd, Cu, Fe, Ni, Pb, Zn, V, Cr, Zn, As, Se and Hg) in the moss (*Hylocomium splendens*) and the lichens (*Flavocetraria nivalis*) at several Greenland locations including locations in the Disko Bay area was reported by Pilegaard (1997). Generally, there was no clear regional pattern in concentrations of these elements in Greenland. Dust derived from soil erosion in areas appeared to be the factor controlling the levels seen. Table 11 shows the levels of selected compounds found at locations at Disko.

Table 11. Range of mean concentrations (mg/kg dry weight) of Hg, Cd, Pb, As found in the moss (*Hylocomium splendens*) and the lichens (*Flavocetraria nivalis*) in the early 1980's in the Disko-Nuussuaq area.

	Cetraria nivalis	***Hylocomium splendens***
Hg		0.12-0.16
Cd	0.07-0.08	0.10-0.21
Pb	1.7-4.4	2.1-2.9
As	0.11-0.12	8.1-8.7

Table 12. Geometric mean concentrations (µg/g wet weight) of Pb, Cd, Hg and Se in biota sampled in the 1980s from the northern part of central West Greenland (selected data from Dietz et al. 1996).

Species	Tissue	Pb	Cd	Hg	Se
Molluscs					
Blue mussels	Soft tissue	0.467	0.599		
Crustacea					
Parathemisto libellula	Whole		1.38		0.28
Shrimp	Whole > 5 g		5.20	0.119	1.58
Fish					
Capelin	Whole	0.147	0.029		
Greenland cod	Muscle		<0.015		
Spottet wolfish	Muscle		<0.015		
Spottet wolffisk	Liver	0.013	2.11		
Shorthorn sculpin	Muscle	<0.010	<0.015		
Sorthorn sculpin	Liver	0.011	0.423		
Greenland halibut	Muscle	<0.010	<0.015		
Seabirds					
Common eider	Muscle	<0.018	0.122	0.100	0.907
Common eider	Liver	0.048	3.12	0.644	6.37
King eider	Muscle		0.316	0.109	0.539
King eider	Liver		4.52	0.440	6.34
Glaucuos gull	Muscle		0.041		
Glaucous gull	Liver		2.90		
Black guillemot	Muscle	<0.018	0.133	0.170	0.620
Black guillemot	Liver	<0.018	3.40	0.595	2.32
Marine mammals					
Ringed seal (1 year old)	Muscle	0.029	0.068		
Ringed seal (1 year old)	Liver	0.366	0.229		

Baseline data on Pb, Cd, Hg and Se levels in molluscs, crustaceans, fish, seabirds, seals, walruses, whales and polar bears have been compiled for different geographical regions, including northern part of central West Greenland defined as the area between Uummannaq as the northern border and Kangaatsiaq in the south (Dietz et al. 1996).

Table 12 shows selected geometric mean concentrations in the marine environment from central West Greenland found in the late 1980s. More recent concentrations in a few species obtained by the regularly contaminant monitoring's programme (Arctic Monitoring and Assessment Programme (AMAP)) are shown in Table 13.

Table 13. Mean concentrations (μg/g wet weight) of Cd, Hg and Se in biota sampled in Qeqertarsuaq during the AMAP monitoring programme (unpublished data).

Species	Year	Tissue	Cd	Hg	Se
Blue mussel	2004	Soft tissue	0.564	0.008	0.584
Shorthorn sculpin	2014	Liver	2.53	0.071	0.816
Ptarmigan	2004	Liver	1.97	0.030	0.223
Ptarmigan	2004	Kidney	9.20	0.042	0.624
Black guillemot	2006	Liver	1.15	0.225	2.25
Black guillemot	2000	Egg		0.260	0.489
Ringed seal juvenile	2014	Liver	2.87	1.40	1.13

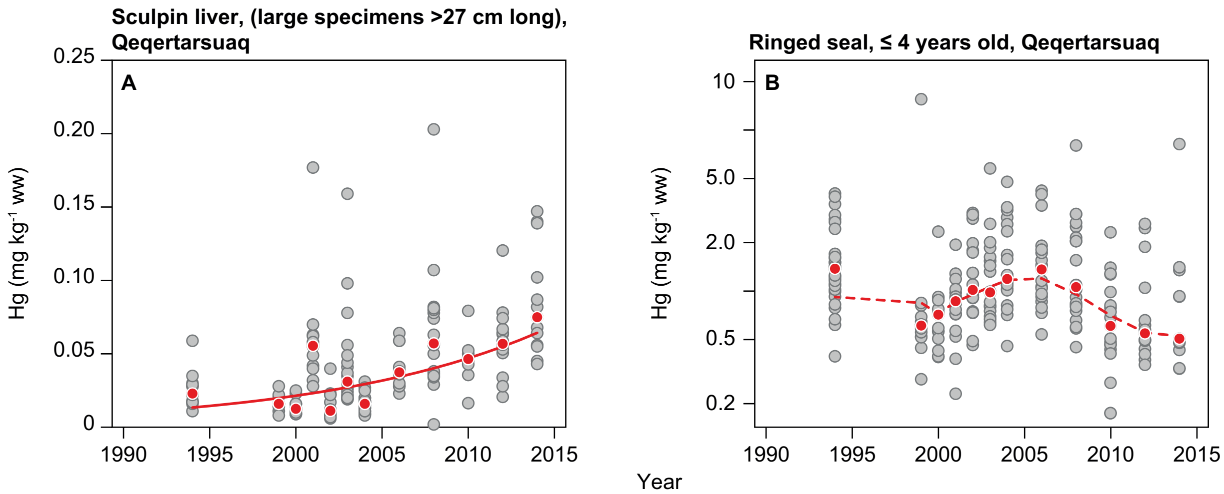


Figure 14. Temporal trend of Hg concentrations (mg/kg wet weight) in liver of shorthorn sculpin and ringed seal at Qeqertarsuaq. Note the different scale of the Hg concentration. Red dots show median values. Solid red line is a log-linear regression line and dotted red line is a three year running average – used as it describes better the data than the log-linear line (Data from Greenland AMAP monitoring programme, F. Rigét unpublished).

In general, the highest Hg concentrations in biota are found in top predators in the marine food chains and reach mean levels of above 1 mg/kg wet weight in liver of juvenile ringed seals from Qeqertarsuaq. When comparing with the more recent concentrations of Cd, Hg and Se (Table 13) no large differences are notable. This is in accordance with Rigét et al. (2007), who did not found systematic temporal trends of Hg concentrations in shorthorn sculpin and ringed seals sampled at Qeqertarsuaq (Figure 14).

The highest levels of Cd in Arctic biota are found in kidney and liver of marine mammals from the eastern Canadian Arctic and West Greenland (AMAP 2005). Cd levels in biota probably reflect the geochemical environment rather than anthropogenic gradients (AMAP 2005), e.g., expressed as an increased Cd level in caribou across the Canadian Arctic to West Greenland, where the geometric means in liver ranged from 0.121 to 0.695 mg/kg wet weight (Aastrup et al. 2000). In Greenland, Cd concentrations are in general higher in marine biota from the north western part of Greenland compared to southern areas (Dietz et al. 1996). Cd in liver of shorthorn sculpin and ringed seal from Qeqertarsuaq has levels of 2.53 and 2.87 mg/kg wet weight, respectively (Table 13, Figure 15).

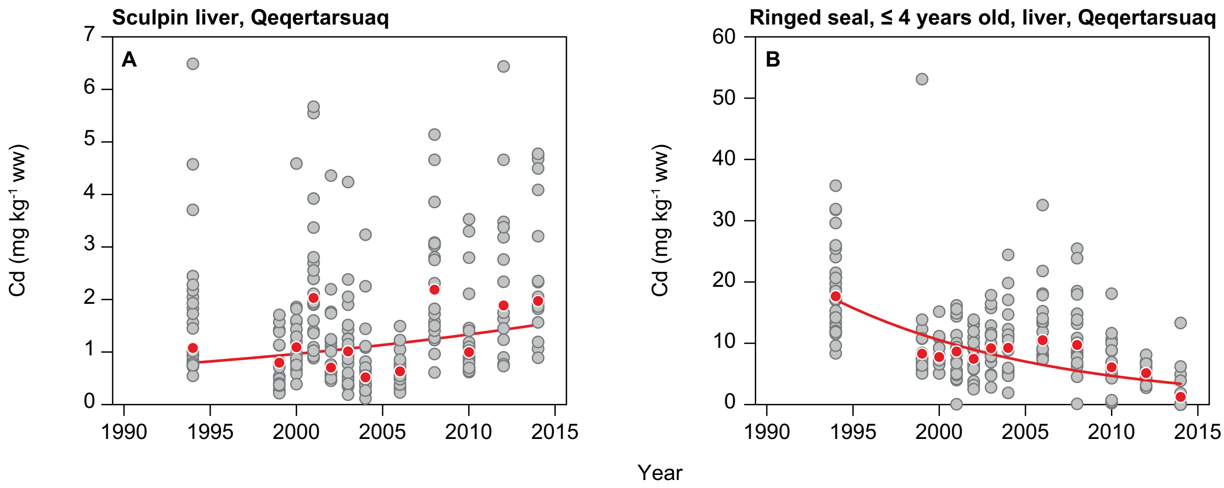


Figure 15. Temporal trend of Cd concentrations (mg/kg wet weight) in liver of shorthorn sculpin and ringed seal at Qeqertarsuaq. Red dots show median values. Solid red line is a log-linear regression line and black line is similar, but not significant (Data from Greenland AMAP monitoring programme, F. Rigét unpublished).

The atmospheric deposition of Pb has been reduced dramatically in Arctic regions as a result of banning the use of leaded gasoline during the 1970s and 1980s in many countries (AMAP 2005). Pb do not bio-magnify in the food chains and in the assessment area highest concentration was in the 1980s found in blue mussels of approximately 0.5 mg/g wet weight (Table 11). Pb from lead shots used during bird hunting is another source and appears to be an important source of human exposure (Johansen et al., 2006a). However, the use of Pb for hunting game birds was banned in 2012 in Greenland.

8.2 Persistent organic pollutants (POPs)

Persistent organic pollutants (POPs) have a long lifetime in the environment, and therefore have the potential to be transported over long distances. Most of the total quantity of POPs found in the Arctic environment is derived from the industrialised southern regions (AMAP 2004). POPs are mainly transported to the Arctic by the atmosphere and ocean currents. However, the increased human activities in the Disko-Nuussuaq area in connection with hydrocarbon exploration and exploitation constitute a risk of local contamination of POPs. POPs bio-accumulate and bio-magnify in the Arctic food chains. Most of them are lipophilic, which means they are found in highest concentrations in fatty tissues. The use of several POPs has been banned or restricted for decades and international actions have been established to reduce emissions and releases to the environment, such as the UNEP Stockholm Convention on POPs and the POPs Protocol to the Convention on Long-range Trans-boundary Air Pollution. Many of these POPs show declining concentrations in Arctic biota (AMAP 2014), e.g. dichlorodiphenyltrichloroethane (DDTs), 'drins' (aldrin, endrin and dieldrin), polychlorinated biphenyls (PCBs) and chlordanes. In ringed seals collected in Qeqertarsuaq declining levels of these compounds are also seen (Rigét et al. 2013) (Figure 16). In human blood from the Arctic including from people living in the Disko area most POPs are also decreasing (Krüger at al. 2012, Long et al. 2015) probably due to a combination of the international regulation and reduction in the consumption of traditional food such as seals and whales (Long et al. 2015). However, many POP levels in Arctic biota are still high enough that certain species, including many top predators, may be at risks for biological effects from these compounds (Letcher et al. 2010, NCP, 2013). POPs are also found in human maternal blood indicating foetus exposure and possible influencing foetus development (Long et al. 2015).

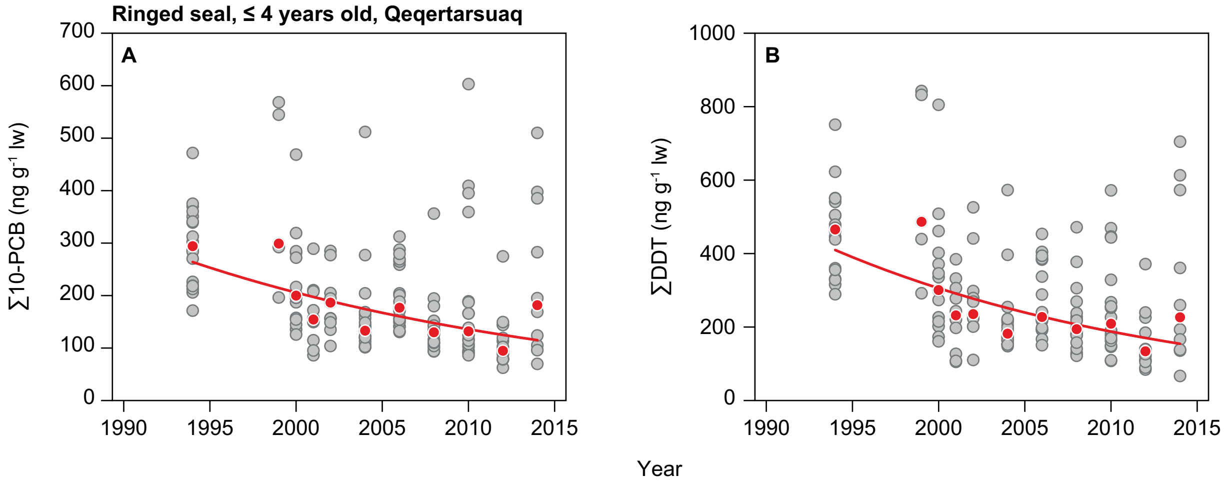


Figure 16. Temporal trend in PCB (left) and DDT (right) concentrations (mg/kg lipid weight) in blubber of ringed seal at Qeqertarsuaq. Red dots show median values. Solid red line is a log-linear regression line (Data from Greenland AMAP monitoring programme, F. Rigét unpublished).

Levels of POPs concentrations (ng/g lipid weight) in biota from Qeqertarsuaq are summarized in Table 14.

The levels of POPs are in general decreasing in the order ∑PCB > ∑DDTs > ∑CHLs > Toxaphene > HCB > ∑HCHs, as is also seen in marine biota from Disko (Table 14). In general, the levels of POPs found in biota from West Greenland are lower than in biota from East Greenland (Rigét et al. 2015).

Polybrominated diphenyl ethers (PBDEs) is a group of POPs, which was phased out at a national level (U.S., Canada and European Union) in the mid-2000s, and in 2009 the technical mixtures PentaBDE and OctaBDE were included in the Stockholm Convention. Levels of PBDEs in both animals and humans are much lower than the above mentioned POPs, which have been regulated for a longer period. In juvenile ringed seals from Qeqertarsuaq the levels of the congener PBDE-47 has increased in the last three decades and is now at a level of about 7 ng/g lipid weight (Table 14). This temporal pattern is different from several other trend patterns found in Arctic biota, where the levels have increased until the mid-2000ies, after which concentrations have either decreased or stabilized (AMAP 2014).

Perfluorinated alkylated substances (PFASs) are another group of compounds which is very persistent in the environment. In biota and humans, PFASs bind to blood proteins and, therefore, bioaccumulate mainly in liver, kidneys and bile secretions in contrast to most other POPs which are lipophilic.

Perfluorooctane sulphonate (PFOS) is usually found in much higher concentrations compared to other fluorinated compounds in Arctic wildlife. The largest producer of PFOS, the 3M US company, announced in 2000 it would phase out its production. PFOS was banned in the EU in June 2008, and in 2009 PFOS was included in the Stockholm Convention on POPs. Likely as a response to the regulation PFOS concentrations in several wildlife species are now declining after a period with increasing levels (NCP 2013). Also in ringed seals from Qeqertarsuaq PFOS concentrations have decreased after it peaked around 2006, and is now at a level of 35 ng/g wet weight in the liver of juvenile ringed seal (Rigét et al. 2013) (Figure 17). However, in blood from Greenlanders from Nuuk, West Greenland PFOS have increased in the period from 1998 to 2005 (Long et al. 2012).

Table 14. Recent mean concentrations (ng/g lipid weight) of POPs in biota from Disko. Data from the AMAP monitoring programme.

POPs mean concentration	Year	Biota	Conc.	Reference
$\sum_{10}$PCB	1994	Blue mussel soft tissue	0.59	Cleemann et al. 2000a
$\sum_{10}$PCB	2001	Black guillemot egg	803	Rigét, unpublished
$\sum_{10}$PCB	1994	Glaucous gull liver	469	Cleemann et al. 2000b
$\sum_{10}$PCB	1994	Icelandic gull liver	37.9	Cleemann et al. 2000b
$\sum_{10}$PCB	2014	Ringed seal blubber	234	Rigét, unpublished
∑DDTs	1994	Blue mussel soft tissue	0.24	Cleemann et al. 2000a
∑DDTs	2001	Black guillemot egg	435[1]	Rigét, unpublished
∑DDTs	1994	Glaucous gull liver	396	Cleemann et al. 2000b
∑DDTs	1994	Icelandic gull liver	35.8	Cleemann et al. 2000b
∑DDTs	2014	Ringed seal blubber	321	Rigét, unpublished
HCB	1994	Blue mussel soft tissue	0.027	Cleemann et al. 2000a
HCB	2001	Black guillemot egg	228	Rigét, unpublished
HCB	1994	Glaucous gull liver	32	Cleemann et al. 2000b
HCB	1994	Icelandic gull liver	11	Cleemann et al. 2000b
HCB	2014	Ringed seal blubber	9.1	Rigét, unpublished
∑HCH	1994	Blue mussel soft tissue	0.39	Cleemann et al. 2000a
∑HCHs	2001	Black guillemot egg	54.9	Rigét, unpublished
∑HCHs	1994	Glaucous gull liver	3.2	Cleemann et al. 2000b
∑HCHs	1994	Icelandic gull liver	1.4	Cleemann et al. 2000b
∑HCHs	2014	Ringed seal blubber	21.2	Rigét, unpublished
Toxaphene	2001	Black guillemot egg	515	Rigét, unpublished
Toxaphene	2014	Ringed seal blubber	21.4	Rigét, unpublished
∑CHLs	2001	Black guillemot egg	363	Rigét, unpublished
∑CHLs	2014	Ringed seal blubber	222	Rigét, unpublished
PBDE-47	2014	Ringed seal blubber	7.1	Rigét, unpublished
PFOS[2]	2014	Ringed seal liver	34.7	Rigét, unpublished

$\sum_{10}$PCB = cb18+cb31+cb52+cb101+ cb105+cb118+cb138+cb153+cb156+cb180
∑DDTs = *p,p*-dde + *p,p*-ddd + *p,p*-ddt
∑CHLs = *trans*- and *cis*-chlodane + *trans*- and *cis*-nonachlor + oxychlordane
∑HCHs = α-, β- and γ-HCH
Toxaphene = chb26+chb40+chb41+chb50+chb60
[1]p,p-dde + p,p-ddd
[2]ng/g wet weight

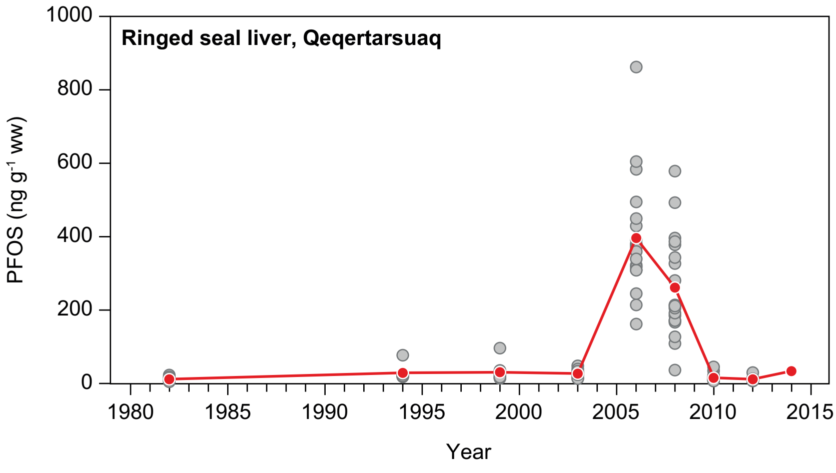


Figure 17. Temporal trend in PFOS concentrations (ng/g wet weight)in liver of ringed seals at Qeqertarsuaq. Red line just connects the median values (red dots) (Data from Greenland AMAP monitoring programme, F. Rigét unpublished).

8.3 Petroleum Hydrocarbons and Polycyclic Aromatic Hydrocarbons (PAH)

Petroleum hydrocarbons represent several hundred chemical compounds originating from crude oil e.g. gasoline, kerosene, and diesel fuel. Of primary interest for the assessment of environmental impacts are the aromatic hydrocarbons (i.e., benzene, ethylbenzene, toluene, and xylenes). Another important group are polycyclic aromatic hydrocarbons (PAHs), which originate from two main sources: combustion (pyrogenic) and crude oil (petrogenic). PAHs represent the most toxic fraction of oil and are released to the environment through oil spills and discharge of produced water (see also Section 9.3.3). Sixteen PAHs are included on the lists of priority chemical contaminants by the World Health Organization and the U.S. Environmental Protection Agency (EPA).

Levels of petroleum hydrocarbons (incl. PAHs) are generally low in the Arctic marine environment and often close to background concentrations, except in areas with anthropogenic impact such as harbours. Presently, the majority of petroleum hydrocarbons in the Arctic originate from natural sources such as seeps (AMAP 2010).

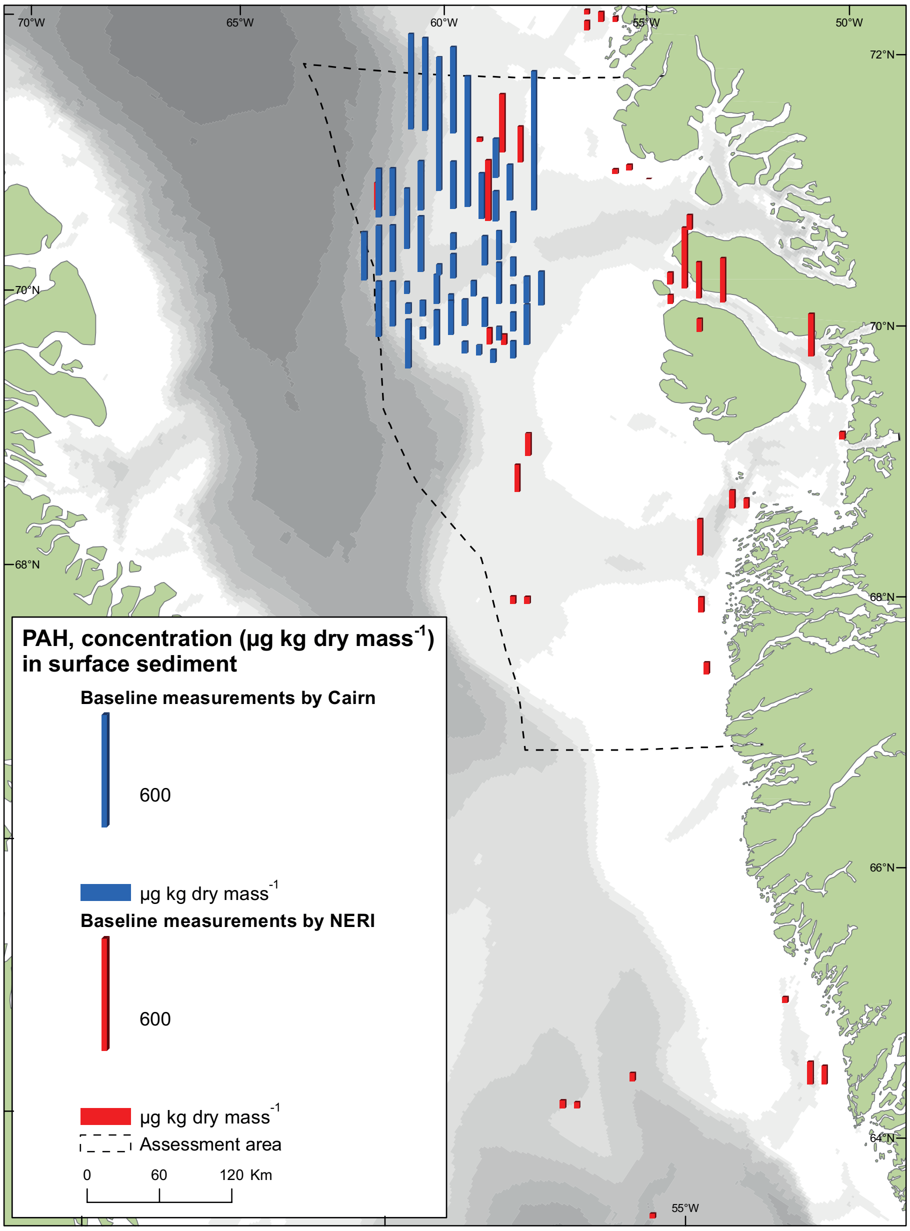
From the studies performed so far in Greenland, including the assessment area, regarding PAH levels in biota and sediment (including sediments from offshore areas, municipal waste dump sites and sites with no known local pollution sources), levels of petroleum compounds in the Greenland environment appear to be relatively low and are regarded as background concentrations (Figure 18).

Total petroleum hydrocarbons (TPH) and PAH levels were measured at natural seeps off Marraat in the Disko Bay area in sediments and biota (blue mussels, shorthorn sculpins, Greenland cod) in 2005 (Mosbech et al. 2007). TPH levels in the sediment were relatively low and therefore gave no real indication of oil seeps or other local petrogenic sources. The PAH levels ranged from low values up to approx. 1600 µg/kg dry weight but there was no clear spatial pattern. However, samples from greater depths (200–400 m) and further away from the coast showed 3–4 times higher levels than those closer to the coast. The reason for this is presently not clear (Mosbech et al. 2007b).

The higher PAH concentrations in some areas off the coast of the Nuussuaq Peninsula (Figure 18) could probably be attributed to the Marraat oil seep, which has been studied some years ago (Mosbech et al. 2007b).

As part of a baseline study performed by Capricorn in 2010 and 2011 in relation to offshore drill sites, PAH content in surface sediments were analysed offshore Disko Bay to document background level prior drilling. The PAH content in the sediments were usually low (Figure 18).

Figure 18. Background levels of PAH in sediments in West Greenland.



9 Impact assessment

David Boertmann, Wendy Loya, Janne Fritt-Rasmussen and Susse Wegeberg

9.1 Methodology and scope

The following assessment is based on available information from the Disko/Nuussuaq area, reviewed in the previous sections (2 to 7) and include the background information which was collected during field work in 2015 (Wegeberg et al. 2016, Boertmann & Petersen 2016).

9.1.1 Boundaries

The assessment area is the area described in the introduction (Figure 1) and the terrestrial part of it covers approx. 13,000 km^2.

The assessment includes, as far as possible, all activities associated with oil exploration and exploitation including decommissioning.

9.1.2 Impact assessment procedures

The first step of an assessment is to identify potential interactions (overlap/contact) between the activities and the ecosystem components in the area both in time and space. If interactions may cause impacts these are evaluated with regards to their temporal and spatial extent and mitigating actions are discussed.

The spatial extent of effects is indicated as local, regional or global. Local refers to impacts in the nearby environment (up to ~ 100 km^2). Regional encompasses effects on wider areas including the entire assessment area.

Global refer to impacts which may affect a total population of species or the entire global environment such as emission of greenhouse gasses.

The temporal extent of effects varies from immediate over short-term to long-term or even permanent.

Quantification of the potential impacts on ecosystem components is difficult, and the available data from the assessment area are generally not adequate for this task. Moreover, the spatial coverage of most activities cannot be assessed, as it is not known where the activities (such as exploration drilling) will take place. In addition, climate change also impacts the ecosystems, complicating assessment of separate and cumulative impacts from hydrocarbon and mineral activities.

Different measures exist to mitigate and reduce the environmental impacts from the described activities. These are described and proposed and overarching in this respect are:

- application of the principles of BAT and BEP, including new and up-to-date techniques,
- careful planning of activities (with inclusion of up-to-date and detailed environmental background information),
- strict regulation by the authorities.

Many sources have been drawn upon to assess impacts from hydrocarbon activities. Especially important in this respect are the Arctic Council Oil and Gas

Assessment (AMAP 2010) and the assessment of cumulative environmental effects of oil and gas activities on Alaska's North Slope (NAS 2003).

9.2 Impacts from routine exploration activities

Hydrocarbon exploration can last from a season to a decade or more. Exploration activities include primarily seismic surveys and exploration drilling, and the major environmental impacts include:
- physical impacts from facilities and activities
- disturbance of wildlife
- waste, discharges and emissions
- fresh water consumption

If discoveries are made, an appraisal phase will follow. This can last for several years and include seismic surveys, drilling and well testing. Baseline environmental studies will need to precede significant actions. If the appraisal shows a commercial discovery, development may follow.

Besides the seismic surveys and drilling, exploration activities may also include aerial surveys of gravimetry and magnetism. During exploration drilling there is a risk for blow-outs and subsequent oil spills. The impacts from such events are described in a separate section below.

9.2.1 Physical impacts of exploration activities

The physical impacts occur mainly in the area physically covered by the constructions and activities, such as placement of infrastructure and tracks and trails in the terrain also termed as the footprint. The impacts include changes or damage to the landscape, soil, permafrost and vegetation and they are usually related to seismic surveys and exploration drilling. Deposition of dust generated by activities is also considered as a physical impact.

Seismic surveys
It is evident that extensive land areas can be physically impacted by seismic activities especially from 2D seismics. This is for example the case in many areas of the Arctic Russia and on the North Slope of Alaska. The most significant physical impact of seismic surveys are the footprints on the terrain and vegetation due to survey lines, trails, disrupted or removed vegetation and compressed soil. However, the Arctic vegetation without trees in the assessment area, preclude one of the major impacts seen in e.g. Alaska, where tree clearing of survey lines is a major issue (Yukon Government 2006). Further, experience from other Arctic areas shows that especially terrain damages have the potential to be enlarged by wind and/or water erosion and in areas with permafrost there is a risk of inducing thermokarst (Bellamy et al. 1971).

It is also important to consider that supporting activities to the seismic surveys can induce physical impacts, for example where surface disturbance is concentrated (e.g. foot traffic around a landing site, off-runway landings by wheeled aircrafts, wakes from boat traffic, or repeated vehicle crossing of a drainage channel at the same site). Vegetative cover is critical to protecting soil properties, particularly providing insulation in areas of permafrost. If the vegetative cover or surface organic material is removed or disturbed, soil erosion or thawing of the permafrost may result in creation of depressions (thermokarst) (Raynolds et al. 2014). Moreover will exposed sediments be vulnerable to wind and water erosion with creation and deposition of dust as potential impacts on the surrounding environment.

These physical impacts on the terrain and vegetation may also contribute to very obvious visual impacts, which in case of the track lines can cover extensive areas.

The use of explosives may induce further impacts. Surface shots will destroy vegetation around the shot point and if explosives are placed in shot holes there is a risk for contamination of nearby waters through the holes.

Mitigation

The most efficient way to mitigate the physical and visual impacts from seismic surveys is to survey in winter when soil is frozen and terrain and vegetation is snow covered. This reduces physical impacts considerably and facilitates moving over moist and wet habitats. The AMAP oil and gas assessment concludes that seismics 'can be conducted in the winter with virtually no permanent footprint on the Arctic tundra' (AMAP 2010). However, damages on terrain and vegetation may occur even after winter seismic surveys, especially in areas with steep altitudinal gradients (Emers & Jorgenson 1997, NAS 2003).

In winter, seismics can also be shot on ice roads or water bodies to avoid crossing the landscape (Yukon Government 2006).

In Greenland, winter seismic surveys were carried out in Jameson Land in the 1986-1989, using vibrators as sound source. Especially in dry habitats where snow cover was slight or in areas where the snow was removed by the driving (e.g. on steep hill sides and river banks), vegetation and terrain were impacted (ruts and trails) and some of these damages are still clearly visible (Hansen et al. 2012).

Impacts can be further reduced by using lightweight vehicles with low-pressure tires. In Canada a 'Low Impacts Seismic' (LIS) approach is now applied, including the use of such light weight vehicles.

Finally, temporal regulation of seismic activities is practiced e.g. in Alaska, where The Department of Natural Resources has specific restrictions on winter and summer tundra travel (DNR 2015): Off-road travel on the tundra in the coastal areas is only permitted when the soil temperature at a depth of 30 cm reaches -5 °C and when there is 15 cm of snow on the ground. In the foothills areas, tundra opening for off road traffic occurs when the soil temperature reaches -5 °C and when there is 58 cm of snow on the ground. The differences for the foothills are related to the presence of steeper slopes as well as the vegetation, including tussocks and shrubs which require greater snow cover for protection. The date of tundra opening has ranged from as early as November 4 to as late as January 27. Once the tundra has been opened in the winter, there are no restrictions on the type of vehicles that may operate on the tundra under a permit. In years of limited snowfall, the tundra may be opened conditionally with specific operating restrictions. The tundra is closed when it appears that thawing conditions have resulted in snow that will be too soft or too limited in depth and extent to permit travel without resulting in damage to the tundra. Off-road vehicle operators are then notified and given 72 hours to move their vehicles and other equipment off of the tundra and onto the road system. Permitted summer tundra travel is limited to vehicles that have been tested and approved by the regulating agency. This means that seismic surveys on Alaska's North Slope are only permitted in winter when snow cover is sufficient and soil temperatures are low enough to support necessary vehicles (BLM 2012).

BOX 3

THE GRO#3 EXPLORATION DRILLING

David Boertmann & Susse Wegeberg

In 1996, the Canadian company grønArctic Inc. drilled an exploration well near the Marraat site on Nuussuaq Peninsula (Figure 1). Four stratigraphic slim core holes were drilled in 1994 and 1995 (400-900 m deep) in the same part of Nuussuaq, but the 1996-drilling was with conventional exploration equipment and rig (Christiansen et al. 1997, Christiansen 2014).

3724 tons of equipment was offloaded on the coast in July 10-16. The plan was to transport this to a drill site, designated in June 1996, 15 km into the Aaffarsuaq valley. However, 2.5 km from the coast the terrain was too wet and two caterpillars got stuck and the transportation to the drill site was given up. An alternative wild cat drill site was chosen 1 km from the mobilisation site on the coast (Figure 1, 2).

An accommodation camp, a tank farm and a drill site (lease area) was established on dry almost vegetation less gravel banks and drilling was commenced August 3 and terminated on October 5 after drilling a 2996 m deep well. Only traces of oil and gas were encountered and the well was plugged and the drill site left October 23 after remediation of the area (Christiansen et al. 1997, 1999, grønArctic 1997).

The major part (volume unknown) of the water based drilling mud was reinjected into the wellbore and the rest separated into a solid fraction and a liquid fraction. The solid fraction was deposited in the flare pit (sump) and the liquid fraction (100 m^3) was sprayed on the lease area's gravel banks. The cuttings (300 m^3) were also distributed on the lease area s and this area was grated afterwards (Figure 2).

Deep tracks, ruts and the holes from the stuck bulldozers was filled in with gravel and levelled. Culvert at crossings of creeks were removed and gravel pits, gravel embankments etc. were levelled.

The site has been monitored by photo documentation at several occasions: 1998, 2007 and 2015 in order to follow the remediation measures.

In 1998, a shallow depression where the solid drilling mud was deposited was observed. In 2007, three new depressions (Figure 5) were seen there and apparently the drilling mud had subsided. All depressions were still obvious in 2015, but not as conspicuous (Figure 6).

Profile samples from ÷95 cm to surface in the person-indicated depression in Figure 5 and 6 were obtained for identification of disposed drilling mud (by analyzing for barium concentrations as proxy) (Figure 6a), and for the purpose of analyzing for potential remaining other drilling mud substances. The results of the analyses were compared to the Barium concentrations in samples from the drilling mud obtained in 1996.

Figure 1. The drill site at GRO#3 in 1996.

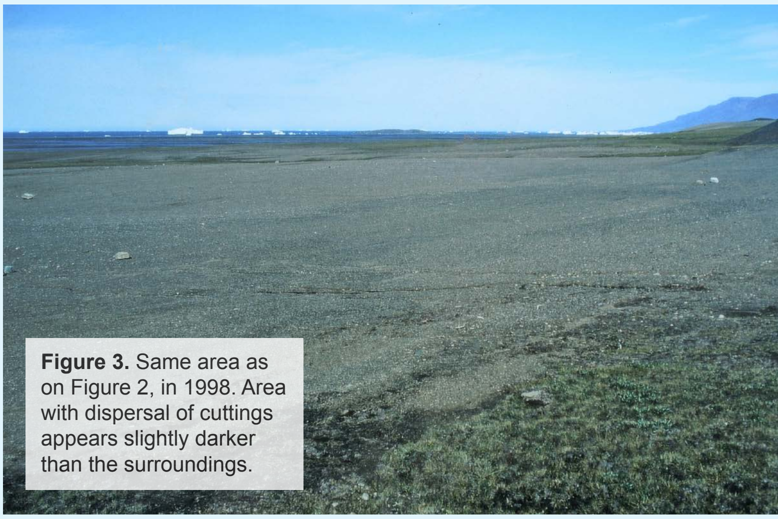


Figure 3. Same area as on Figure 2, in 1998. Area with dispersal of cuttings appears slightly darker than the surroundings.

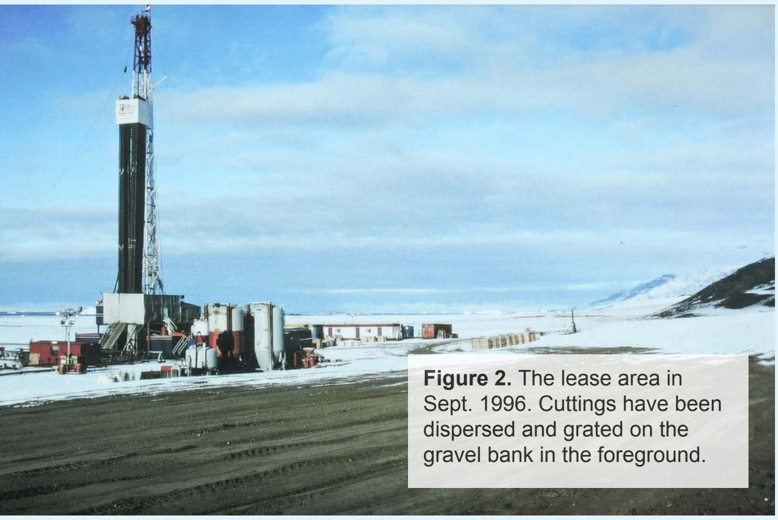


Figure 2. The lease area in Sept. 1996. Cuttings have been dispersed and grated on the gravel bank in the foreground.

Figure 4. Same area as in Figure 2 and 3 from a slightly different angel in 2015.

Figure 5. The flare pit in 2008, with two depressions developed since 1998.

Figure 6. The same area as in Figure 5, in 2015.

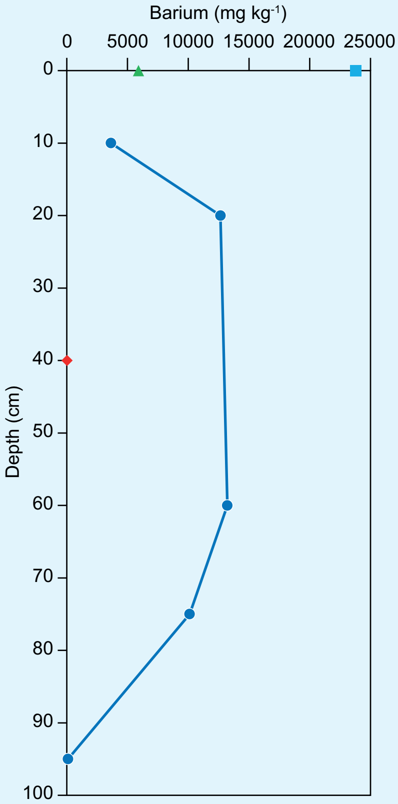


Figure 7. Profile of soil content of barium within 1 m depth from the flared pit in which the solid fraction of the drilling mud was informed disposed, sampled in 2015. Red ruby indicates background level on the gravel bank, green triangle indicate barium concentration in the sludge fraction after stripping, and blue square, the barium concentration in a sample from mixed drilling mud before use.

The Barium concentrations in the 2015 samples, when they were highest (10,115, 12,651, 13,217 mg kg^{-1}), showed that drilling mud, as expected, was disposed of in the flared pit. The Barium concentrations here reached 50% of the Barium concentrations measured in the drilling mud sample from 1996 (23,770 mg kg^{-1}), whereas the Barium concentration of the reference sample, taken in the same area, however, 200 m away from the expected drilling mud disposal in 40 cm depth, reached a level of only 25 mg kg^{-1}. The Barium concentration of the stripped drilling mud fraction from 1996 was measured to 5,909 mg kg^{-1} (Figure 7a).

The extensive gravel plains where camp and lease area were situated, appeared in 2015 almost like similar un-impacted plains. At close range tracks from bulldozers and trucks could be observed, but on distance these area were indistinguishable from un-impacted plains. Vegetation, which originally was extremely scarce, had reestablished and in the flare pit also even rather lush vegetation (including *Chamaenerion latifolium*) – perhaps due to nutrient enrichment or to shielding from the wind (Figures 3, 4).

The deep gravel filled and levelled tracks were still obvious, however, vegetation had begun to reestablish, and the deeper wet areas appeared as being under reestablishment. No thermokarst appeared to have developed in this area (Figures 8-11).

In conclusion, the area was generally remediated. The most pitiable impacts from the 1996 activities are the many tracks from off-road driving with small vehicles (ATVs etc.). These have left a network of still visible track in vegetation and in soft soil, and they will be visible for decades assessed from the restoration rate from 2007 to 2015.

Figure 8. Tracks created by bulldozers in July 1996, photographed in Sept. 1996. They were subsequently filled in with gravel and levelled.

Figure 9. The same tracks as in Figure 8, photographed in 1998.

Figure 10. The same site as in Figure 8 and 9 in 2007. Vegetation is under establishment.

Figure 11. Same site as in Figure 8, 9 and 10, now in 2015.

In the assessment area the lowland areas with dense vegetation will be particular sensitive to seismic surveys carried out in summer. There are however, large areas in riverbeds and at higher elevations where such activities could be carried out, if they were accessible to vehicles. But as seismic lines cannot be restricted to these areas, the most convenient way to reduce physical impacts from seismic surveys in the assessment area will be to do it in winter, when snow and ice form a protective layer over vegetation and terrain. Moreover, the use of explosives must generally be avoided, and if necessary restricted to sites inaccessible to vibrating devices.

Exploration drilling

The footprint from exploration drilling includes the drill and camp area, the mobilization/staging area and the roads and trails connecting these areas.

The more wells are drilled and the further away from a staging area on the coast, the larger an impacted area will be.

Such impacts may cause habitat loss for local fauna and flora, of which rare plants with very restricted distribution will be the most vulnerable, and transport corridors may block migration routes for caribou or in case of rivers also Arctic char.

In 1996, drilling equipment was brought in by ship and landed on the beach of the Nuussuaq Peninsula. Through extensive transport activity with large trucks and bulldozers, equipment was brought to the drill site 1 km from the coast (Box 3). During another transport operation in the same area in 2007, a 31 km long access road was constructed between the coast and a mineral exploration site in the central area of the Nuussuaq Peninsula (Box 1). Even though the company remediated the terrain, the road is still visible in 2015, and will remain so until erosional forces transform the entire landscape and revegetation then occurs (Box 1). Impacts were exceptionally significant where the road crosses a moist area and the road was built up to nearly a meter thickness with gravel on fibre cloth and geo grid. During limited remediation activities, these materials were levelled, leaving a very conspicuous mark in the terrain (Box 1). Regardless, the damage to the grassland vegetation and permafrost likely would result in a permanent scar even if remediated.

If activities are allowed in summer, there will be a risk for significantly greater impacts than from the 2007 activities. The demand for gravel for pads and embankments is high when operating in wet habitats found in the valleys of both the Nuussuaq Peninsula and Disko Island, while the need for gravel will be small in dry and well drained areas. The gravel would have to be taken from pits or mines, which would increase both the physical and the visual impacts. The construction of embankments in wet habitats would also alter the drainage pattern (Box 1), with potential large impacts on the surrounding terrain (impoundment, diversion, increased sediment runoff, etc.) and permafrost (see Section 3.4).

A specific impact in an Arctic area such as Disko/Nuussuaq is thermokarst, which is melting and subsidence of the permafrost layer (Box 1).

The physical impact on terrain and vegetation may also result in visual impacts which, in unspoilt Arctic landscapes such as these, can be extensive and profound.

Uncontrolled off road driving (often with ATVs as leisure activity) in 1996 and in 2007 caused a network of tracks in the terrain near the operation areas. This is mostly an aesthetic impact, but should nevertheless be avoided, as these tracks will be visible for decades.

The footprint of the 1996-drilling is today (2015) limited to remains of trails and some terrain damages caused by bulldozers, which stuck in moist areas in the melting period in late spring. Tracks from off road driving with ATVs are also still visible (Box 3).

Mitigation
One of the most efficient ways to mitigate physical impacts on the local environment when operating onshore is to restrict the exploration activities to the winter season, when soil is frozen and the terrain is snow covered. Heavy equipment can be then mobilized with the least impact to the ground (AMAP 2010). Moreover can roads, embankments and drill pads be made from ice. Upon completion of the exploration drilling all equipment should be removed before spring and snowmelt when ice roads or snow trails melt (NRP-A 2012), and ice constructions leave much lesser physical damages on terrain and vegetation when they melt away.

There are more advantages to operations in the winter as construction of gravel pads and embankments in wet habitats are not necessary.

This means that today exploration occurs almost exclusively in winter on Alaska's North Slope (BLM 2012).

Careful planning (including remediation) and regulation (BAT and BEP principles applied), including new and up-to-date techniques are other important measures to include when physical impacts shall be minimized. For example, the crossing of rivers with ice roads will require attention to potential fish stocks wintering there and to diversion of streams in spring time when the rivers opens.

Winter operations will be the preferred way to operate in the assessment area if physical environmental impacts shall be minimized. Summer operations could however, be carried out in dry coastal areas without significant physical impacts, where transport corridors will be short - like the GRO#3 site.

9.2.2 Disturbance of wildlife

Petroleum exploration has a high potential to disturb terrestrial wildlife. Disturbance includes displacement (scaring away) and behavioural changes. Seismic surveys that slowly move through the terrain may impact wildlife briefly in a large region. However, traffic to a permanent facility has the potential to impact wildlife more continuously throughout the season. Helicopters commuting between a drill site and nearest airport would have the potential to disturb wildlife over larger regions.

The most disturbance sensitive wildlife in the assessment area are the geese and the caribou and they may be displaced from critical habitats if surveys are repeated over several seasons in the sensitive periods. But also moulting seaducks, especially king eiders are sensitive to disturbance for instance from over flying helicopters and boat traffic.

The geese are only present in the summer and both the large flocks of moulting geese and the breeding geese are vulnerable. Caribou are present throughout the year, but vary in habitat preferences between seasons: They are likely to be at lower elevations in winter and in the summer, they are likely to use higher elevation habitats. Arctic hare and ptarmigan are also likely to be impacted (displaced), while Arctic Fox may be attracted to support camps.

The use of airguns during seismic surveys in the assessment area is unlikely as most lakes are very small and the few large are so narrow that seismic lines in most cases can be placed on the shores. Impacts of airguns on fish in the marine environment is reviewed in the strategic environmental impact assessment of petroleum activities in the Disko West area (Boertmann et al. 2013)

Mitigation

Identification of caribou seasonal habitats prior to seismic surveys and drilling will aid in minimizing impacts of exploration as well as development. Summer exploration activities may impact the populations of moulting and breeding Greenland white-fronted goose and Canada goose in the assessment area. These occur especially in the relatively lush wetlands in the lowland areas. A single activity has the potential to displace geese from a large area, but they would probably re-occupy such areas the following season if activities were terminated. If exploration occurred over several years, it may take longer for geese to recolonize an area or they may be displaced permanently. The impacts can be reduced by careful planning and avoidance of the sensitive areas in the sensitive periods. The MLSA/EAMRA 'field rules' designate goose areas in both Nuussuaq and Disko (Figure 10) where activities are regulated in order to reduce disturbance (Link).

Aircraft operators should be made aware of the potential effects of low-flying aircraft on wildlife and take the appropriate actions (maintaining altitudes above 500 m whenever possible) to minimize those effects.

To protect fish habitat, surveys of larger lakes and rivers that may support winter populations will identify where winter water withdrawals need to be restricted. Water depths in fish bearing waters must have adequate unfrozen water to provide unfrozen habitat and avoid depletion of dissolved oxygen.

For summer water use, it is also important to understand which rivers may support anadromous Arctic char populations, and sufficient water levels must be maintained.

9.2.3 Waste, discharges and emissions

Both seismic surveys and drilling activities emit greenhouse gasses and other air pollutants produced by 1) drilling equipment required for exploratory wells, (2) trucks and other vehicles used to support exploration, (3) intermittent activities such as mud degassing and well testing, (4) power generation emissions and (5) waste incineration, if permitted.

Especially drilling requires combustion of large amounts of fuel and the offshore drillings carried out in West Greenland in recent years (2010, 2011) increased the Greenland greenhouse gas budget significantly. The emissions also include NO_x and SO_2, which contribute to formation of Arctic haze, and which may impact local vegetation by acidic precipitation, especially if the buffer capacity of the soil is low (See Section 2.1.3).

Drilling also creates large amounts of drilling mud and drill cuttings to be disposed of at the end of activities (Section 2.1.3). Sumps have been an often-used option for disposal of drilling waste during exploration drilling in the Arctic (Russia, Alaska, Canada). The intention is that the drilling waste shall freeze into the permafrost. This is however, often problematic and especially now, with increasing temperatures and a general reduction in the permafrost layer. There are also examples of drill mud containing so much salt, that it cannot freeze, and in many cases sumps have leaked their contents to the surroundings if not underlain by an impermeable barrier. Sumps often subside and this may increase the risk of leaching of mud chemicals and hydrocarbons to the environment. Drill cuttings may contain Naturally-Occurring Radioactive Materials (NORM) if certian types of shale have been penetrated and such shall be deposited safely (likewise if it contians other environmentally hazardous substances).

After the drilling on Nuussuaq in 1996, the flare pit was used as sump for the solid fraction of the remaining drilling mud (a part of it was left in the wellbore). The fluid fraction was sprayed over the lease area and cleaned cuttings were spread over a part of the lease area and grated (Box 3). The site was inspected in 1998 (Boertmann 1998) and again in 2015 and the area with the cuttings looked indistinguishable from the other parts of the lease area, which was also grated, and in 2015 establishment of vegetation had begun. However, the sump had subsided in 1998 and this subsiding had developed further in 2007 and in 2015 (Box 3).

Mitigation

Requiring the use of ultra-low sulphur diesel in all vehicles and equipment can help maintain air quality. As trace constituents in diesel fuel, sulphur compounds may cause adverse air quality impacts through formation of sulfate particulate matter (affecting visibility) and deposition of acidic aerosols. These impacts would be reduced significantly by utilizing ultra-low sulphur diesel fuel. In addition, ultra-low sulphur diesel fuels burn cleaner and produce less light absorbing carbon particulate matter (soot, also called black carbon). When burned, ultra-low sulphur diesel emissions are much lower than those generated by previous fuels, reducing fine particulate (soot), sulfuric acid, and sulfate (visibility) impacts.

Water quality impacts are likely to be significantly less with winter exploration. Spills may be easier to clean up on frozen ground or rivers. Using the liners, booms and other protective devices where petroleum and chemicals are used and transferred can minimize the impacts of spills on water quality during all seasons.

In Alaska sumps are not used anymore and mud and cuttings are reused, recycled, reinjected or transported to approved deposition facilities. Moreover, old sumps are remediated. But in other Arctic areas, such as in Russia and Canada, deposition in sumps is still used (AMAP 2010).

The use of sumps in the assessment area, should be prevented like in Alaska, in order to minimize environmental impacts. However, if certain conditions may require the deposition of drilling waste in sumps, it shall be secured that the drilling mud is water based and contain only chemicals that are on the OSPAR HOCNF list or are listed as ‘green’ according to the Norwegian offshore regulation, and moreover that an impermeable barrier liner is in place to prevent leaching of materials into the surrounding environment.

9.2.4 Fresh water consumption and contamination

Significant amounts of water are required for drilling and associated support activities and this water will have to be taken from nearby lakes or rivers. Careful monitoring will be needed to ensure restricted water sources are not run dry, which would destroy them as habitat for freshwater fauna and waterbirds. During the 1996 drilling on Nuussuaq in West Greenland, fresh water was taken from an artificial lake created by damming a small creek.

In case of winter activities, the construction of ice roads and pads contributes to the use of large amounts of fresh water. According to NAS (2003) construction of one mile ice road would consume 3.800-5.700 m^3 of water. Especially the smaller lakes and ponds in the assessment area may be impacted significantly if they are used as fresh water resources during exploration drilling or the construction of ice roads and ice pads. Moreover may winter conditions restrict availability of fresh water and de-salinization of sea water may be the only way the get fresh water to support constructions/activities.

Other significant uses of water include camps where typically 30-60 people are needed to operate a drilling rig and infrastructure operations.

The most important issue in the context is the rivers with spawning stocks of arctic char, where water use could affect spawning fish and winter habitats by lowering water levels.

In this regard it is also important not to pollute freshwaters with waste water from camps and activity areas.

9.3 Impacts from routine exploitation activities

Before oil is found and the location of infrastructure is selected, it is difficult to assess specific environmental impacts, but a more general assessment can be made.

Development of an oil field and production of hydrocarbons can have long lasting impacts, as oil fields may produce for decades. The major conflicts with the environment derive from:

- physical impacts from facilities and activities
- disturbance of wildlife (and hunting)
- waste, discharges and emissions
- fresh water consumption

Further, extensive environmental impacts may derive from a large accidental oil spill. Impacts of oil spills are described in a separate section below.

Many of the same impacts and concerns described for exploratory drilling apply to exploitation drilling. For example, concerns about handling of drilling waste are similar, but of potentially greater magnitude, depending on the number of production wells drilled.

9.3.1 Physical impacts

The physical environmental impacts of oil extraction in Disko/Nuussuaq would naturally depend on the size of the oil field and on the actual location. For example, the distance to a shipment facility on the coast would be decisive for the length and routing of a pipeline.

In general, the environment in the assessment area is less sensitive to physical impacts from production activities than Arctic Russia and the North Slope, because in most areas facilities can be established on rocky or other stable and dry subsurfaces.

The infrastructure of a producing oil field includes camps, airstrip, pipelines, processing facilities, access roads, multiple well sites, gravel mines, shipment facilities, waste disposal facilities and tank farms creating a substantial physical footprint. A recent estimate of surface disturbance for a stand-alone oil exploitation facility in Alaska is at least 20 hectares (BLM 2012).

Important issues to consider when establishing more permanent structures in the assessment area will be permafrost and water regimes. All kinds of structures placed on the ground and also drill pipes penetrating the frozen layer may cause thawing and ultimately thermokarst.

Freshwater drainage patterns may be impacted by the infrastructure. Snowdrifts caused by gravel structures would increase the soil surface temperature in winter and increase thaw depth in the soil near the structures. Blockage of natural drainage patterns can lead to the formation of impoundments. On the surface, impoundment of water may occur in the melting season and especially where gravel roads cross wetlands (Box 1). The impounded water may destroy habitats for terrestrial animals, but may on the other hand improve the conditions for animals associated with open waters. Impoundments also have the potential to cause thermokarst. On the North Slope tundra in Alaska such impoundment problems have been significant (Walker et al. 1987, NAS 2003).

Dust formation is also characterized as a physical impact. This may occur on gravel roads with extensive traffic, and the dust may settle as far as 1 km from the road and impact snow melt, permafrost and vegetation (Myers-Smith et al. 2006).

Removal of gravel from areas near streams and lakes can result in changes to stream or lake configurations, stream-flow hydraulics, lake shorelines, flow patterns, hyporheic flow, erosion, sedimentation and ice damming (Kondolf 1994). Locating gravel pits at an adequate distance from streams and lakes would minimize these impacts.

Pipeline construction would depend on the location and number of commercial-size discoveries. Narrow streams could be crossed using elevated pipelines on suspension spans. Trenching and burying insulated pipelines in the riverbed could be used to cross wider, shallow rivers. All entrenched crossings should be constructed in the winter at locations selected to minimize disturbances to tundra. All pipelines should be routed to avoid lakes. Once installed, suspended and entrenched pipelines would have no effect on stream and water flow characteristics. Buried pipelines could have potential thermokarst, subsidence, and possible exposure by stream erosion beyond the construction phase.

The physical impacts related to ecology and biology is primarily habitat loss and habitat fragmentation. Habitats may simply be physically destroyed, and this can be critical to species with very restricted distributions or with very small populations.

Habitat fragmentation can be significant especially where animal movements are obstructed e.g. by gravel embankments or pipelines. Rivers can be obstructed for migrating fish such as Arctic char and for example roads may affect migration of caribou even though they are capable of crossing the road (Wilson et al. 2016).

Finally, all the infrastructure of oil extraction can contribute with visual impacts, which may impact local tourist industries, using the unspoiled Arctic environment as their primary asset.

Mitigation
The technical development has in recent decades reduced the footprint from production sites, e.g. by the use of directional drilling, where several wells are drilled from the same drill site. Other ways to mitigate these impacts are by careful planning including in-depth background studies of the potentially impacted environment.

In Alaska, on the North Slope, permafrost damage was prominent in the early period of the development. Such effects are less evident now, where heated structures and pipelines are elevated. Elevated pipelines may cause additional impacts in the form of visual impacts on landscapes and minor effects on the microclimate surrounding them.

In many parts of the assessment area infrastructure and constructions can be established on rock and other stable ground, but there are areas where impacts on permafrost would be evident, if no actions are taken to counteract thawing. This may especially be the case in the lowlands of the large valleys.

In this context climate change would tend to aggravate the problems with impacts on the permafrost layer.

Habitat loss and fragmentation shall be counteracted by new, detailed and site specific back ground studies carried out as a part of the planning process.

There are a number of operating guidelines from other areas that can be implemented to minimize impacts on wildlife, particularly caribou (BLM 2012). Pipelines and roads should be designed to facilitate caribou passage (BLM 2012) by (1) elevating all aboveground pipelines at least 2.3 meters above the ground, providing better passage during winter when snow is on the ground; (2) burying insulated pipelines; or (3) providing ramps. In addition, requiring that a minimum distance of 165 meters separate pipelines and roads, when feasible, will minimize the barrier effect of infrastructure on caribou movement. If fully implemented these requirements would be effective in reducing (but not eliminating) the impacts from hydrocarbon development on caribou movements.

The visual impacts from a production facility may be concealed by the topography, which may allow hiding infrastructure from being seen from the coast and may facilitate application of unobtrusive and landscape adapted facilities.

9.3.2 Disturbance of wildlife

Disturbance derives from the presence of infrastructure and from the human activity related to them, such as traffic on roads, helicopter flying and just people walking around in the surroundings.

Disturbance may displace animals from critical habitats, and may in special cases be a serious threat to small populations with a limited distribution.

Ground nesting birds are sensitive to disturbance from traffic and humans moving around in their habitat, and it has been shown that shorebirds avoid nesting at distances between 50 m and 220 m from roads (Glahder et al. 2011). This may, combined with the habitat loss created by the footprint, reduce the populations in close vicinity to hydrocarbon installations. Some species would probably show habituation, and re-enter the affected areas after some years.

In Disko/Nuussuaq the most disturbance sensitive species are the geese, the seabirds and the caribou. Especially the moulting geese and king eiders are very sensitive to disturbance, because they are not able to fly and need undisturbed marshes / lakes and fjords respectively (Mosbech & Glahder 1991, Madsen et al. 2009, Mosbech & Boertmann 1999). Exploitation activities may displace moulting geese and king eiders from the surroundings. If a larger hydrocarbon field is established in an important moulting site, as for example Aaffarsuaq in central Nuussuaq or at Nordfjord on Disko ; all geese or king eiders from these sites would most likely be displaced, with possible negative consequences for the population. The Aaffarsuaq holds internationally important numbers of Greenland white-fronted geese (in 2015 201 in Aaffarsuaq (Box 2) – 190 represent currently the limit for being of international importance – 1% of the total numbers of the flyway population).

Breeding colonies of seabirds on the coast are also vulnerable to disturbance, and depending of species at the colony there is a risk of scaring away an entire colony.

A special case of this issue is attraction of predatory animals (subsidized predators), mainly Arctic foxes and ravens, which can feed on discards from the kitchen. These predators may increase the predation pressure on birds (especially on nests) and small mammals living in nearby environment, while their population may increase due to reduced natural mortality during the winter.

Mitigation
Disturbance can be mitigated by strict regulation of traffic and human activities, for example based on studies on of how to optimize habituation among the sensitive species. But the impact cannot be completely removed.

Since caribou are sensitive to disturbance from humans on foot and moving vehicles, there would be some negative effects on their ability to move freely through the area, regardless of how well a field is designed. To minimize the effects of low-flying aircraft on caribou and nesting and moulting geese, it is suggested that aircraft maintain an altitude of at least 500 meters above ground level (except for take offs and landings).

Subsidized predators shall be mitigated by making all kind of edible waste unavailable and feeding of the wildlife must be prevented. Designing facilities in a way that discourages animals seeking shelter, such as by enclosing the base of buildings with a skirt and putting screens on culverts, will reduce colonization of species such as Arctic Fox.

9.3.3 Waste, discharges and emissions

The production of water from production wells (Section 2.2) is a significant environmental issue. The produced water contains small amounts of oil, substances from the reservoir and chemicals added during the production process. Some of the substances are acute toxic, radioactive, contain heavy metals, have hormone disruptive effects or act as nutrients. Some are persistent and have the potential to bioaccumulate.

Produced water is often discharged to rivers (Russia) after cleaning for oil residues. However, in Alaska this practice is now abandoned and all produced water is re-injected into the wells. Injection wells are a potential ground water contamination source if not properly located, constructed, and maintained.

Well drilling continues during the production phase and large amounts of drilling mud and cuttings shall be handled just as during the exploration phase (Section 9. 2. 3).

Ideally, all waste water, spent fluids, and chemicals would be disposed of in injection wells or brought to treatment facilities, depending upon waste characterization. Solid, non-burnable waste would be deposited in large dumpsters or other suitable containers located at each site. These containers would be backhauled to approved offsite landfills or taken to an approved incinerator.

The amount of waste from a production site can be considerable and waste management plans shall secure that the environment is not polluted.

Emissions to air are mainly combustion gases from the energy producing machinery (for drilling, production, pumping, transport, etc.). For example, the drilling of a well may produce 5 million m^3 exhausts per day (LGL 2005). But also flaring of gas, trans-loading of produced oil and de-pressurizing of produced water contribute to emissions. The emissions consist mainly of the greenhouse gases carbon dioxide (CO_2) and methane (CH_4), as well as nitrous oxides (NO_x), volatile organic compounds (VOCs) and sulphur dioxide (SO_2).

Oil production activities produce large amounts of CO_2, in particular exemplified by the emission from a large Alaska field (Prudhoe Bay) estimated by Jaffe et al. (1995) to more than 7.3 million tonnes in 1990, a figure raised by a factor 4-6 by another study (Brooks et al. 1997). This is more than ten times present day total contribution from Greenland.

Methane (CH_4) is a very active greenhouse gas, which is released in small amounts together with other VOCs from produced oil when loading oil between tanks.

SO_2 contributes to acidic precipitation and black carbon and NO_2 to formation of Arctic haze (see Section 2.1.3).

Mitigation
As drilling continues during the production phase, drilling mud and cuttings will be produced and have to be disposed of. As described above in the exploration section, disposal in sumps is problematic seen from an environmental point of view. However, reinjection in old wells is an option in the production phase.

The impacts from discharges are mitigated by reducing discharges applying the principles of BAT and BEP. They encompass for example re-injecting produced water, disposal of drilling waste at controlled sites and exclusively use of ultra-low sulphur diesel (ULSD, < 15 ppm) in all vehicles and machinery.

The produced water probably presents the most important discharge problem to solve before oil production is initiated. It will cause significant pollution problems if discharged into rivers, lakes or to the sea (via pipeline), why the only recommendable solution will be to re-inject it into the wells. If re-injection is not possible and discharge is the only alternative, it is recommended that the water is effectively cleaned before it is released, and that the emission is continuously monitored both chemically and biologically to secure that effect on the environment are kept at acceptable levels.

The atmospheric emissions have the potential to impact vegetation on nutrient poor soil, which is widespread in the assessment area and also to contribute to the fromation of Artic haze, where the large valleys of both Disko and Nuussuaq are typical sites for accumulation of Arctic haze. The CO_2 emission from large-scale activities such as oil production could increase the total Greenland greenhouse gas contribution many fold.

Encouraging the use of renewable energy wherever possible, including hydro and wind power, can help maintain air quality and reduce greenhouse gas emissions.

Best management practices that address solid and liquid-waste disposal, fuel handling, and spill clean-up should, if properly implemented, substantially reduce the potential effects of oils and other waste on terrestrial mammals.

9.3.4 Impacts on fresh water resources

As with exploration drilling, water use is also significant during production. Drilling continues and there will be an increased numbers of workers in camps, requiring approximately 375 liters per person per day (BLM 2014).

Mitigation
Fresh water bodies with fish stocks (Arctic char) should be protected so water levels do not become so low that lakes and rivers freeze to the bottom. In the assessment area it should be possible to find lakes at higher elevation, from where water can be retrieved without threatening for example fish habitats.

9.3.5 Impacts on use of local recourses

Caribou is the most important terrestrial species hunted by the inhabitants in and near the assessment area. The hunt is limited by an annual quota of 624 divided in an autumn quota and a winter quota.

Many of the activities of oil exploitation have the potential to impact the availability of the caribou on Nuussuaq, and displacement of caribou from areas that have been traditional hunting areas is a risk.

In Alaska, there is also a change in hunter behaviour associated with the perception that animals inhabiting areas where oil exploitation is occurring may be contaminated (Braund & Associates 2009, NAS 2003). Further, shooting restrictions in areas where infrastructure, especially pipelines, is present can alter local resource use. On the other hand, some hunters may find that roads provide easier access to inland areas for hunting.

The establishment of an oil field in an otherwise almost inaccessible area will open for other human activities with environmental impacts. Especially if roads between the coast and production site inland are established. This may lead to facilitated access to inland resources such as the caribou on Nuussuaq.

Moreover, the establishment of an oil terminal and the associated potential pollution and the shipping activities will affect the use of coastal resources, such as capelin, Arctic char and seabirds.

Mitigation
Planning based on precise background knowledge may mitigate most impacts in this respect, but changed habits of migrating caribou and therefore changed availability to hunters cannot be eliminated.

9.4 Impacts from decommissioning activities

Abandonment activities would likely begin stepwise through the life of the field and could last 2 to 5 years after the end of production (BLM 2012). Abandonment operations generally include removing all equipment, plugging all wells, restoring the site, cutting well casing at least 3 feet below the surface and conducting final environmental studies (Barclay et al. 2001).

A significant impact from these activities can be remobilization and spreading of accumulated contaminants.

Decommissioning activities also include intensive transport with the risk of disturbing wildlife along transport corridors and at shipment facilities, just like during the development phase.

Decommissioning operations may take place over many years, as revegetation and environmental monitoring studies should continue to document the long-term effects of past operations at a particular site.

Mitigation
The impacts from decommissioning shall be mitigated by careful planning, applying the BEP and BAT principles. In this regard it is important to consider decommissioning during the planning phase, to secure that infrastructure and facilities are constructed in a way so future removal is facilitated. The extent of decommissioning will include an environmental cost–benefit analysis.

9.5 Accidental oil spills

A severe threat to the environment from hydrocarbon activities in the Disko/Nuussuaq area will be a large oil spill. During exploration, development and production large oil spills could be the result of a blow-out of a well, while pipeline rupture, spills during loading adds to the risk during exploitation/transport. Accidents with barges transporting oil on rivers is another potential source to oil spills in the inland (freshwater), however, no rivers in in the assessment area are navigable. Oil spills may not be restricted to crude oil, as refined oil products are used in large quatities both during exploration and production. Accidents during loading, storage and use of fuel oils are frequent, but generally spills from such events are small and restricted. If not

BOX 4

OIL SPILL EXPERIMENTS IN JAMESON LAND

Christian Bay & Peter Aastrup

As part of the background studies carried out in the 1980ies an oil spill experiment was set up near Mestersvig in 1982 (Holt 1987). Crude and diesel oil was spilled on five different plant communities, with 10 L/m². Vegetation communities included wet marsh, grassland, and three different dwarf shrub heaths. The effects were monitored over the subsequent three seasons.

Shortly after the experiment was initiated, plants in the study sites started to loose chlorophyll, both those treated with crude oil and those treated with diesel. Already the first year, the number of vascular plants decreased significantly and the total plant cover decreased to less than 5% of the original cover (Bay 1997).

The status after three, eleven and thirty-two years are described below.

Crude oil spills

After three years (1985)

Shrubs showed moderate recovery. *Salix arctica* showed best recovery, while *Dryas octopetala* and *Vaccinium uliginosum* hardly showed any recovery. In wetter areas, graminoids recovered moderately, but very little or not at all in dry sites. In the third year forbs had a few seedlings, but otherwise showed no recovery. Mosses showed moderate to good recovery in the wetter plots, but almost no recovery in the drier plots. Generally, wet and moist plant communities showed the best recovery (Holt 1987).

After eleven years (1993)

Woody species, herbs and graminoids had recovered less than 1 %, in crude oil sites. Mosses growing in soils with high water content recovered to 70 % in fens, and approximately to 30 % in grasslands (slightly higher than in crude oil spills). In dry sites, recovery was less than 1 %.

After 32 years (2014)

In the dry sites vegetation had almost recovered (Figure 1) and did not differ significantly from the surrounding vegetation. The wet sites had recovered completely.

Figure 1. Plot treated with crude oil in 1982 and photographed in 2014.

Figure 2. Plot treated with diesel oil in 1982, and photographed in 2014.

Diesel oil spills

After three years (1985)

Shrubs showed no recovery. Among graminoids, only *Carex bigelowii* had moderate recovery, while the others had next to none. Forbs did not recover, except for very few seedlings. In dry plots, there was a moderate recovery of mosses, while they recovered excellently in wetter sites.

For mosses, recovery was higher in diesel spills compared to crude oil spills.

After eleven years (1993)

For woody species, herbs and graminoids, less than 1 % recovered.

Mosses in wet habitats had a recovery of 53 %, close to 30 % in grassland and less than 1 % in dry habitats.

After 32 years (2014)

Recovery in dry sites was still not complete. Figure 2 show a marked difference to the surrounding and untreated vegetation. Wet sites had recovered completely.

The long-term impacts of diesel oil were more pronounced for the plant cover in dry habitats. Mainly due to the recovery of mosses, plant cover was moderate in moist habitat and good in wet habitat. All woody plants and most herbs were dead by the last recording date in diesel oil treated plots. Even, after 32 years a marked difference to the surrounding vegetation was obvious.

Plots treated with crude oil generally showed after eleven years better or near equal recovery compared to that of diesel oil – primarily due to the mosses ability to recover. The number of vascular plant species remained significantly reduced in all plant communities, most notably those on dry soils. New species colonising the plots were often dead the following year, and more than half of the new species were recorded for the first time eleven years after the oil spill. Most new species were recorded in the wet fens. The first fertile plants were seen after six years. There seemed to be no difference in frequency of fertile plants between crude oil and diesel oil treated sites (Bay 1997). After 32 years both dry sites and wet sites had recovered.

McKendrick (2000) reports similar results from a series of studies in Alaska's North Slope oil fields. In some wet habitats, recovery was complete after 20 years without any cleaning after the spill. Moreover resulted a speedy clean up (by burning off crude oil spills) in faster recovery for the plant communities.

cleaned up, however, large amounts may accumulate and need to be removed when activities are terminated.

In contrast to marine oil spills, which have the potential to impact extensive coastlines, terrestrial oil spill usually will be confined to a limited area close to the source, unless the spill makes its way to wetlands and watercourses, which facilitates the spreading of the oil. However, the movements of spilled oil on land and especially if oil penetrates to subsurface layers are much more complex and unpredictive than oil spilled on water (Fingas 2012).

Oil trapped in snow in wintertime would be able to spread with the melting snow in spring. But snow can also be used during spill response, if snow with oil is removed before spring thaw (see below).

The hitherto largest terrestrial oil spill occurred in the Komi Republic (Russia) in 1994, when a pipeline ruptured at several sites along 18 km and leaked more than 100,000 tons of crude oil to tundra, wetlands and rivers. Estimates of impacted land areas vary between different sources from 21 km^2 to 70 km^2 (NAS 2003, AMAP 2010). There is no information on ecological effects; recovery and toxicity available from the spill, but at least concern for the fish resources and the fishery in the affected rivers was expressed. Poorly maintained pipelines seem to be a significant source to terrestrial oil spills in Arctic Russia. Terrestrial oil spills have also happened in Alaska, but of much smaller scale than the Komi-spill.

Impacts of oil spills in the marine environment adjacent to the assessment area are dealt with in the Strategic Environmental Impact assessment of hydrocarbon activities in the Disko West area (Boertmann et al. 2013). An oil spill originating from land or from the shipment facilities have the potential to impact vast areas in the coastal environment, where for instance moulting seaducks will be at risk in the summer and autumn.

Oil spilled on land may destroy vegetation (Box 4) and accumulate in soils, where it can be preserved for many years due to low temperatures.

If oil reaches watercourses, fish resources will be impacted over long sections. If concentrations are high, fish and other freshwater fauna may be killed (Giessing et al. 2002, Mosbech 2002), but low concentrations would cause tainting, making fish useless for consumption. Since rivers and streams tend to melt upstream first, frozen areas downstream might work as blocks, forcing oil contaminated water out of the river and onto the land causing impact on vegetation (e.g. Collins et al. 1994). Birds living on and near oil-contaminated water may also be fouled with oil, usually with detrimental effect (Mosbech 2002).

Larger mammals will probably avoid oil contaminated areas (Boertmann & Aastrup 2002), while small mammals probably would die in heavily contaminated areas. There are however, no small mammals (lemmings, stoats, etc.) in the assessment area.

An oil spill restricted to land areas in the assessment area may destroy the vegetation locally and revegetation may take decades. If berms and dikes can restrict the dispersion, the impacted area can be limited to the drill site and the immediate surroundings. If oil moves further, a larger area may be impacted.

An oil spill would most likely not impact the caribou population, and in most cases only few water birds would be harmed if oil assembles in nearby lakes, and population effects on waterbird populations would not be expected even from a large oil spill, especially if the spill is contained by dikes and berms. Small land mammals such as foxes and hares and land birds wich occur in oil impacted areas may be fouled (and cross contamination between individuals will occur), but numbers will be restricted and population effects are unlikely.

In many areas of Disko/Nuussuaq, drilling would have to take place on cliff ground and gravel banks where oil would run off and assemble in depressions and potentially also make its way to water courses. If this happens, there would be a high risk of oil reaching the marine environment, where impacts can spread over a much larger areas and hit much more sensitive ecological elements such as seabirds and coastal habitats.

Oil spill impacts in the marine environment of the assessment area are described in the Strategic Environmental Impact Assessment of oil activities in the Disko West area (Boertmann et al. 2013).

Mitigation
Accidental oil spills are mitigated by keeping the highest Health, Safety and Environmental (HSE) standards, by applying the BAT and BEP principles and by strict regulation and careful planning, for example avoiding unstable areas for pipeline construction and by constructing berms around well sites and tanks in order to control spilled oil and preventing it from moving into watercourses and wetlands. In an area like the assessment area, with many rivers and few lakes, it will be essential to keep spilled oil away from the rivers, because the distance to the sea is short.

9.5.1 Oil spill response

Besides preventing oil spills, it is also important to be well prepared for an oil spill response operation and make sure that the equipment is in place, fit for the purpose and that the oil spill responders know what to do and how to use the equipment in different situations.

The preparations should also include mapping of surface types as oil spreading varies for example between bedrock, gravel and wetlands. The location of structures which can act as barriers, direct or accumulate moving oil such as fissures and depressions in bedrock are also important to know in advance. In the subsurface, water table, water flow direction and permafrost should also be mapped as subsurface oil may move along such features. This mapping is also important for decisions on oil spill response strategy.

Protective measures can also be established before activities are initiated. For example can trenches and berms be constructed around an exploration drill site.

Finally a strategy for containing, removal and treatment of spilled oil must be in place. Oil contaminated soil can for instance be treated by bio remediation (land farming) near the spill site (Paudyn et al. 2008) and oil can be burned or transported away for treatment at controlled sites elsewhere.

But if an oil spill occurs, the first thing to do is to stop oil from leaking into the environment. Oil spilt on soil and snow can spread horizontally depending of the viscosity of the oil and the roughness on the ground (e.g. vegetation, soil type). But also the air/ground temperature and slope steepness defines the rate of the oil movement (Owens 2002). The oil can migrate into the ground where the driving forces are gravity, pressure and capillary forces. The capillary forces can retain the oil (residual oil) so that it cannot be recovered by use of hydraulic forces (Henriksen & Sørensen 2008). Oil can also migrate through snow depending on the density (compactness) of the snow and also the oil properties and it can move into and through permafrost layers. Thus, it is important to dam the oil and hinder any further spreading, in particular to water resources, to limit the impact on the environment. The next step hereafter is to recover the oil by use of different techniques and measures. The choice of methods depends on the size of the oil spill and where the oil is spilt e.g. on/in soil, on/in snow, on/in ice, on permafrost, on bedrock or on fresh water (moving or stagnant).

The following description of response measures is based on Henriksen & Sørensen (2008) where nothing else is stated.

It is possible to absorb the oil from the ground by use of special absorption materials that have affinity for oil; this is of particular relevance for small oil spills. Snow, soil or peat can also be used for absorption. The oil contaminated materials have to be collected in tight containers and stored until proper disposal. For larger spills also skimmers and pumps can be used for the recovery of the oil and subsequent storage in large tanks. If the oil is located in the ground the way to hinder further spreading is to dig a deep trench (to below the groundwater level) perpendicular to the flow direction. From the trench the oil is removed by e.g. pumps/skimmers. If the soil is oil saturated a method could be to remove the polluted soil; this should be done with care and consideration for the further clean-up of the polluted area and the environment.

For oil contaminated soil, a trench can also be dug around the contaminated areas which then is saturated with water. The oil will gather on the surface of the water in the trench and can be removed from there by skimmers or absorption pads (R. Tatner pers. comm.).

It might be difficult to detect oil spills in snow as the oil can migrate (depending on the density of the snow) until it meets an impermeable layer (e.g. ice layer, bedrock). Oil within ice or snow cannot be seen from the air, thus other methods must be used (e.g. dogs, digging trenches/pits) to locate the oil (EPPR 2015). The polluted snow should be removed and stored/handled safely. This can be quite large amounts; however the snow's ability to contain the oil will be improved if the snow is compacted. If the oil polluted snow is removed before spring thaw, such spills would tend to give less environmental impacts compared to spills in snow free areas. It should be remembered that oil in snow can evaporate. Another way to handle the contained polluted snow is by burning. Oil in snow (up to 70 % snow by weight) has been burned with success (Buist 2000). There is a risk of injuring the root mat by this method (EPPR 2015). The snow itself, if compacted, can be handled and used as a barrier to confine the oil and the effectiveness of this will be further improved if water is sprayed on the snow to create an ice sheet (EPPR 1998).

On solid bedrock the oil should be contained (by embankments) to meet thicknesses that allows recovery with pumps/skimmers and reduce further spreading. High-pressure cleaning could be used, however with great care and consideration for responders and the environment.

No measures have been identified to handle oil in/on permafrost. However, it is difficult to dig into permafrost and this action should be avoided. Permafrost is usually not impermeable to oil and it may spread both horizontally and vertically thus the migration of oil in permafrost can vary significantly from place to place.

In an area like Nuussuaq/Disko with many rivers and few lakes, it will be essential to keep spilled oil away from the rivers, because the distance to the sea is relatively short and oil may quickly be transported to the marine environment. Response measures to recover oil from lakes and rivers (with and without ice) are available.

On fresh water, the oil will spread rapidly out in a thin film on the surface and weathering processes acting on such oil are similar to those for marine oil spills (NPR-A 2012), including evaporation, spreading, dispersion, emulsification and degradation. Booming can be effective in calm waters, but it can be difficult to handle oil in strong currents. If the flow is not too high (<1 m/s) containment booms can be deployed in a way that the downstream transport of the oil is limited (McCleneghan et al. 2002) and oil can be directed to a place with little or no currents for recovery. Lessons learned from responding to an oil spill in a river during winter are given in McCleneghan et al. (2002).

If the water is ice and/or snow covered, oil spilt on top of the ice/snow can be contained either by use of the snow to build berms as described above or by making a trench in the ice. Thereafter the oil is scraped or pumped/skimmed away. For oil spilt under ice a hole/trench can be constructed in the ice from where the oil can be recovered by e.g. direct pumping or skimming. Burning could also be considered in such situations (Buist et al. 2013). If the ice is cracked and not continuous, skimming is often not possible. Burning might be an alternative in some situations, but often little can be done.

Overall the following tactics for responding to oil spills in terrestrial environments in the Arctic include (from EPPR 2015, Owens 2002, Chaîneau 2003):

- Manual removal of oil and oiled material
- Mechanical removal (e.g. lifting, scraping, brushing or cutting)
- Recovery of fluid oil with skimmers, vacuums and pumps
- Use of sorbent materials (including snow)
- Flooding with water to float oil
- Flushing with water to mobilise oil
- Trenching to intercept oil
- Burning (also oiled vegetation)
- Cutting oiled vegetation
- Bioremediation

As for the other oil exploration/production related activities, care should be taken in relation to transport in connection with the response operations and vehicles with low ground pressure tires should be used to minimize the impact on the ground. Before a decision is made on which response methods to use, a Net Environmental Benefit Analysis (NEBA) should be conducted, to make sure that no additional impacts on the environment are made as a result of the response.

9.6 Other accidental events which may impact environment

Accidental spills may also include chemicals from the various processes related to oil exploration and exploitation.

Accidental and uncontrolled fires originating from an oil activity may also cause environmental impacts, primarily on vegetation. Especially in dry areas, such as the dwarf scrub heaths in the Disko/Nuussuaq area, fires can cover extensive areas.

Accidents of this kind shall be mitigated by strict HSE-regulation and by applying the BAT and BEP principles.

9.7 Cumulative impacts

An oil exploration activity or the development of an oil field will cause cumulative impacts in combination with other activities in the assessment area. The most obvious relevant other impacts here are hunting (primarily caribou) and mining exploration. Hunting especially for caribou takes place today (see Section 6.3), while there is no current mining activities. There are however, two active mineral exploration licences in the assessment area, and activities there are expected.

10 Missing knowledge

The preliminary SEIA of activities in Nuussuaq Peninsula (Boertmann et al. 2008) emphasize that there was a need for more comprehensive studies on the local Nuussuaq caribou population. This is indeed the situation today, as no caribou studies have been carried out in the meantime. Such studies should include habitat use, distribution patterns, calving areas, migrations and biology.

The preliminary SEIA moreover indicated some data gabs related to the Greenland white-fronted Goose. These were partly filled in by the background study survey in 2015 (Box 2), while the question of presence of potential spring staging areas is still un-answered.

Another question to address is whether or not there are Arctic char in the river of the valley Aaffarsuaq in central Nuussuaq.

Regarding vegetation, there will be a need for a more precise mapping of the occurrence of rare plants, in case larger infrastructures are planned to be constructed in the assessment area. Moreover, classification of the vegetation should be carried out based on satellite images and the data collected in 2015 (Box 2).

Even if these studies are carried out, environmental background studies are still required both on a regional strategic level and on a project specific level. Environmental data will be needed for the planning of oil spill contingency strategies and of oil spill counter measures. New studies are also needed to provide adequate data for future site-specific EIA-reports, to provide data to identify sensitive areas, to regulate activities and as a baseline for both monitoring industrial activities and 'before and after' studies in case of environmental impacts from large accidents. Furthermore, the dynamics of climate variability is a confounding factor that needs to be included in the baseline and monitoring. DCE/GINR recommends that such information is in place before any production of hydrocarbons is initiated.

In that context it is also important to remember that an important lesson learned after the oil spill disasters in Prince Willian Sound in 1989 and in the Gulf of Mexico in 2010 was that the level of pre-spill information on the environment was insufficient to assess the environmental impacts, to establish criteria for recovery and for sorting out natural variation (Lubchenco 2012, Wiens 2013). Although these were marine oil spills, this awareness also applies to the terrestrial environment of the assessment area.

10.1 Proposed studies to fill data gaps

10.1.1 Studies to be performed before large scale activities on Nuussuaq are initiated

Of the information needs mentioned above, the most immediate are the caribou studies, as the previous studies were carried out in 2002 (Cuyler 2004, 2005). For example could a representative number of caribou of both the native and the introduced animals be equipped with satellite transmitters, and their movements tracked at least for one year, but if possible for more. Another important task is to get an estimate of the numbers of caribou present in the area, and a survey – possibly aerial – should be carried out. These studies need at least two years to be completed.

10.1.2 Studies to be carried out before exploitation activities in the assessment area are planned

Less immediate, but still important will be a contaminant baseline study. A sample plan should be developed. Some of the samples can be collected on an ad hoc basis when other surveys are carried out. But a dedicated ship based survey should be performed along the coasts, perhaps supplemented by inland sampling from helicopter. Field work can be performed during one summer and analyses the following winter season.

Seabird breeding colonies on the shores of the assessment area and adjacent coasts should be surveyed from ship before extensive activities are initiated. This can be carried out during a single summer.

In the coastal environment there will be a need to survey moulting king eiders in the peak period for moulting (the 2015 survey took place before this peak).

Knowledge for studies of physical features such as permafrost, precipitation and snow cover will be essential to prevent accidents and unforeseen damages, which may have environmental implications (e.g. oil spills).

Fate of oil spilled in the terrestrial environment of the assessment area should be studied.

10.1.3 Studies to be carried out as part of specific EIAs

Information on rare plants and their habitats is not immediate, but should be collected before specific activities requiring placement of large structures are initiated.

In the same way, rare inland fauna should also be searched for before activities are initiated.

Marine coastal flora and fauna should be studied before large scale oil exploitation activities are initiated.

A baseline of contaminant loads shall be established where oil fields are planned to be established.

10.1.4 Monitoring

A three level monitoring program shall be in place before production is initiated. This to secure and to further develop the mitigating measures of disturbance of wildlife and allowed discharges: 1) onsite discharge monitoring (pipe concentrations), 2) focused chemical and biomarker environmental monitoring locally around the discharge sites and 3) regional monitoring of key ecosystem components.

BOX 5

VEGETATION STUDIES IN 2015

Caroline Ernberg Simonsen & Christian Bay

In August 2015, four selected localities were visited with the purpose of establishing a vegetation baseline for the assessment area (Figure 1). This baseline shall primarily be used for ground truthing of satellite vegetation images of the region, to identify vegetation types and to locate the most lush and most species rich areas in the region. The data are intended to be used for auto-classification of the vegetation and as background knowledge for regulation of future hydrocarbon and mineral activities.

Materials and Methods

The localities were selected prior to the fieldwork based on high resolution satellite imagery. These maps were also used for field surveys of vegetation in the four study areas, and they were created using Landsat-7 ETM+ (from 6 July 2010, 8 July 2011) and Landsat-8 OLI satellite (2 August 2014) images. From these a false colour composite image, showing vegetation in green, bare ground in red and snow/ice in bluish colours was prepared (Figure 2).

Figure 1. Location of the four study areas with the number of vascular species recorded in parentheses.

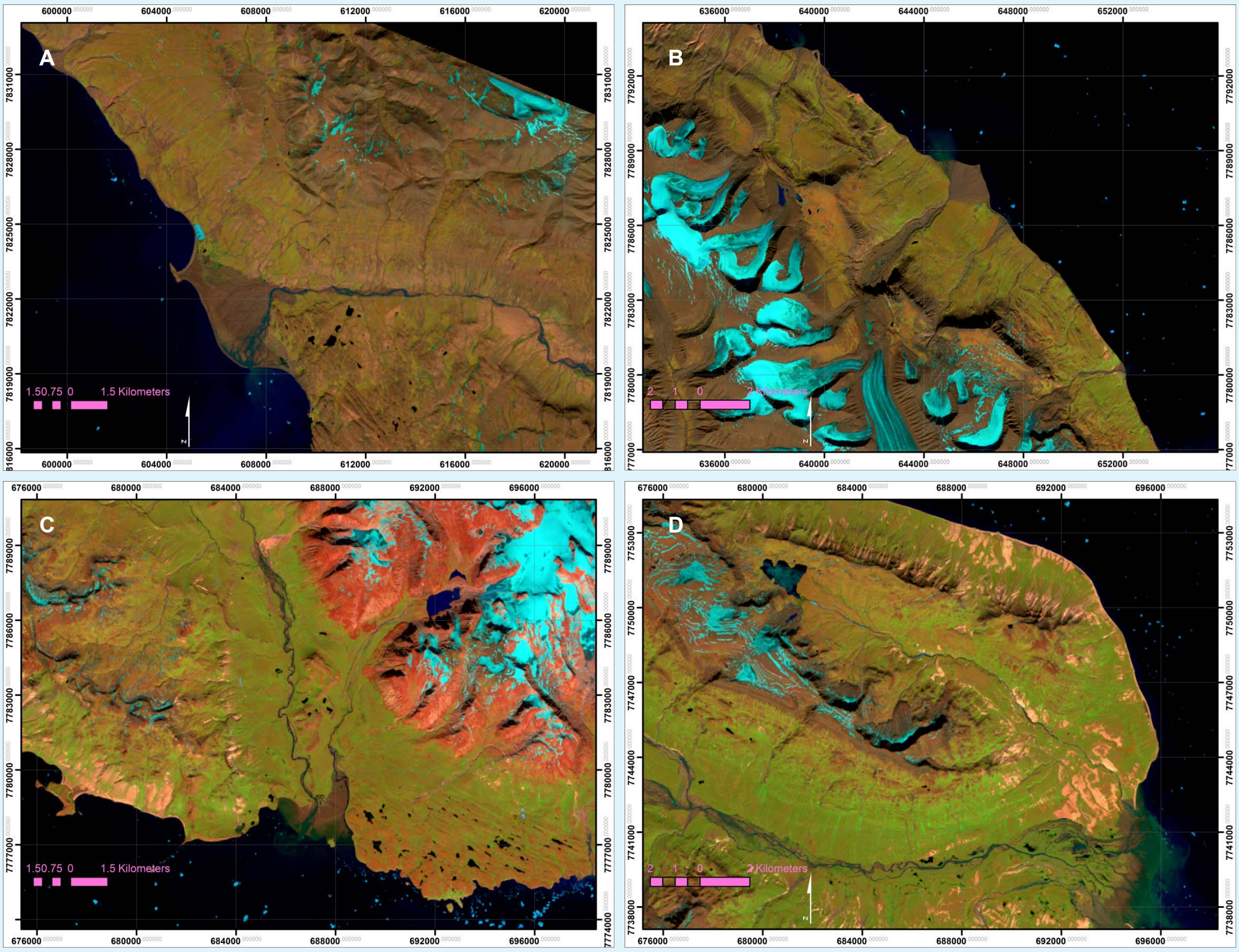


Figure 2. The four study areas on a false-colour high resolution satellite imagery with vegetation shown in green. A) Marrat, Aaffarsuaq Valley, Nuussuaq peninsula; B) Qullissat; C) Saqqaq Valley; D) Mudderbugten.

The localities covered areas with the highest species diversity and vegetation cover in order to optimize the ground truthing data. The following localities were selected:

1. Marrat and Aaffarsuaq Valley on Nuussuaq. The study area comprised the lowland up to 230 m above sea level (a.s.l.) from the coast and ca. 4 km into the Aaffarsuaq valley both south and north of the delta southeast of the tip of Nuussuaq.
2. Qullissat, Disko. The study area comprised the surroundings of the old abandoned mining settlement. The study area covers areas from the coast up to 450 m a.s.l. at a maximum distance from the sea of 3 km. The terrain is generally north exposed and intersected by smaller rivers.
3. Saqqaq Valley. The study area covers areas from the lowland and up to 450 m a.s.l. at a maximum distance from the sea of 2.5 km. The terrain is generally east exposed and consists of river bank silty soils, heath types, fens and fell-fields.
4. Mudderbugten. The study area comprises the areas from the coast and up to 5.5 km inland in western direction from 0-350 m a.s.l. The terrain is generally south exposed and consists of river bank silty soils, heath types, fens and fell-fields.

The coloured satellite images further provided base for the on-site decisions at each locality of the specific tracks to be followed to locate as many vegetation types as possible. In all vegetation types, plots were placed and analysed with a standard procedure:

Within a homogenous vegetation type of at least 1000 m^2, plot were placed and

- a waypoint with the GPS was marked,
- landscape picture were taken showing the distribution of the vegetation types,
- physical parameters (extent of vegetation type (m × m), elevation, aspect, slope (degrees) and wetness were recorded,
- wetness followed the index : 1 = desiccated, 2 = dry, 3 = moist, 4 = wet, 5 = standing water
- within a 2 m radius circle the following vegetation characteristics were noted: vegetation type, vascular plant species cover (%), the three most dominating species, moss cover (%), lichen cover (%), total cover (%), all vascular plant species within the circle were identified and recorded.
- signs of animal use of the area (droppings, tracks, nests, etc.) were noted.

At each locality all vascular plant species were recorded and the frequency was noted according to the index: 5 = very common, 4 = common, 3 = scattered occurrence, 2 = rare (3-5 finds), 1 = very rare (1-2 finds).

Taxonomy followed Böcher et al. (1978). However, the low arctic *Salix glauca* and the high arctic *Salix arctica* have overlapping distribution in the Disko-Nuussuaq area, which makes the identification of the species difficult because of hybridization. Consequently, the taxon is given as *Salix glauca/S. arctica* if identification to either of the species was not possible.

Results

Totally, 318 plots were analysed and 186 vascular species were recorded and 17 rare species were registered in the areas investigated (Table 1). The number of species recorded at each locality was very similar (124, 129, 130), except from at Qullissat (85) (Table 1, Figure 2). This may be due to 1) the north exposure of the slope compared to the other localities with primarily east and west exposed slopes and 2) lower effort as only 1½ days were used for the vegetation survey compared to about 3 days at the other localities and also because fewer researchers were doing the work.

Table 1. Activities and results from the four study localities.

Site	No. of plots	No. of species	No. of rare species
Loc. 1	63	124	2
Loc. 2	35	85	2
Loc. 3	126	129	4
Loc. 4	94	130	9
Total	318	186	17

Finds of particular interest are listed in Table 2, with species, locality and comments on distribution.

Table 2. Notable records of rare and endemic vascular plants from the four study sites in the assessment area August 2015, based on Fredskild (1996).

Taxon	Locality	Comment
Alchemilla glomerulans	4	Rare near its northern distribution limit
Angelica archangelica ssp. norvegica	4	Rare near its northern distribution limit
Arctostaphylos alpina	3	Rare near its northern distribution limit
Calamagrostis langsdorffii	4	Rare near its northern distribution limit
Corallorhiza trifida	4	At the northern distribution limit
Draba aurea	2	Rare to the north
Erigeron borealis	2	Rare near its northern distribution limit
Luzula groenlandica	3	Rare near its northern distribution limit
Parnassia kotzebuei	1	Very rare. Only known from Nuussuaq and South Greenland
Phleum commutatum	4	At the northern distribution limit
Platanthera hyperborea	4	At the northern distribution limit
Potentilla ranunculus	4	Endemic species to Greenland
Primula stricta	4	Third find on Nuussuaq
Puccinellia rosenkrantzii	3	Southernmost find of this endemic species
Pyrola minor	4	Rare near its northern distribution limit
Sagina saginoides	1	New northern distribution limit
Utricularia intermedia	3	New northern distribution limit

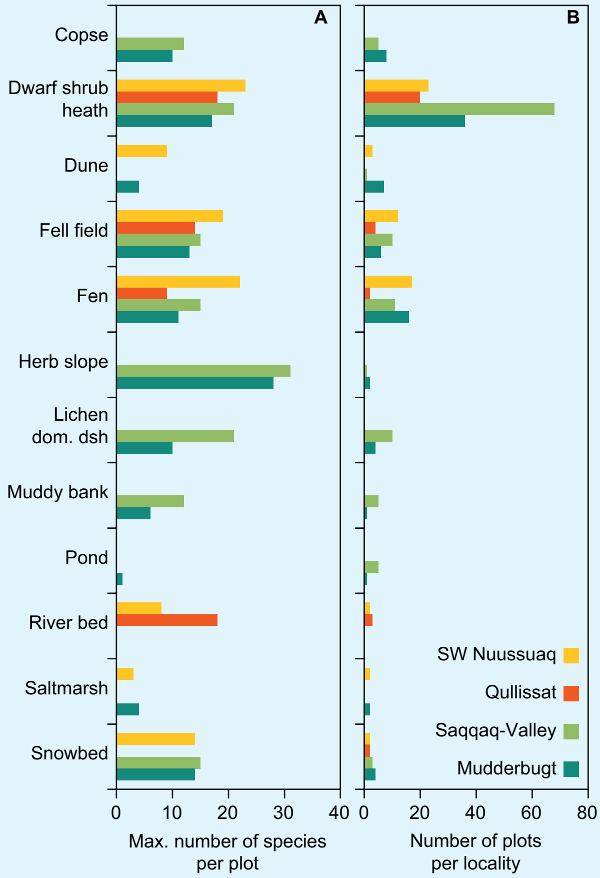


Figure 3. Distribution of max number of species compared to number of plots in terms of vegetation type per locality. A) Number of plots and B) maximum number of species per plot in the vegetation type. dsh = dwarf shrub heath.

Figure 3. shows A) the number of plots and B) max number of species in a plot, in relation to vegetation type and locality. The most species rich vegetation types are, apart from the lush herb slopes, also the dominant vegetation types such as dwarf shrub heaths, fens and fell-fields riches (Figure 3B, Figure 4).

Please consult the field report (Wegeberg et al. 2016) for full floristic descriptions of each of the localities investigated as a full list of species recorded.

At all plots investigated the vegetation type was recorded and plotted with different colours (Figure 4) on maps where height above sea level is indicated by isoclines. The plots show a general dominance of dwarf shrub heath, fens and fell-field vegetation reflected in the number of plots per vegetation type (Figure 3A). The dominant vegetation types had characteristic floristic elements such as:

Dwarf shrub heath: *Salix arctica/glauca*, *Betula nana*, *Vaccinium uliginosum* ssp. *microphyllum*, *Empetrum nigrum* ssp. *hermaphroditum*, *Cassiope tetragona*

Fen: *Carex bigelowii*, *Eriophorum angustifolium* ssp. *subarcticum*, *Equisetum arvense*

Fell-field: Dryas integrifolia, *Vaccinium uliginosum* ssp. *microphyllum*, *Saxifraga tricuspidata*

The maps show where rare or endemic species of particular environmental concerns are located. These species are:

- *Corallorhiza trifida*; recorded in the river bank areas in Mudderbugten (Figure 4.D)
- *Parnassia kotzebuei*: recorded in vegetation along a stream at on the north side of the Aaffarsuaq Valley and in the river bank area of the Saqqaq Valley (Figure 4A, C)
- *Platanthera hyperborea*; recorded in the river bank areas in Mudderbugten (Figure 4D)
- *Primula stricta*: recorded in the river bank area of the Saqqaq Valley (Figure 4C)

The coverage of the vegetation was recorded at all plots (Figure 5) showing that most plots had a very high degree of vegetation cover of (60) 80-100%. Even though the plots within an area were randomly selected by throwing a marker centering the plot circle, some tendency towards selecting plot areas with more pronounced vegetation may somewhat bias this picture.

In addition, the floristic biodiversity for all plots are shown in Figure 6, showing that the south-ward exposed slopes of the Aaffarsuaq and Saqqaq valleys were the most species rich.

Discussion

From the calculation of NDVI and vegetation studies of primarily the Aaffarsuaq Valley conducted in 2003, Tamstorf (2004) found that there were too few field observations to carry out a proper vegetation mapping, but he gave a rough classification of the vegetation types (Table 3).

The present vegetation study supports the findings of Tamstorf (2004). According to Figures 3B and 4A, the most abundant vegetation types are dwarf shrub heath and fen.

In addition, from comparing the NDVI for the western part of Aaffarsuaq Valley in Tamstorf (2004) and the high resolution satellite imagery (Figure 1) it is shown that the most dense vegetation is found in the area investigated by the present study. From the plots, it is verified that 63% of the plots (36 out of 57) have a vascular plant vegetation cover of 80-100% (Figure 5A).

Table 3. Classification system from NDVI, vegetation characterization of the NDVI classes and % cover of vegetation types. From Tamstorf (2004).

Classification	Characterization	% of vegetated land
Wet –High greenness	grassland and fens / dwarf shrub heath and fens	48.3
Wet – Low greenness	snow bed areas and areas along streams	14.8
Moist – Medium Greenness	dwarf shrub heath of varying vascular plant species	26.0
Dry – Medium greenness	dwarf shrub heath and lichens	4.7
Dry – Low greenness	fell-fields	6.3

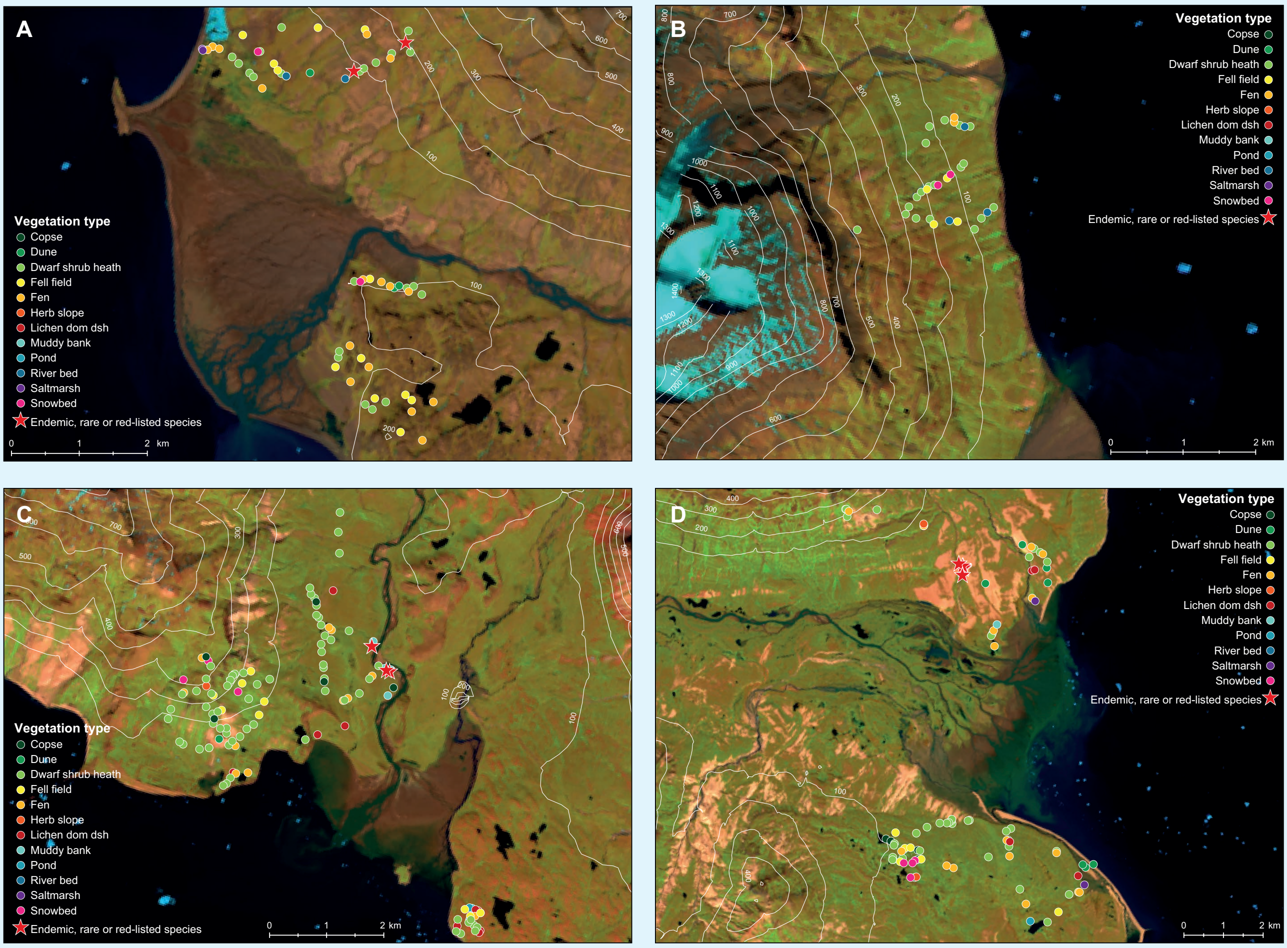


Figure 4. Vegetation types of all plots investigated per locality. The different colours indicate the vegetation types recorded at each plot. Finds of particular interest are marked with a red star, Isoclines show height above sea level. A) Marrat, Aaffarsuaq Valley, Nuussuaq peninsula. ★Parnassia kotzebuei; B) Qullissat; C) Saqqaq Valley. ★Parnassia kotzebuei, Primula stricta; D) Mudderbugten. ★Corallorhiza trifida, Platanthera hyperborea.

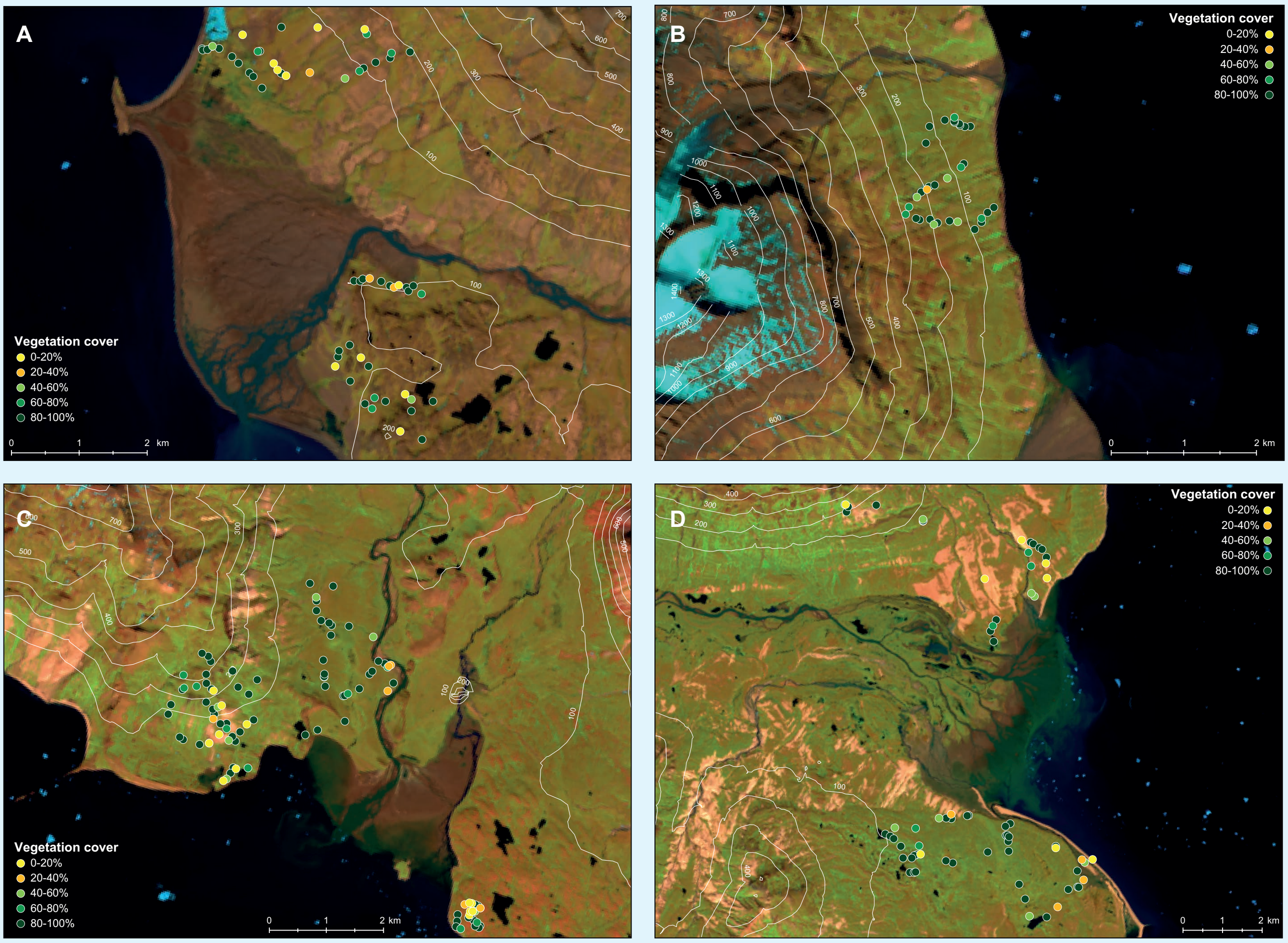


Figure 5. Percentage of vegetation cover recorded at each plot investigated per locality. The different colours indicate the percentage of vegetation cover. A) Marrat, Aaffarsuaq Valley, Nuussuaq peninsula; B) Qullissat; C) Saqqaq Valley; D) Mudderbugten.

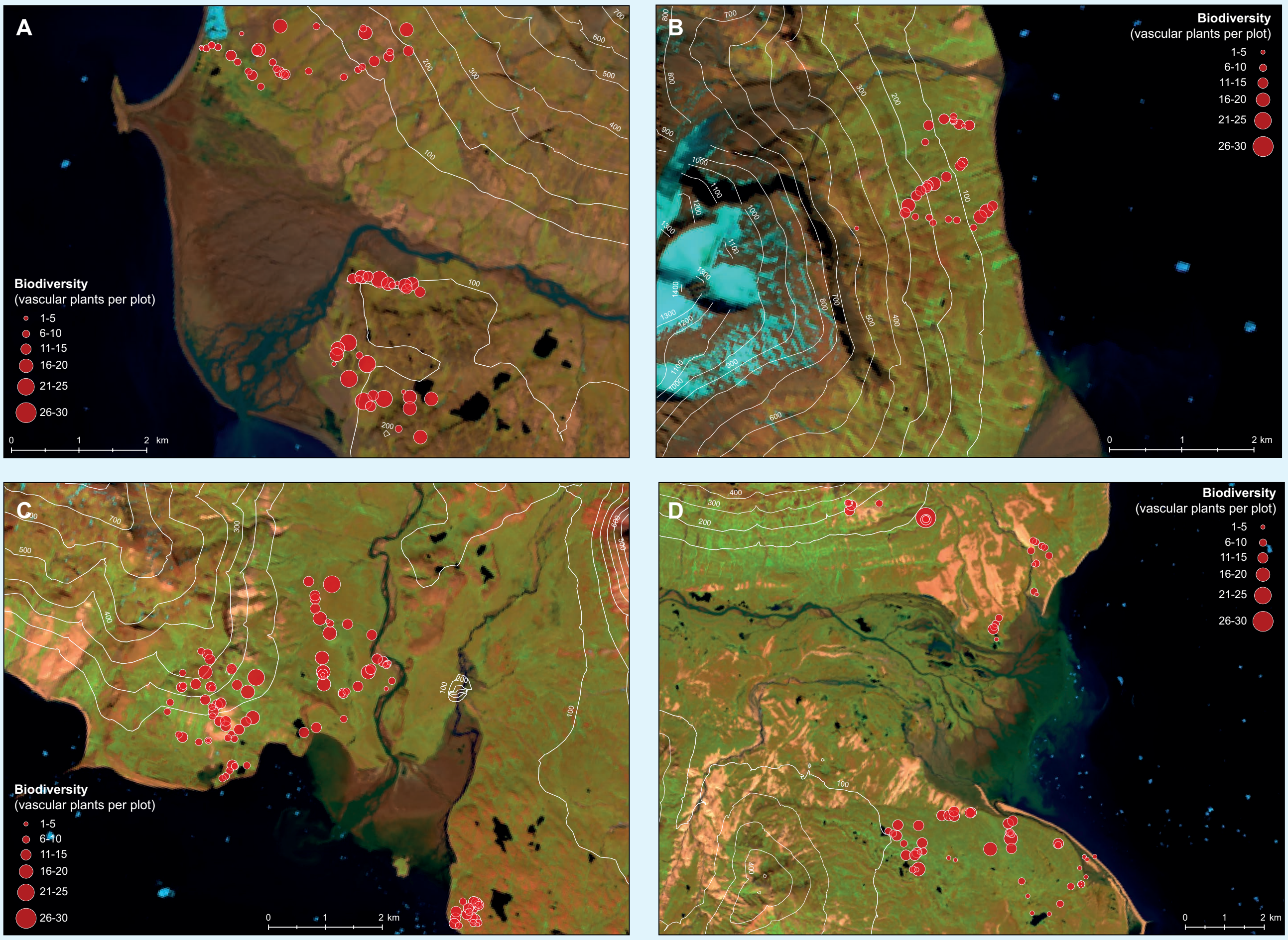


Figure 6. Floristic biodiversity at the plots investigated. The size of the red circles indicates the number of species recorded at each plot. A) Marrat, Aaffarsuaq Valley, Nuussuaq peninsula; B) Qullissat; C) Saqqaq Valley; D) Mudderbugten.

Fredskild (1996) has carried out a phytogeographical study of West Greenland between 62° 20´ N. and 74° N and recorded 379 vascular plant species. In present study a total of 186 species were recorded at the four localities (Table 1), which is 49% of the species recorded by Fredskild (1996). The total number of species found at a single site, as summarized in Fredskild (1996), varies between 127 and 141 on Nuussuaq and between 128 and 212 on Disko Island, whereas in present study the total species number in the most species rich location of the peninsula, Saqqaq Valley, and on Disko, Mudderbugten, reached 129 and 130 species, respectively. It can therefore be concluded that the studies in 2015 covered representative areas of the assessment area.

Furthermore, three species (*Potentilla ranunculus, Puccinellia groenlandica, Puccinellia rosenkranzii*) out of seven species considered as endemic and rare to the study area by Fredskild (1996), were recorded at the three most species rich locations (Table 2). Of rare species, the most conspicuous were the records of two orchids, *Corallorhiza trifida* and *Platanthera hyperborea*, both very rare with very few finds in the assessment area (Table 2). *Corallorhiza trifida*, however, was very numerous at the one plot in the Mudderbugten locality. Also the records of *Parnassia kotzebuei,* which is very rare in Greenland only known from Nuussuaq and South Greenland, and *Primula stricta*, now still with only three finds on Nuussuaq (Table 2), added to the lush impression of the vegetation in the assessment area. For more details, please consult the field report (Wegeberg et al. 2016) for vegetation descriptions.

Hence, regarding regulation of oil exploration activities in the area, these species and their habitats, are of high environmental concern.

11 References

Aastrup, P., Rigét, F., Dietz, R. & Asmund, G. 2000. Lead, zinc, cadmium, mercury, selenium and copper in Greenland caribou and reindeer (Rangifer tarandus). – Sci. Total Environ. 245: 149-159.

AMAP 2004. AMAP Assessment 2002: Persistent Organic Pollutants in the Arctic. – Arctic Monitoring and Assessment programme (AMAP), Oslo, Norway.

AMAP 2005. AMAP Assessment 2002: Heavy Metals in the Arctic. – Arctic Monitoring and Assessment programme (AMAP), Oslo, Norway.

AMAP 2010. Assessment 2007: Oil and Gas Activities in the Arctic – Effects and Potential Effects. Volume I. – Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP 2011. Snow, water, ice and permafrost in the Arctic (SWIPA): Climate change and the cryosphere. – Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP 2014. Trends in Stockholm Convention Persistent Organic Pollutants (pPOP2) in Arctic air, Human media and Biota. – AMAP Technical Report No. 7, Arctic Monitoring and Assessment programme (AMAP), Oslo, Norway.

Asmund, G. & Nielsen, S.P. 2000. Mercury in dated Greenland marine sediments. – Sci Total Environ. 245:61-72.

Ballem, J.B. 2008. The Oil and Gas Lease in Canada. – University of Toronto Press.

Barclay, I., Pellenbarg, J., Tettero, F., Pfeiffer, J., Slater, H., Staal, T., Stiles, D., Tilling, G. & Whitney, C. 2001. The beginning of the end: a review of abandonment and decommissioning practices. – Oilfield Review 13: 28-41.

Bay, C. 1997.Effects of experimental oil spills of crude and diesel oil on arctic vegetation. A long-term study on high arctic terrestrial plant communities in Jameson Land, central East Greenland. – NERI Technical Report no. 205, 44 pp. Link

Bellamy, D., Radforth, J., & Radforth, N.W. 1971. Terrain Traffic and Tundra. – Nature 231: 429-432.

Biggar, K.W., Haidar, S., Nahir, M. & Jarrett, P.M. 1998. Site investigations of fuel spill migrations into permafrost. – Journal of cold regions engineering 12: 84-104.

BLM 2012. National Petroleum Reserve-Alaska: draft integrated activity plan/environmental impact statement. – Anchorage, Alaska.

BMP 2011. BMP Guidelines - for preparing an Environmental Impact Assessment (EIA) report for activities related to hydrocarbon exploration and exploitation off shore Greenland. – Greenland Bureau of Minerals and Petroleum. Link

Boertmann, D. 1998. Inspection of the GRO#3 well site, Nuussuaq peninsula, West Greenland. – NERI research Note No. 89

Boertmann, D. 2007. Besigtigelsesrapport: Kørespor anlagt af Green Mining Ltd (tidl. Vismand Exploration Inc.) i Kuussuaq dalen på Nuussuaq-halvøen. – Notat til Råstofdirektoratet.

Boertmann, D. 2008. Grønlands Rødliste 2007. – Grønlands Hjemmestyre og Danmarks Miljøundersøgelser, 152 p.

Boertmann, D. & Aastrup, P. 2002. Impact on mammals. Pp. 113-117 in Mosbech, A. (ed.): Potential Environmental impacts of oil spills in Greenland. An assessment of information status and research needs. – NERI Technical Report No. 415. National Environmental Research Institute, Denmark. Link

Boertmann, D. & Egevang, C. 2002. Canada geese Branta canadensis in West Greenland: In conflict with Greenland white-fronted geese *Anser albifrons flavrostris*? – Ardea 90: 335-336.

Boertmann, D. & Petersen, I.K. 2016. Aerial survey of geese, seaducks and other wildlife in the Disko Bay area, West Greenland, July 2015. – Technical Report from DCE – Danish Centre for Environment and Energy No. 78. Link

Boertmann, D., Mosbech, A. & Frimer, O. 1997. Autumn migration of light-bellied Brent geese *Branta bernicla hrota* through North-west Greenland. – Wildfowl 48: 98-107.

Boertmann, D., G. Asmund, C.M. Glahder & Tamstorf, M.P. 2008, A preliminary strategic environmental impact assessment of mineral and hydrocarbon activities on the Nuussuaq peninsula, West Greenland. – NERI Technical Report 652. Link

Boertmann, D., Mosbech, A., Bjerrum, M., Labansen, A.L. & Merkel, F. 2010. The Greenland seabird colony register. – Poster from 1st Seabird World Conference, Victoria 7-11 Sept. 2010 (available from Research Gate).

Boertmann, B., Mosbech, A., Schiedek, D. & Dünweber, M. (eds) 2013. Disko West. A strategic environmental impact assessment of hydrocarbon activities. – Scientific Report from DCE – Danish Centre for Environment and Energy no. 71. Link

Bojesen-Koefoed, J.A., Christiansen, F.G., Nytoft, H.P. & Pedersen, A.K. 1999. Oil seepage onshore West Greenland: evidence of multiple source rocks and oil mixing. Pp 305-314 in Fleet, A. J. & Boldy, S.A.R. (eds). Petroleum Geology of Northwest Europe: Proceedings of the 5th Conference. – The Geological Society, London.

Braund, S. & Associates 2009. Impacts and Benefits of Oil and Gas Development to Barrow, Nuiqsut, Wainwright, and Atqasuk Harvesters. – Prepared for the North Slope Borough Department of Wildlife Management. Link

Brides, F. 2013. Results from the Canadian light-bellied brent goose census. – GooseNews 12: 21

Brooks, S.B., Crawford, T.L. & Oechel, W.C. 1997. Measurements of Carbon Dioxide emissions plumes from Prudhoe Bay, Alaska oil fields. – Journal of Atmospheric Chemistry 27: 197-207.

Brown, J., Ferrians, O., Heginbottom, J.A. & Melnikov, E. 2002. Circum-Arctic Map of Permafrost and Ground-Ice Conditions, Version 2. Permafrost extent (permaice). – Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. [Date Accessed, 2013-11-19].

Buist, I. 2000. *In situ* burning of oil spills in ice and snow. – Alaska Clean Seas, International Oil and Ice workshop 2000, Anchorage and Prudehoe Bay, p. 1-38.

Buist, I., Potter, S.G., Trudel, B.K., Shelnutt, S.R., Walker, A.H., Scholz, D.K., Brandvik, P.J., Fritt-Rasmussen, J., Allen, A.A. & Smith, P. 2013. *In Situ* Burning in Ice-Affected Waters: State of Knowledge Report. – Report in preparation for the International Association of Oil & Gas Producers, London, UK.

Böcher, T.W. 1963. Phytogeography of Middle West Greenland. – Meddr Grønland 148 (3): 289 pp.

Chaîneau, C.H., Yepremian, C., Vidakie, J.F., Ducreux, J. & Ballerini, D. 2003. Bioremediation of a crude oil.pollutede soil: Biodegredation, leaching and toxicity assessements. – Water, Air, and Soil Pollution 144: 419-440.

Christensen, J.H., Olesen, M., Boberg, F., Stendel, M. & Koldtoft, I. 2016. Fremtidige klimaforandringer i Grønland: Qaasuitsup Kommune. – Videnskabelig Rapport fra DMI 15-04(5/6). Link

Christiansen, H.H. 1995. Observations of open system pingos in a marsh environment, Mellemfjord, Disko, Central West Greenland. – Geografisk Tidsskrift – Danish Journal of Geography 95: 42-48.

Christiansen, F.G. 2014. Greenland petroleum exploration: history, breakthroughs in understanding and future challenges. Pp. 647-661 in Spencer, A.M., Embry, A.F., Gautier, D.L., Stoupakova, A.V. & Sørensen, K. (eds). Arctic Petroleum Geology. – Geological Society, London Memoirs, 35.

Christiansen, H.H. & Humlum, O. 2000. Permafrost. Pp. 32-35 in Jakobsen, B.H., Böcher, J., Nielsen, N., Guttesen, R., Humlum, O. and Jensen, E. (eds). Topografisk Atlas, Grønland. – Det Kongelige Geografiske Selskab og Kort and Matrikelstyrelsen.

Christiansen, F.G., Boesen, A., Dalhoff, F., Pedersen, A.K., Pedersen, G.K., Riisager, P. & Zinck-Jørgensen, K. 1997. Petroleum geological activities onshore West Greenland in 1996, and drilling of a deep exploration well. – Geology of Greenland Survey Bulletin 176: 17-23.

Christiansen, F.G., Boesen, A., Bojesen-Koefoed, J.A., Chalmers, J.A., Dalhoff, F., Dam, G., Hjortkær, B.F., Kristensen, L., Larsen L.M., Marcussen, Mathiesen, A.C., Nøhr-Hansen, H., Pedersen, A.K., Pulvertaft, T.C.R., Skaarup, N & Sønderholm, M. 1999: Petroleum geological activities in West Greenland in 1998. – Geology of Greenland Survey Bulletin 183, 46-56.

Chuvelin, E.M. & Miklyaeva, E.S. 2003. An experimental investigation of the influence of salinity and cryogenic structures on the dispersion of oil and oil products in frozen soils. – Cold Region Science and Technology 37: 89-95.

Clark, C.E. & Veil, J.A. 2009 Produced water volumes and management practices in the United States. – Environmental Science Division, Argonne National Laboratory, 59 pp.

Clausen, D., Johansen, K.L., Mosbech, A., Boertmann, D. & Wegeberg, S. 2012. Environmental Oil Spill Sensitivity Atlas for the West Greenland (68°-72° N) Coastal Zone, 2nd revised edition. – Scientific Report from DCE – Danish Centre for Environment and Energy, No. 44. Link

Cleemann, M., Rigét, F., Paulsen, G.B., Klungsøyr, J. & Dietz, R. 2000a. Organochlorines in Greenland marine fish, mussels and sediments. – Sci. Total Environ. 245: 87-102.

Cleemann, M., Rigét, F., Paulsen, G.B. & Dietz, R. 2000b. Organochlorines in Greenland glaucous gulls (*Larus hyperboreus)* and Icelandic gulls (*Larus glaucoides*). – Sci. Total Environ. 245: 117-130.

Collins, C.M., Racine, C.H. & Walsh, M.E. 1994. The Physical, Chemical, and Biological Effects of Crude Oil Spills after 15 Years on a Black Spruce Forest, Interior Alaska. – Arctic 47: 164-175.

Cordsen, A., Galbraith, M. & Pierce, J. 2000. Planning land 3-D seismic surveys. – Geophysical developments series; no. 9, Society of Exploration Geophysicists.

Cuyler, C. 2004. Caribou (*Rangifer tarandus*) in Nuussuaq. Pp. 49-52 in Boertmann, D. (ed.) Background studies in Nuussuaq and Disko, West Greenland. – National Environmental Research Institute, Technical Report No. 482.

Cuyler, C., 2005, Caribou recovery and coexistence with introduced feral reindeer on the Nuussuaq Peninsula (70-71° N), West Greenland. – Rangifer, v. 25, p. 137-142.

Dam, G., Pedersen, G.K., Sønderholm, M., Midtgaard, H.H., Larsen, L.M., Nøhr-Hansen, H. & Pedersen, A.K. 2009. Lithostratigraphy of the Cretaceous–Paleocene Nuussuaq Group, Nuussuaq Basin, West Greenland. – Geological Survey of Denmark and Greenland Bulletin, v. 19, p. 171.

Dietz, R., Rigét, F. & Johansen, P. 1996. Lead, cadmium, mercury and selenium in Greenland marine animals. – Sci Total Environ. 186: 67-93.

DNR 2015. Off-Road travel on the North Slope on State Land (Fact Sheet). – Alaska department of Natural Resources. Link

Egevang, C. & Boertmann, D. 2001. The Ramsar sites of Disko, West Greenland. A Survey in July 2001. – National Environmental Research Institute, Denmark. Technical Report no. 368.

Emers, M. & Jorgenson, J.C. 1997. Effects of winter seismic exploration on tundra vegetation and the soil thermal regime in the Arctic National Wildlife Refuge, Alaska. Pp. 443-454 in Crawford, R.M.M. (ed.) Disturbance and recovery in Arctic lands. – Kluwer Academic Publishers, Dordrechts, the Netherlands.

EPPR 2015. Guide to Oil Spill Response in Snow and Ice Conditions. – Emergency Prevention, Preparedness and Response (EPPR), Arctic Council.

EPPR 1998. Field Guide for Oil Spill Response in Arctic Waters 1998. – Emergency Prevention, Preparedness and Response, Environment Canada, Yellowknife, NT Canada.

grønArctic 1997. Well History report 1996 Exploration Program, Nuussuaq Peninsula, Nuussuaq Kugssuaq GRO#3. – grønArctic Inc.

Fingas, M. 2012. The basics of oil spill cleanup. Third Edition. – Lewis Publishers.

Fox, A.D. & Glahder, C.M. 2010. Post-moult distribution and abundance of white-fronted geese and Canada geese in West Greenland in 2007. – Polar Research 29: 413-420.

Fox, D.T., Stroud, D., Walsh, A., Wilson, J., Norriss, D. & Francis, I. 2006. The rise and fall of the Greenland White-fronted Goose: A case study in international conservation. – British Birds 99: 242-261.

Fox, A.D., Sinnett, D., Baroch, J., Stroud, D.A., Kampp, K., Egevang, C. & Boertmann, D. 2012. The status of Canada Goose *Branta canadensis* subspecies in Greenland. – Dansk ornitologisk Forenings Tidsskrift 106: 87-92.

Fox, T., Francis, I, Norriss, D. & Walsh, A. 2014. Report of the 2013/2014 international census of Greenland white-fronted geese. – Greenland white-fronted goose study & National Parks and Wildlife Service, Wildfowl and Wetlands Trust, 27 pp. Link

Fox, T., Francis, I, Norriss, D. & Walsh, A. 2015. Report of the 2014/2015 international census of Greenland white-fronted geese. – Greenland white-fronted goose study & National Parks and Wildlife Service, Wildfowl and Wetlands Trust, 22 pp. Link

Fredskild, B. 1996. A phytogeographical study of the vascular plants of West Greenland (62° 20´N). – Meddr Grønland, Biosci. 45. 157 pp.

Frimer, O. 1993. Occurrence and distribution of King Eiders *Somateria spectabilis* and Common Eiders *S. mollissima*, West Greenland. – Polar Research 12: 111-116.

Frimer, O. & Nielsen, S.M. 1990. Bird observations in Aqajarua-Sullorsuaq, Disko, West Greenland, 1989. – Dansk Orn. Foren. Tidsskr. 84: 151-158.

Fritt-Rasmussen, J. 2006. Olie- og tungmetalforurening i Arktis. En undersøgelse fra Tasiusaq en bygd i Nordvestgrønland. – Center for Arktisk Teknologi.

Giessing, A., Andersen, O. & Banta, G. 2002. Impact on invertebrates. Pp 65-77 in Mosbech, A. (ed.): Potential Environmental impacts of oil spills in Greenland. An assessment of informations status and research needs. – NERI Technical Report No. 415, National Environmental Research Institute, Denmark. Link

Glahder, C.M. 1999. Moulting Greenland White-fronted Geese: Distribution and concentrations in West Greenland: Pp 118-142 in Glahder, C.M. Sensitive areas and periods of the Greenland White-fronted Goose in West Greenland. – Ph.D. thesis. National Environmental Research Institute, Denmark, 142 pp.

Glahder, C.M. & Walsh, A.W. 2007. Experimental disturbance of moulting Greenland White fronted Geese *Anser albifrons flavirostris*. In Boere, G.C., Galbraith, C.A. & Stroud, D.A. (eds). Waterbirds around the world. – Edinburgh Stationary Office.

Glahder, C.M., Fox, A.D. & Walsh, A.J. 2002. Spring staging areas of White-fronted Geese in West Greenland; results from aerial survey and satellite telemetry. – Wildfowl 53: 35-52.

Gustavson, K., Wegeberg, S., Boertmann, D, Mosbech, A. & Fritt-Rasmussen, J. 2013. Forslag til strategi for miljøvurdering og bortskaffelse af bore-mudder og borekemikalier i forbindelse med olie- og gasaktiviteter i grønlandske farvande. – Memo from DCE. Link

Hansen, B.U., Elberling, B., Humlum, O. & Nielsen, N. 2006, Meteorological trends (1991–2004) at Arctic Station, Central West Greenland (69° 15’N) in a 130 years perspective. – Geografisk Tidsskrift/Danish Journal of Geography 106: 45-55.

Hansen, J. Asmund, G., Aastrup, P., Mosbech, A., Bay, C., Tamstorf, M. & Boertmann, D. 2012. Jameson Land. A strategic environmental impact assessment of hydrocarbon and mining activities. – Scientific Report from DCE – Danish Centre for Environment and Energy No. 41. Link

Heath, M.F. & Evans, M.I. 2000. Important Bird Areas in Europe: Priority sites for conservation 1, Northern Europe. – Bird Life International Conservation Series No. 8.

Heegaard, M., Heldbjerg, H. & Jepsen, B.I. 1994. Homoterme kilder og deres virkning på fugletætheden. In Arktisk Biologisk Feltkursus, Qeqertarsuaq/Godhavn 1994. – University of Copenhagen.

Henderson, G., Schiener, E., Risum, J. Croxton, C. & Andersen, B. 1981. The west Greenland basin. Pp. 399-428 in J. W. Kerr, A. J. Fergusson, and L. C. Machan (eds), Geology of the North Atlantic Borderlands. – Can. Soc. Pet. Geol. Mem.

Henriksen, N. 2008. Geological History of Greenland. – Geological survey of Denmark and Greenland.

Henriksen, P. & Sørensen, H-S. 2008. Manual til håndtering af oliespild, Forebyggelse af oliespild, håndtering af tidligere forureninger. – Niras Greenland A/S for Grønlands Hjemmestyre, Direktoratet for Miljø og Natur.

Hollesen, J., Buchwal, A., Rachlewicz, G., Hansen, B.U., Hansen, M.O., Stecher, O. & Elberling, B. 2015. Winter warming as an important co-driver for *Betula nana* growth in western Greenland during the past century. – Global change biology, v. 21, p. 2410-2423.

Holt, S. 1987. The Effects of Crude and Diesel Oil Spills on Plant Communities at Mesters Vig, Northeast Greenland. – Arctic and Alpine Research 19: 490-497.

Humlum, O. 1996. Origin of rock glaciers: observations from Mellemfjord, Disko Island, central West Greenland. – Permafrost and Periglacial Processes 7: 361-380.

IUCN 2016. IUCN Red List of Threatened Species. Version 2016-2. Link

Jaffe, D.A., Honrath, R.E., Furness, D., Conway, T.J., Dlugokencky, E. & Steele, L.P. A determination of the CH_4, NOx and CO_2 emissions from the Prudhoe Bay, Alaska oil development. – Journal of Atmospheric Chemistry 20: 213-227.

Joensen, A.H. & Preuss, N.O. 1972. Report on the ornithological expedition to Northwest Greenland 1965. – Meddr Grønland 191, 5: 58 pp.

Johansen, P., Pedersen, H.S., Asmund, G. & Rigét, F. 2006a. Lead shot from hunting as a source of lead in human blood. – Environmental Pollution, 142, 93-97.

Johansen, P., Mulvad, G., Pedersen, H.S., Hansen, J.C. & Rigét, F. 2006b. Accumulation of cadmium in livers and kidneys in Greenlanders. – Sci. Total Environ. 372. 58-63.

Khan, M.I. & Islam, M.R. 2008. The Petroleum Engineering Handbook: Sustainable Operations. Gulf Publishing Company. – Elsevier Inc.

Kondolf, G.M. 1994. Geomorphic and environmental effects of instream gravel mining. – Landscape and Urban Planning 28: 225-243.

Kristensen, R.M. 2006. De varme kilder, pp. 310-315 in Bruun, L., Kristensen, R.M., Nielsen, N., Pedersen, G.K. & Pedersen, P.M. Arktisk Station 1906-2006. – Rhodos, København.

Kristiansen, J.N. & Jarrett, N.S. 2002. Inter-specific competition between White-fronted and Canada Geese moulting in West Greenland; mechanisms and consequenses. – Ardea 90: 1-13.

Krüger, T., Rigét, F., Skov, H., Jesper Christensen, H. & Bonefeld-Jørgensen, E.C. 2012. Comparison of trends of persistent organic pollutants in Inuit, ringed seals and atmosphere in Greenland (Sam-trend). – Project report for the Danish Environmental Protection Agency. DANCEA.

Letcher, R.J., Bustnes, J.O., Dietz, R., Jenssen, B.M., Jørgensen, E.H., Sonne, C., Verreault, J., Vijayan, M.M. & Gabrielsen, G.W. 2010. Exposure and effects assessment of persistent organohalogen contaminants in arctic wildlife and fish. – Sci. Total Environ. 408. 2995-3043.

Levermann, N. & Raundrup, K. 2004. Do the Greenland white-fronted geese stand a chance against the invasive Canadians? – Unpublished field report.

LGL 2005. Husky delineation/exploration drilling program for Jeanne d'Arc Basin area environmental assessment. LGL Rep. SA845. – Report by LGL Limited, Canning and Pitt Associates, Inc., and PAL Environmental Services, St. John's, NL for Husky Oil Operations Limited, St. John's, NL. 340 p. + appendix.

Long, M., Bossi, R. & Bonefeld-Jørgensen, E.C. 2012. Level and temporal trend of perfluoroalkyl acids in Greenlandic Inuit. – Int. J. Circumpolar Health 71:17998-DOI:10.3402/ijch.v71i10.17998.

Long, M., Knudsen, A-K. S., Pedersen, H.S. & Bonefeld-Jørgensen, E.C. 2015. Food intake and serum persistent organic pollutants in the Greenlandic pregnant women: The ACCEPT sub-study. – Sci. Total Environ. 529. 198-212.

Lubchenco, J., McNutt, M.K., Dreyfus, G., Murawski, S.A., Kennedy, D.M., Anastas, P.T., Chu, S., & Hunter, T. 2012. Science in support of the Deepwater Horizon response. – PNAS 109: 20212-20221.

Madsen, J. 2004. Survey of moulting and breeding geese in Nuussuaq and north Disko. Pp. 15-18 in Boertmann D. (ed.). Background studies in Nuussuaq and Disko, West Greenland. – National Environmental Research Institute, Technical Report No. 482.

Madsen, J. Tombre, I. & Eide, N.E. 2009. Effects of disturbance on geese in Svalbard: implications for regulating increasing tourism. – Polar Research 28: 376-389.

Malecki, R.A., Fox, A.D. & Batt, B. 2000. An aerial survey of nesting Greater White-fronted and Canada Geese in West Greenland. - Wildfowl 51: 49-58.

McCleneghan, K., Reiter, G.A., Hardwick, J.E. & McGovern, P.T. 2002. Management of oil spill response and cleanup in a river under severe winter conditions. – Spill Science and Technology Bulletin 7: 163-172.

McKendrick, J.D. 2000.Vegetative responses to disturbances. Pp. 35-56 in Truett, J.C. & Johnson, S.R. (eds). The Natural History of an Arctic Oil Field – Development and the Biota. – Academic Press, San Diego, CA.

Meldgaard, M. 1986. The Greenland Caribou: zoogeography, taxonomy and population dynamics. – Meddelelser om Grønland, Bioscience 20: 1-93.

Merkel, F.R. 2010. Evidence of recent population recovery in common eiders breeding in western Greenland. – Journal of Wildlife Management 74: 1869-1874.

Mosbech, A. 2002. Impact of oil spill on fish. Pp. 79-91 in Mosbech, A. (ed.) Potential Environmental impacts of oil spills in Greenland. An assessment of informations status and research needs. – National Environmental Research Institute, Denmark. NERI Technical Report No. 415. Link

Mosbech, A. & Boertmann, D. 1999. Distribution, abundance and reaction to aerial surveys of post-breeding king eiders (Somateria spectabilis) in western Greenland. – Arctic 52: 188-203.

Mosbech, A. & Glahder, C. 1991. Assessment of the impact of helicopter disturbance on moulting pink-footede geese *Anser brachyrhynchus* and barnacle geese *Branta leucopsis* in Jameson Land, Greenland. – Ardea 79: 233-238.

Mosbech, A., Danø, R., Merkel, F.R., Sonne, C., Gilchrist, H.G. & Flagstad, A. 2006. Use of satellite telemetry to locate key habitats for King Eiders *Somateria spectabilis* in West Greenland. Pp 769-776 in Boere, C.G., Galbraith C., Stroud, D.A. (eds). Waterbirds around the world. – The Stationery Office, Edinburgh.

Mosbech, A., Hansen, A.B., Asmund, G., Dahllöf, I., Petersen, D.G. & Strand, J. 2007. A chemical and biological study of the impact of a suspected oil seep at the coast of Marraat, Nuussuaq, Greenland. With a summary of other environmental studies of hydrocarbons in Greenland. National Environmental Research Institute, University of Aarhus. – NERI Technical Report 629, 56 pp. Link

Myers-Smith, I.H., Thompson, R.M. & Chapin, F.S. 2006. Cumulative impacts on Alaska arctic tundra of a quarter century of road dust. – Écoscience 13: 503-510.

Naalakkersuisut 2014a. Greenland's oil and mineral strategy 2014-2018. Link

Naalakkersuisut 2014b. Letter of Invitation to apply for Exclusive Licences for Exploration for and Exploitation of Hydrocarbons in Greenland in a Licensing Round Onshore Areas on Disko and in Nuussuaq, West Greenland. – Link, accessed Mar. 10, 2016.

Naalakkersuisut 2015. Press release. Rensdyr og Moskusokser 2015/2016. – Link, accessed Mar. 8, 2016.

NAS 2003. Cumulative environmental effects of oil and gas activities on Alaska North Slope. – National Academy of Science, National Academy Press, 304 pp.

NCP 2013. Canadian Arctic Contaminants Assessment Report on Persistent Organic Pollutants in Canada's North 2013. – Northern Contaminants Program, Aboriginal Affairs and Northern Development Canada, Ottawa ON.

NPR-A 2012. National Petroleum Reserve-Alaska. Integrated Activity Plan/Environmental Impact Statement. Final. Volume 2, chapter 4.

OGP 2013. Environmental management in Arctic oil and gas operations: Good practice guide. – Report no. 449 iv + 111pp.

Olsvig, S. & Mosbech, A. 2003. Fiskeriressourcer på det lave vand i det nordlige Vestgrønland. En interviewundersøgelse om forekomsten og udnyttelsen af lodde, stenbidder og ørred. – Arbejdsrapport fra DMU, 74 pp.

OSPAR 2009. CEMP assessment report: 2008/2009 Assessment of trends and concentrations of selected hazardous substances in sediments and biota. – Monitoring and assessment series.

Owens, E.H. 2002. Response strategies for spills on land. – Spill Science and Technology 7: 115-117.

Paudyn, K., Rutter, A., Rowe, R.K. & Poland, J.S. 2008. Remediation of hydrocarbon contaminated soils in the Canadian Arctic by landfarming. – Cold Regions Science and Technology 53: 102-114.

Phillip, M. 1978. Vegetation of a snow bed at Godhavn, West Greenland. – Holarct. Ecol. 1: 46-53.

Pilegaard, K. 1997. Appendix 5.2. AMAP Greenland, 1994-1996. – Environmental Projekt No. 356.

Porsild, A.E. 1926. Contribution to the flora of West Greenland at 70°-71°45´ N. lat. – Meddr Grønland 58 (2): 157-196.

Porsild, M.P. 1902. Bidrag til en skildring af Vegetationen på Øen Disko. – Meddr Grønland 25: 91-308.

Porsild, M.P. 1910a. List of vascular plants from the south coast of the Nugsuaq peninsula in West Greenland. Meddr. Grønland 47 (5) 239-248.

Porsild, M.P. 1910b. The plant life of Hare Island off the coast of West Greenland. – Meddr Grønland 47 (6): 251-274.

Porsild, M.P. 1912. Vascular plants of West Greenland between 71° and 73° N. lit. – Meddr Grønland 50: 351-389.

Porsild, M.P. 1920. The flora of Disko Island and adjacent coast of West Greenland. – Meddr Grønland 58: 1-156.

Post, E.S. & Bøving, P.S. 1993. Botanical nature of Qeqertarssuaq (Disko) and West Greenland. Report on the vegetative characteristics of several areas on Qeqertarssusaq in relation to a proposed introduction of muskoxen. – Internal report, 16 pp.

Raundrup, K., Levermann, N. & Poulsen, M. 2012. Overlap in diet and distribution of two species suggest potential for competition at a common moulting area in West Greenland. – Dansk Orn. Foren. Tidsskr. 106: 93-100.

Raynolds, M.K., Walker, D.A., Ambrosius, K.J., Brown, J., Everett, K.R., Kanevskiy, M., Kofinas, G.P., Romanovsky, V.E., Shur, Y. & Webber, P.J. 2014. Cumulative geoecological effects of 62 years of infrastructure and climate change in ice-rich permafrost landscapes, Prudhoe Bay Oilfield, Alaska. – Global change biology 20: 1211-1224.

Rigét, F., Dietz, R., Born, E.W., Sonne, C. & Hobson, K.A. 2007. Temporal trends of mercury in marine biota of west and northwest Greenland. – Mar. Pollut. Bull.: 54. 72-80.

Rigét, F., Bossi, R., Sonne, C., Vorkamp, K. & Dietz, R. 2013. Trends of perfluorochemicals in Greenland ringed seals and polar bears. – Indications of shifts to decreasing trends. Chemosphere 93: 1607-1614.

Rigét, F., Vorkamp, K., Bossi, R., Sonne, C., Letcher, R.J. & Dietz, R. 2015. Twenty years of monitoring of persistent organic pollutants in Greenland biota. A review. – Environmental Pollution 217: 114-123.

Talbot, S.S., Yurtsev, B.A., Argus, G.W., Bay, C. & Elvebakk, A. 1999. Atlas of rare endemic vascular plants of the Arctic. – Conservation of Arctic Flora and Fauna (CAFF) technical Report No. 3. U.S. Fish and Wildlife Service, Anchorage, AK. 73 pp.

Tamstorf, M. 2004. Vegetation studies. Pp. 19-27 in Boertmann D. (ed.). Background studies in Nuussuaq and Disko, West Greenland. – National Environmental Research Institute, Technical Report No. 482.

Trupp, R., Hastings, J., Cheadle, S. & Vesely, R. 2009. Seismic in arctic environs: Meeting the challenge. - The Leading Edge28: 936-942.

Yukon Government 2006. Best Management practice. Oil and Gas, Seismic Exploration. – Yukon, Energy, Mines and Resources, 37pp. Link

Vestergaard, P. 1978. Studies in vegetation and soil of coastal salt marshes in the Disko area, West Greenland. – Meddr Grønland 204 (2): 51 pp.

Walker, D.A, Webber, P.J, Binnian, E.F, Everer, K.J, Lederer, N.D., Nordstrand, E.A. & Walker, M.D. 1987. Cumulative Impacts of Oil Fields on Northern Alaskan Landscapes. – Science 238: 757-761.

Wegeberg, S., Simonsen,. C.E., Nymand, J., Loya, W., Bay, C., Clausen, D.S., Hansen, J., & Boertmann, D. 2016. Miljøundersøgelser på Disko og Nuussuaq, Vestgrønland, august 2015. – Teknisk Rapport fra DCE nr. 90.

Wiens, J.A. 2013. Oil in the environment. Legacies and lessons of the Exxon Valdez oil spill. – Cambridge University Press.

Wilson, R.R., Parrett, L.S., Joly, K. & Dau, JR. 2016. Effects of roads on individual caribou movements during migration. – Biological Conservation 195: 2-8.

Winter, O., Maxwell, P., Schmid, R. & Watt, H. 2014. First production application of high-density vibroseis acquisition on Alaska’s North Slope. – The Leading Edge 33: 554-562.

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