UUMMANNAP KANGERLUA AND SIGGUUP NUNAA (SVARTENHUK) – REGIONAL ENVIRONMENTAL BASELINE ASSESSMENT FOR MINING ACTIVITIES

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Abstract: This regional environmental baseline assessment of mining activities in Uummannap Kangerlua and Sigguup Nunaa (Svartenhuk) is based on a project idea developed between Environmental Agency for Mineral Resource Activities (EAMRA), Greenland Institute of Natural Resources (GINR) and Danish Centre for Environment and Energy, Aarhus University (DCE/AU). The purpose of the project is to provide a basis for supporting environmentally sound planning and regulation of mining activities by summarising existing regional background information supplemented with new studies and making these results operational and easily accessible.

Keywords: Regional baseline assessment, Uummannaq, Uummannap Kangerlua, Sigguup Nunaa, Mining, Environmental assessment

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Front page photo: Campsite 2 – Eqi at Sigguup Nunaa, towards Tasiusaq (the valley) and Tasiusaq Imaa (the fjord), Katrine Raundrup

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Contents

Preface

The purpose of a Regional Baseline Assessment (RBA) is to provide a basis for supporting environmentally sound planning and regulation of mining activities by summarising existing regional background information supplemented with new studies and making these results operational and easily accessible.

This RBA for Uummannap Kangerlua and Sigguup Nunaa (Svartenhuk) compiles existing baseline information on geology, environmental chemistry, biodiversity, human use, and archeology of the area. The existing information has been supplemented with a vegetation mapping study and additional sampling and chemical analysis of environmental samples during fieldwork at Sigguup Nunaa summer 2022. The RBA includes identified data gaps, proposals for future monitoring and areas where DCE/GINR would have special attention in relation to environmental impacts from mining operations.

The available information is presented and described on a general level in the report and supported by overview maps. The full data is given at NatureMap.gl and through an integrated project-specific webGIS (rba.eamra.gl).

The Uummannap Kangerlua and Sigguup Nunaa (Svartenhuk) area was selected by the Environmental Agency for Mineral Resource Activities (EAMRA) in dialogue with DCE – Danish Centre for Environment and Energy (at Aarhus University) and Greenland Institute of Natural Resources (GINR) as it is considered relevant from a geological as well as a biological point of view and due to lack of overview of environmental and biodiversity conflict zones.

The report has been prepared by DCE and GINR.

The project was funded by EAMRA.

Sammenfatning

Formålet med en regional baggrundsundersøgelse (RBU) er at tilvejebringe oplysninger til støtte for miljømæssig forsvarlig planlægning og regulering af mineaktiviteter. Det gøres ved at sammenfatte eksisterende regionale baggrundsoplysninger suppleret med nye undersøgelser og gøre disse resultater operationelle og let tilgængelige. RBU'en for Uummannap Kangerlua og Sigguup Nunaa samler eksisterende rumlige baggrundsoplysninger om geologi, miljøkemi, biodiversitet, menneskelig brug og kulturarvsværdier i området. De eksisterende oplysninger er suppleret med en vegetationskortlægningsundersøgelse samt yderligere indsamling og kemiske analyser af miljøprøver. Baseret på de nuværende oplysninger er der udarbejdet en integreret rumlig overlay-analyse, der fremhæver zoner med flere interessenter herunder mulige fremtidige minedriftsaktiviteter og områder med relevans af biologisk, menneskelig og kulturarvsmæssig karakter. Sådanne områder er vigtige at kende i forhold til fremtidig minedrift. Rapporten indeholder desuden en sammenfatning af forventede klimaændringer og der foreslås områder, hvor DCE/GN vil have særlig fokus i forhold til miljømæssige påvirkninger fra mineaktiviteter.

De tilgængelige oplysninger præsenteres og beskrives på et overordnet niveau i rapporten og understøttes af oversigtskort. Alle data findes på NatureMap.gl og i en integreret projektspecifik webGIS (rba.eamra.gl). Nærværende videnskabelige rapport "Uummannap Kangerlua and Sigguup Nunaa – Regional Environmental Baseline Assessment for mining activities" består af ni kapitler og fire bilag.

Kapitel 1 Introduktion – Regionale baggrundsundersøgelser (RBU) af mineaktiviteter i Uummannap Kangerlua og Sigguup Nunaa

Mineaktiviteter (efterforskning, udnyttelse og transport) vil nødvendigvis forventes at have en vis indvirkning på natur og miljø. I Grønland, som i andre lande, er det ofte nødvendigt at oprette midlertidige industrizoner i forbindelse med minedrift. Minedrift har en negativ indvirkning på naturen, de oprindelige miljøforhold og lejlighedsvis kulturarvsværdier, og kan begrænse andre former for menneskelig brug af området. Miljøbestemmelser og naturplanlægning har til formål at sikre, at den eksisterende natur og det eksisterende miljø ikke ødelægges til skade for nuværende såvel som kommende generationer, samtidig med at der skabes mulighed for at udvikle minedrift. Tilstrækkelig baggrundsviden om procesteknologi, geokemi, økotoksikologi, biodiversitet og økologiske sammenhænge kan hjælpe med at forudsige konsekvenser af nye mineprojekter. Planlægning, afbødning og regulering kan i vid udstrækning begrænse eventuelle effekter ud over det faktiske udnyttelsesområde.

I udvalgte områder af særlig interesse i forhold til landbaserede mineaktiviteter vil RBU tilvejebringe:

- viden om forekomsten af sårbare og biologisk vigtige områders placering gennem undersøgelser af plante- og dyrearters udbredelse samt lokalkendskab til områderne.
- opdateret viden om naturlige baggrundsniveauer for udvalgte grundstoffer.
- forbedret offentlig adgang til opdateret miljørelevant viden og data.

Kapitel 2 De geologiske rammer for Vestgrønland fra et minedriftsperspektiv

Dette kapitel giver et kort overblik over de geologiske forhold i Uummannap Kangerlua og Sigguup Nunaa med fokus på en beskrivelse af lokaliteter af økonomisk interesse, herunder specifikationer af berigede grundstoffer. Disse oplysninger giver en vigtig forståelse af de geologiske baggrundsniveauer i interesseområdet ("Area of Interest", AOI).

Kapitel 3 Baggrundsmiljøkemi i Uummannap Kangerlua og Sigguup Nunaa

Dette kapitel giver et overblik over tilgængelige miljøkemiske baggrundsdata fra Uummannap Kangerlua og Sigguup Nunaa-området. Data stammer fra forskellige projekter og præsenteres her som median, minimum og maksimum-værdier for forskellige prøvetyper. Data kan findes i miljøkemidatabasen "AMDA", der vedligeholdes af DCE/GINR Environmental Datacenter. De vigtigste typer af miljøprøver, der er tilgængelige, er blåmuslinger (*Mytilus edulis*), sne-kruslav (*Flavocetraria nivalis*), sedimenter, ferskvand (filtreret og ufiltreret), korthornet ulk (*Myoxocephalus scorpius*) og tang (*Fucus vesiculosus* og *Ascophyllum nodosum*). Analyser af andre prøvetyper er også tilgængelige i AMDA-databasen.

Miljøkemien i Uummannap Kangerlua og Sigguup Nunaa er blevet undersøgt i løbet af de seneste ca. 40 år, hovedsageligt i forhold til den tidligere Maarmorilik bly- og zinkmine, som fungerede fra 1973 til 1990. Maarmorilik-mineaktiviteterne resulterede i betydelig forurening af fjordsystemerne tæt på minen med høje koncentrationer af opløst bly, zink og cadmium i havvandet og høje niveauer af bly i blåmuslinger og tang. Tabel 3.2 giver et overblik over AMDA-prøver indsamlet i det potentielt forurenede område som følge af de tidligere mineaktiviteter (Figur 3.1).

AMDA-baggrundsprøver taget uden for området, der er berørt af den tidligere Maarmorilik-mine, tæller 159 prøver og ca. 8400 individuelle målinger af koncentrationsværdier. Bilag 2 viser koncentrationsværdier for ca. 60 forskellige grundstoffer for ni forskellige prøvetyper baseret på dette datasæt. Cr, Ni, Cu, Zn, Cd, REE, Hg og Pb anses for at være særligt relevante, og for disse grundstoffer præsenteres detaljerede kort for de individuelle målinger (også i Bilag 2).

Næsten en tredjedel af baggrundsprøverne stammer fra feltarbejdet udført på Sigguup Nunaa i 2022. Prøver af lav, jord, blåmuslinger, tang og ferskvand (filtreret og ufiltreret) blev indsamlet på tre lokaliteter (Figur 3.3). I disse prøver var Cr-, Ni- og Cu-værdierne alle generelt højere end de grønlandske medianværdier (Figur 3.4 og 3.5). Zn og Pb er af særlig fokus i Maarmorilik-området, men er tilsyneladende mindre relevante på Sigguup Nunaa. Resultaterne fra feltarbejdet på Sigguup Nunaa stemmer godt overens med data fra elvsedimentprøver indsamlet af GEUS. Kort, hvor disse prøveresultater er interpoleret, viser således også forhøjede naturlige niveauer af Cr, Ni og Cu på Sigguup Nunaa (Figur 3.6).

Kapitel 4 Biodiversitet og biologisk vigtige og beskyttede områder

Dette kapitel giver et overblik over det biologiske miljø. Det omfatter en præsentation af den almindeligt forekommende fauna samt populationernes betydning på tre forskellige niveauer: på AOI-skala, på grønlandsk skala og på global skala. Trusselsstatus i forhold til rødlisten (på baggrund af IUCNtrusselskategorierne: LC (least concern), mindst bekymring; NT (near threatened), nær truet; VU (vulnerable), sårbar; EN (endangered), truet; og CR (critically endangered), kritisk truet) på både nationalt og globalt plan fremgår af Tabel 4.1 (fauna) og Tabel 4.2 (flora).

Da det åbne hav ikke er medtaget, er det kun kystnære havpattedyr og fisk, der er omfattet. Af havpattedyrene er narhval (*Monodon monoceros*) og grønlandshval (*Balaena mysticetus*) af særlig betydning. Uummannaq-fjorden er et vigtigt område for narhvaler i oktober – januar, men de findes også langs kanten af fastisen ved Uummannaq om foråret. Grønlandshvaler er normalt kun forårsgæster i AOI, men under feltarbejdet udført som en del af dette projekt blev adskillige hvaler observeret i Tasiusap Imaa-bugten, hvilket potentielt kan tyde på ændringer i migrationsmønstrene.

En stor del af dette kapitel er dedikeret til land- og ferskvandsfugle samt havfugle. Tre store vådområder på Sigguup Nunaa rummer flere fuglearter, herunder ynglende og fældende gæs (Figur 4.1). Den mest talrige art er canadagås (*Branta canadensis*) efterfulgt af grønlandsk blisgås (*Anser albifrons flavirostris*). Edderfugl, kongeedderfugl og andre havænder fælder i bestemte fjorde i den nordlige del af AOI (Figur 4.2). Der er adskillige havfuglekolonier i AOI, herunder mallemuk (*Fulmarus glacialis*, Figur 4.3) og havterne (*Sterna paradisaea*, Figur 4.4).

Der findes knap 380 plantearter i Vestgrønland mellem 62°20′ og 74°N, og af disse findes ca. 170 i AOI. Seks af disse arter er rødlistede (sårbare og nær truede). Der blev lavet et opdateret vegetationskort (skala 10x10 m) for AOI med fire vegetationstyper (dværgbuskhede, lavholdig dværgbuskhede, græsland og kær; Figur 4.12). I Bilag 4 findes detaljeret information om de metoder, der er anvendt til at lave vegetationskortet.

I følge grønlandsk lovgivning reguleres mineralaktiviteter gennem "*Rules for field work and reporting regarding mineral resources (excluding hydrocarbons) in Greenland*. De såkaldte feltregler indeholder et antal "Vigtige områder for dyreliv", hvor der er restriktioner for mineralaktiviteter. Feltreglerne og de vigtige områder for dyreliv bliver løbende opdateret og udvidet. Det gøres via notater, når ny biologisk viden bliver tilgængelig. De regulerede områder kan ses på WebGis siden NatureMap (https://naturemap.eamra.gl).

Der er adskillige områder relateret til fuglebekendtgørelsen i AOI. Disse omfatter tre såkaldte fuglebeskyttelsesområder: havfuglekolonierne ved Qeqertat-øerne (Schades Øer) i den nordlige Uummannaq Fjord og øerne Issortusoq og Uigorleq (Lille Fladø) vest for Upernavik Kujalleq. Men ifølge fuglebekendtgørelsen er alle havfuglekolonier omfattet af en række beskyttelseszoner med varierende størrelse (op til 3 km) i forhold til forskellige faktorer (f.eks. jagt, forstyrrelse, overflyvning) i ynglesæsonen. Endvidere er de to saltsøer på øen Ikerasak i den sydlige del af AOI og en homotermisk kilde i Umiiarfik beskyttet som naturtyper under naturbeskyttelsesloven med begrænsning af aktiviteter inden for en zone på 100 m.

På grund af manglende viden om udbredelse og diversitet er svampe, mosser og hvirvelløse dyr ikke inkluderet i denne rapport. Desuden er nogle af resultaterne i dette kapitel baseret på relativt gamle data. Dette gælder især for udbredelsen af plantearter, og flere af fuglekolonierne er ikke blevet undersøgt i de senere år.

Kapitel 5 Menneskelig brug

Dette kapitel giver et overblik over menneskelig brug i AOI, dvs. udsættelse af moskusokser, anvendelse af marine ressourcer samt turisme. Kapitlet har desuden også et afsnit om jordskred og risikoen for tsunamier, der medfører begrænset menneskelig adgang til specifikke områder (Afsnit 5.7).

I 1991 blev 31 moskusokser (*Ovibos moschatus*) udsat på Sigguup Nunaa. Den seneste minimumsundersøgelse estimerede 193 dyr i 2002, men lokal viden og observationer resulterede i indførelsen af kvotebaseret jagt for flere år siden. Selvom den nuværende bestandsstørrelse er ukendt, var den årlige jagtkvote på 150 dyr i 2022.

Langs store dele af kysten udnyttes fiskeressourcer til både privat såvel som kommercielt. Generelt er erhvervsfiskeriet i AOI begrænset i forhold til andre grønlandske farvande. I rapporten præsenteres de vigtige områder for fiskeri af fjeldørred (*Salvelinus alpinus*; Figur 5.3), torsk (*Gadus morhua*, Figur 5.4) og hellefisk (*Reinhardtius hippoglossoides*; Figur 5.5).

Kapitel 6 Kulturhistorie og -arv

Dette kapitel giver et overblik over kulturhistorien. Kulturarvszonerne i Uummannap Kangerlua og Sigguup Nunaa fremgår af Figur 6.2 og 6.3. Endvidere viser Figur 6.4 tætheden af registrerede steder med kulturarv inden for et 5 km hexagon grid i Uummannap Kangerlua og Sigguup Nunaa. Tætheden af steder med kulturarv viser både omfanget af arkæologiske undersøgelser, men også til en vis grad det faktiske omfang af tidligere bosættelser, og den giver et fingerpeg om, hvilken kulturarvsforvaltningsindsats Greenland National Museum & Archives kræver forud for aktiviteter i et givet område.

Lokaliteter med kulturarv findes næsten overalt i Grønland, men i visse landskabstyper og ved visse landskabstræk er det mere sandsynligt at finde nye, uregistrerede steder - især større lejre eller bosættelser. De landskabstræk, der normalt får øget opmærksomhed under arkæologiske undersøgelser – og bør få det samme under efterforsknings- og udviklingsaktiviteter pga. den øgede sandsynlighed for at frembringe kulturarvssteder/landskabstræk – kan ses i Tabel 6.1.

Kapitel 7 Integreret rumlig analyse af overlappende interesser

De forskellige kort i rapporten viser kendte udbredelsesområder for vigtig flora og fauna, menneskelig brug og områder med kulturarv. Alle disse træk kan betragtes som landskabsmæssige interesser, der bør tages i betragtning ved planlægning af aktiviteter med efterforskning efter mineralressourcer eller udvindingsaktiviteter. Dette kapitel giver sammenfattende analyser af, hvor mange af disse forskellige landskabsmæssige interesser, der overlapper hinanden i forskellige dele af undersøgelsesområdet. Der blev udført tre forskellige analyser (Tabel 7.1): en hovedanalyse omfattende 28 kortlag, der afspejler både flora og fauna, menneskelig brug og kulturarv (Figur 7.1 og 7.2), en delanalyse omfattende 19 kortlag med primært biologisk relevant information (Figur 7.3a) og en delanalyse baseret på 16 kortlag med information, der primært afspejler menneskelig brug og kulturarvsinteresser (Figur 7.3b).

Hovedanalysen fremhæver primært Sigguup Nunaa som et område med mange overlappende interesser. Her optræder mange vigtige biologiske interesser samtidigt, f.eks. vegetation, fælde-/yngleområder, ferskvandssystemer med fjeldørred og moskusokser. Menneskelige interesseområder omfatter vigtige moskusjagtområder og udnyttelse af kystnære ressourcer af fisk såsom lodde og stenbider. Inden for Sigguup Nunaa er det især et område sydøst for Maligiaq/Svartenhavn i vest, et område vest for Itsaku-halvøen i øst og et område nordøst for Tasiusap Imaa-bugten i syd, der er fremhævet (Figur 7.2). Delanalysen af de biologisk relevante lag (Figur 7.3a) fremhæver nogenlunde de samme områder som hovedanalysen, hvorimod delanalysen for menneskelig brug primært lægger vægt på kystområder i den nordlige og sydlige del af undersøgelsesområdet. Menneskelig brug er således koncentreret i kystområder i nærheden af byer og bygder, hvor størstedelen af jagt- og fiskeriaktiviteterne foregår, og hvor de fleste kulturarvssteder er registreret.

Det er vigtigt at understrege, at selvom analyserne klassificerer et område som rødt eller gult, betyder det ikke nødvendigvis, at råstofaktiviteter vil have en høj miljømæssig og/eller negativ social påvirkning her. Det understreger dog, at der med vores nuværende viden er behov for at tilgodese flere forskellige interesser. Det er vigtigt at være opmærksom på datahuller, når man fortolker resultaterne af overlay-analyserne, og nye data vil helt sikkert føje detaljer til billedet. Vi vurderer dog, at det overordnede resultat af analyserne, især for de fremhævede områer på Sigguup Nunaa, er rimelig robust.

Kapitel 8 Minedrift og miljøpåvirkninger

I dette kapitel gives en oversigt over de typiske miljøpåvirkninger, der kan forventes fra moderne miner, der drives i henhold til høje internationale miljøstandarder. Eksempler på den geografiske udstrækning og varighed af de virkninger, der kan forventes ved typisk moderne minedrift, gives for forskellige aktiviteter. Man skal dog huske på, at mineralprojekter er forskellige, og det samme gælder de potentielle miljøpåvirkninger. Det sidste afsnit i dette kapitel beskriver potentielle miljøpåvirkninger fra ulykker.

Kapitel 9 Fremtidsperspektiver og datahuller

Dette kapitel giver et overblik over de fremtidige klimaændringer, der forventes at ske i AOI. Det giver endvidere eksempler på de huller i data, der er identificeret i rapporten, og indeholder et oplæg til fire områder inden for AOI, hvor DCE/GINR vil have særlig fokus i forhold til miljømæssige påvirkninger fra mineaktiviteter. Disse områder omfatter: 1) De store vådområder på Sigguup Nunaa, 2) Salleq-fuglekolonien, 3) vigtige områder for hvalers fødesøgning og 4) fjordene med fældende havænder i den nordligste del af AOI.

Summary

The purpose of a Regional Baseline Assessment (RBA) is to provide information to support environmentally sound planning and regulation of mining activities. This is done by summarising existing regional background information supplemented with new studies and making these results operational and easily accessible. The RBA for Uummannap Kangerlua and Sigguup Nunaa compiles existing spatial baseline information on geology, environmental chemistry, biodiversity, human use and cultural heritage values of the region. The existing information has been supplemented with vegetation mapping and bird surveys as well as additional sampling and chemical analysis of environmental samples. Based on the information compiled, an integrated spatial analysis has been conducted, which highlights areas with many overlapping biological, human use and cultural heritage interest. Such areas need to be considered in case of future mining activities. The report also contains a summary of expected climate changes, and proposals for future monitoring and areas where DCE/GINR will have special attention in relation to environmental impacts form mining activities.

The available information is presented and described on a general level in the report and supported by overview maps. The full dataset is available through a project-specific WebGIS (rba.eamra.gl). The present scientific report "Uummannap Kangerlua and Sigguup Nunaa – Regional Environmental Baseline Assessment for mining activities" has nine chapters and four appendices.

Chapter 1 Introduction – Regional baseline assessment (RBA) for mining activities in Uummannap Kangerlua and Sigguup Nunaa

Mining activities (exploration, exploitation and transport) are bound to have a certain impact on nature and environment. In Greenland, as in other countries, it is often necessary to set up temporary industrial zones in connection with mining. Mining has a negative impact on nature, the original environmental conditions and occasionally on cultural heritage, and it may limit other types of human use in the area. Environmental regulations and nature planning aim to ensure that the existing nature and environment are not destroyed to the detriment of current as well as future generations, while still creating the possibility of developing mining activities. Sufficient background knowledge about process technology, geochemistry, ecotoxicology, biodiversity and ecological contexts can help to predict the impacts of new mining projects and often, by planning, mitigation and regulation, largely limit any effects beyond the actual area of exploitation.

Regional Baseline Assessments (RBA) of mining activities will, for selected areas of mining interest, provide:

- available knowledge of the location of vulnerable and important areas through studies of the distribution of plant and animal species as well as local knowledge of the areas.
- updated knowledge of natural background levels for selected elements.
- improved public access to updated environmentally relevant knowledge and data.

Chapter 2 Geological setting of West Greenland from a mining perspective

This chapter gives a short overview of the geological setting of Uummannap Kangerlua and Sigguup Nunaa with focus on descriptions of localities of economic interest, including specifications of enriched elements. This information provides an important understanding of the geological baseline levels in the area of interest (AOI).

Chapter 3 The environmental chemistry of Uummannap Kangerlua and Sigguup Nunaa

This chapter gives an overview of available environmental chemistry data from the Uummannap Kangerlua and Sigguup Nunaa area. The data are derived from different projects and presented as median, minimum and maximum element concentration values in different matrices. Data are extracted from the environmental chemistry database "AMDA", maintained by the DCE/GINR Environmental Datacenter. The major types of environmental samples available are blue mussels (*Mytilus edulis*), crinkled snow lichens (*Flavocetraria nivalis*), sediments, freshwater (filtered and unfiltered), shorthorn sculpin (*Myoxocephalus scorpius*) and seaweed (*Fucus vesiculosus* and *Ascophyllum nodosum*). Analyses of other matrices are also available in the AMDA database.

The environmental chemistry of Uummannap Kangerlua and Sigguup Nunaa has been investigated during the past approx. 40 years, mainly in relation to the former Maarmorilik lead and zinc mine, which operated from 1973 to 1990. The Maarmorilik mining activities resulted in severe pollution of the fjord systems close to the mine, with high concentrations of dissolved lead, zinc and cadmium in the seawater and high levels of lead in blue mussels and seaweed. Table 3.2 presents summary statistics of AMDA samples collected within the potentially polluted area from the former mining activities (Figure 3.1).

The AMDA baseline samples from outside the area affected by the former Maarmorilik mine counted 159 samples and approx. 8400 individual element concentration measurements. In appendix 2, based on this baseline dataset, summary statistics of concentration values for approx. 60 different elements across nine different sample types are provided. Cr, Ni, Cu, Zn, Cd, REE, Hg and Pb are considered particularly relevant, and for these elements detailed maps of individual measurements are presented (also in appendix 2).

Almost one third of the baseline samples originate from the fieldwork conducted at Sigguup Nunaa in 2022. Samples of lichens, soil, blue mussels, seaweed and freshwater (filtered and unfiltered) were collected at three localities (Figure 3.3). For these samples, Cr, Ni and Cu measurements were all predominantly higher than the Greenland median values (Figure 3.4 and 3.5). Zn and Pb are of major focus in the Maarmorilik area but apparently less relevant for Sigguup Nunaa. The results from the fieldwork at Sigguup Nunaa correspond well with data from river sediment samples collected by GEUS. Thus, maps interpolated from these samples also show elevated natural levels of Cr, Ni and Cu at Sigguup Nunaa (Figure 3.6).

Chapter 4 Biodiversity and biologically important and protected areas

This chapter gives an overview of the biological environment, presenting the regularly occurring fauna and the significance of the populations at three different scales: AOI, Greenland and global scale. The threat status according to the red list (summarised based on the IUCN threat categories: LC, least concern; NT, near threatened; VU, vulnerable; EN, endangered; CR, critically endangered) at both national and global level is presented in Table 4.1 (fauna) and Table 4.2 (flora).

As offshore areas are not included, only marine mammals and fish occurring in the coastal environment are considered. Of the marine mammals, narwhal (*Monodon monoceros*) and bowhead whale (*Balaena mysticetus*) are of particular importance. The Uummannaq fjord is an important area for narwhales from October to January, but they are also found along the edge of the fast ice in Uummannaq in spring. Bowhead whales are normally only spring visitors in the AOI, but during the fieldwork conducted as part of this project several whales were observed in the Tasiusap Imaa bay suggesting potential changes in migration patterns.

A large section of this chapter is dedicated to terrestrial and freshwater birds as well as seabirds. Three large wetlands found on Sigguup Nunaa hold several species of birds, including breeding and moulting geese (Figure 4.1). The most numerous species is Canada goose (*Branta canadensis*) followed by Greenland white-fronted goose (*Anser albifrons flavirostris*). Common eider, King eider and other seaducks moult in specific fjords in the northern part of the AOI (Figure 4.2). There are several seabird breeding colonies in the AOI, including northern fulmar (*Fulmarus glacialis*, Figure 4.3) and Arctic tern (*Sterna paradisaea*, Figure 4.4).

Almost 380 taxa of vascular plants are known from West Greenland between 62°20′ and 74°N and of these, approx. 170 are found within the AOI. Six of these species are red listed (VU and NT). An updated vegetation map (scale 10x10 m) of the AOI with four vegetation types (dwarf shrub heath, lichen-rich shrub heath, fen and fell field) was made (Figure 4.12). Detailed information on the methods used for making the vegetation map can be found in Appendix 4.

By Greenlandic law mineral resource activities are regulated through the *Rules for field work and reporting regarding mineral resources (excluding hydrocarbons) in Greenland*, containing a number of so-called "Areas Important to Wildlife" with restrictions on mineral activities. The field rules and the associated Areas Important to Wildlife are continuously updated and extended through memos as new biological knowledge becomes available, and the regulated areas are displayed on the WebGIS site NatureMap (https://naturemap.eamra.gl).

Several areas related to the bird protection order are present within the AOI. These include three so-called bird protection areas, defined based on seabird breeding colonies at the Qeqertat-islands (Schades Øer) in the northern Uummannaq fjord and the islands Issortusoq and Uigorleq (Lille Fladø) west of Upernavik Kujalleq. However, according to the bird protection order, all seabird colonies have a number of protection zones of varying radii (up to 3 km) in relation to different stressors (e.g., hunting, disturbance, over-flight) during the breeding season. Further, two salt lakes on the island Ikerasak in the southern part of the AOI and one homothermic spring in Umiiarfik are protected as nature types under the Nature Protection Act with restrictions on activities within a zone of 100 m.

Due to lack of specific knowledge of distribution and diversity, fungi, bryophytes, and invertebrates are not included in this report. Furthermore, some of the results presented in this chapter are based on relatively old data. This holds particularly true for the distribution of plant species, and several of the bird colonies have not been surveyed in recent years.

Chapter 5 Human use

This chapter gives an overview of the human use, i.e., muskox introduction, use of marine resources as well as tourism. The chapter also has a section on landslides and tsunami risk resulting in reduced human access to specific areas (Chapter 5.7).

In 1991, 31 muskoxen (*Ovibos moschatus*) were introduced to the Sigguup Nunaa. The most recent minimum survey estimated 193 animals in 2002, but local knowledge and observations resulted in implementation of quota-based harvesting several years ago. Though the current population size is unknown, the annual hunting quota was 150 animals in 2022.

Long stretches of the coastline have fishing resources for both private as well as commercial use. In general, the commercial fishing in the AOI is limited compared to other Greenland waters. In the report, the important areas for fishing Arctic char (*Salvelinus alpinus*, Figure 5.3), Atlantic cod (*Gadus morhua*, Figure 5.4) and Greenland halibut (*Reinhardtius hippoglossoides*, Figure 5.5) are presented.

Land-based tourism is low, but Uummannaq acts as a hub for both short hikes and boat transfers elsewhere within the AOI.

Chapter 6 Cultural history and heritage

This chapter gives an overview of the cultural history. The heritage zones in Uummannap Kangerlua and Sigguup Nunaa are presented in Figures 6.2 and 6.3. Furthermore, Figure 6.4 shows the density of registered heritage sites within a 5 km hexagon grid in Uummannap Kangerlua and Sigguup Nunaa. The heritage site density illustrates both the concentration of archaeological surveys and, to some extent, the actual past geographical settlement intensity, providing indications of which heritage management actions are required by the Greenland National Museum & Archive prior to the activities in a given area.

While heritage sites in Greenland may be found almost everywhere, particular landscape types and features are predictively more likely than others to produce new, unregistered sites – especially larger camps or settlements. Table 6.1 shows the landscape features that normally receive heightened attention during archaeological surveys and should do so also during exploration and development activities because of their increased probability for producing heritage sites/features.

Chapter 7 Integrated spatial analysis of overlapping interests

The different maps in the report present known distribution areas of important flora and fauna, human use and cultural heritage sites. All these features may be regarded as landscape interests that should be considered when planning mineral resource activities. This chapter provides summary analyses of how many of these different landscape interests overlap in different parts of the study area. Three different analyses were conducted (Table 7.1): a main analysis including 28 map layers, reflecting both flora and fauna, human use and cultural heritage (Figure 7.1 and 7.2), a sub-analysis including 19 map layers with mainly biologically relevant information (Figure 7.3a) and a sub-analysis based on 16 map layers with information primarily reflecting human use and cultural heritage interests (Figure 7.3b).

The main analysis primarily highlights Sigguup Nunaa as an area with many overlapping interests. Here, many important biological features co-occur, e.g., vegetation, geese moulting/breeding areas, freshwater systems with Arctic char and muskoxen. Human use interests include important muskox hunting areas and exploitation of coastal resources like capelin and lumpsucker. Within Sigguup Nunaa, it is particularly an area southeast of Maligiaq/Svartenhavn in the west, an area west of the Itsaku pensinsula in the east and an area northeast of Tasiusap Imaa Bay in the south that are highlighted (Figure 7.2). The sub-analysis of the biologically relevant layers (Figure 7.3a) roughly highlights the same areas as the main analysis, whereas the human use sub-analysis primarily emphasises coastal areas in the northern and southern parts of the study region. Thus, the human use interest clusters in coastal areas in proximity to towns and settlements, where most of the hunting and fishery activities take place, and where most of the cultural heritage sites have been recorded.

It is important to stress that even though the overlay analyses classify an area as red or yellow, it does not necessarily mean that mineral resource activities will have a high environmental and/or negative social impact here. It does, however, emphasise that, given our present knowledge, several different interests need to be addressed. It is important to be aware of data gaps when interpreting the overlay analysis results, and new data will certainly add details to the picture. However, we consider the overall results of the analyses, in particular the areas highlighted on Sigguup Nunaa, to be fairly robust.

Chapter 8 Mining and environmental impacts

In this chapter, an overview of the typical environmental impacts that can be expected from modern mines operated according to high international environmental standards is given. Examples of the geographical extent and duration of the effects that can be expected from a typical modern mining operation are provided for different activities. It should, however, be kept in mind that mineral projects are diverse, and so are the potential environmental impacts.

The last section in this chapter describes potential environmental impacts from accidents.

Chapter 9 Future perspectives and data gaps

This chapter gives an overview of the future climatic changes expected to occur in the AOI. It further provides examples of the data gaps identified throughout the report, and, most importantly, we present four areas within the AOI where DCE/GINR will have special attention in relation to environmental impacts form mining activities. These areas include: 1) the large wetlands of Sigguup Nunaa, 2) the Salleq bird colony, 3) important whale foraging areas and 4) the fjords with moulting seaducks in the northernmost part of the AOI.

Eqikkarnera

Tunuliaqutsiisumik misissuinerup (RBA) siornertaraa nunap immikkoortuani aatsitassarsiortoqassatillugu avatangiisitigut illersorsinnaasumik pilersaarusiortoqarlunilu aaliangersagaliorsinnaanermut paasissutissiinissaq. Tamanna anguneqarpoq maannamut tunuliaqutsiisumik paasissutissat pioreersut maannamut misissuinermit paasissutissat kingulliit toqqammavigalugit paasiuminartumik tamanillu aaneqarsinnaasunik katersinikkut tunniussaqarnikkut.

Uummannap Kangerluani aammalu Sigguup Nunaani RBA annertuumik ujarassiornikkut, uumasoqatigiit katitigaanerat pillugu paasissutissatigut, avatangiisip assigiinngisitaartuuneranik, inuit nunamik atuisimaneranit aammalu kulturikkut qangarsuaaniilli naleqartitat kingornussatigut paasissutissatigut peqarluarpoq. Paasissutissat pigineqareersut nunap naasuisa misissuiffigineqarsimasut nalunaarsuutaanik ilaneqarput kiisalu avatangiisimit akuutissanik misissuinermit katersanik ilaqartinneqarlutik. Paasissutissat maannamut pigineqartut tunngavigalugit katiterneratigut sumiiffimmi siunissami aatsitassarsiorsinnaanissamut, uumasut pillugit ilisimatusarnermut, inuit nunamik atuinerannut aammalu kulturikkut qangarsuaaniilli naleqartitat eriagisassaqarnermut tunngasuusinnaasut tamaasa isummernissamut tunngavissatut itisiliisumik peqartippaatigut. Sumiiffiit taama ittut ilisimaarissallugit pingaaruteqarluinnarput, pingaartumik siunissami aatsitassarsiorsinnaanissaq eqqarsaatigalugu. Nalunaarusiami sammineqarput silap allannguutigisassaatut ilimagineqartut eqiterneqarneri sumiiffiillu ilaasa aatsitassarsiortoqarnissaanik pilersaarusiortoqassatillugu mianerineqarnissaat pissutigalugu DCE/Pinngortitaleriffimmiit immikkut eqqumaffigineqarluartariaqarput.

Paasissutissat pissarsiarineqarsinnaasut saqqummiunneqarput qulequtakkaartumillu nalunaarusiami nassuiaatigineqarlutik ilassuteqarfigineqarlutik quppersakkamik sumiissutsinik ersersitsisumik, Paasissutissat tamarmik [NatureMap.gl] -mi webGIS ([rba.eamra.gl]) aqqutigalugu suliaq pillugu takuneqarsinnaapput. Ilisimatuussutsikkut nalunaarusiaq manna "Uummannap Kangerlua aamma Sigguup Nunaa - Nunap immikkoortuani killissarititap iluani aatsitassarsiortoqassatillugu avatangiisitigut naliliineq" qulinngiluanik kapitaleqarpoq sisamanillu ilassutitaqarluni.

Kapitali 1 Aallarniut – Uummannap Kangerluani aamma Sigguup nunap immikkoortuani aatsitassarsiortoqassatigullu tunuliaqutsiisumik paasissutissat pillugit misissuineq (RBA)

Aatsitassarsiornerit (misissueqqaarnerit, piiaanerit aammalu assartuineq) pinngitsoorani avatangiisinut nunamullu sunniuteqarnissaa naatsorsuutigineqassaaq. Kalaallit Nunaanni, nunat allat assigalugit, aatsitassarsiortoqassatillugu suliffissuaqarfiit killinganik atuukkallartussanik pilersitsisoqartariaqarpoq. Aatsitassarsiorneq avatangiisimut pitsaanngitsumik sunniuteqartarpoq tamassumalu kingunerisarlugu siornatigutulli avatangiisitigut, kulturikkut kingornussatigut naleqartitat pigineqartutigut nunallu inunnit atugaasinnaaneratigut killeqalersitsisarluni.

Avatangiisitigut aalajangersakkat nunamillu atuinermut pilersaarusiornerit tassaapput siunissamut kinguaariit tulliuttunut nunamik atuisinnaanerinut avatangiisillu piusut illersorneqarnissaannik qulakkeerinnittussat, aatsitassarsiorsinnaanissamut periarfissanik suli pilersitsisinnaasumik periarfissatigut pilersitsisussat.

Suliat ingerlannerini teknologi atorlugu paasissutissanik pigisaqarneq naammaginartoq, ujarassiornikkut akuutissatigut, uumasoqatigiit akuutissatigut paasissutissaataatigut, uumasoqassutsikkut assigiinngisitaartuuneq aammalu nunap uumasullu ataqatigiinneratigut suut tamarmik imminut atanerat qulakkiissavaa nutaanik aatsitassarsiorfeqalissagaluarpat kingunerisinnaasai siumoortumik takorloorneqarsinnaassammata. Pilersaarusiorneq, aaqqiisinnaaneq nakkutilliisinnaanerlu piiaaffigineqartussamuinnaq sunniuteqartussaanermik killiliiisinnaasoq.

Sumiiffinni aaliangersimasuni immikkut soqutigineqartuni nunami aatsitassarsiornissamik ingerlatsiviusinnaasumi RBA-p makku saqqummiutissavai:

- Sumiiffiit uumassuseqartunut pingaaruteqartut sumiissusersillugit nunap naaneratigut uumasullu sumiiffiisa siammasissusaata annertussusaa aammalu nunaqartut sumiiffinnut ilisimasaasa ataatsimut ilisimasatigut saqqummiussineq.
- Nunap sananeqaataatigut akuutissat pillugit tunuliaquttatut paasissutissat atorneqartussat nutaanerusunik katersisimaneq.
- Avatangiiseq pillugu paasissutissat ilisimasallu nutaanerusut tamanit aaneqarsinnaasut pitsaanerusut pilersissallugit.

Kapitali 2 Kalaallit Nunaata kitaani aatsitassarsiornerup isaanit isigalugu ujarassiornikkut najoqqutassat

Kapitalimi uani Uummannap Kangerluani aamma Sigguup Nunaani ujarassiornikkut pissutsit pingaartumik aningasarsiorsinnaanikkut soqutiginaateqarsinnaasut immikkut akuutissat akoqarluartut pillugit naatsukullammik sammineqassapput. Paasissutissat taakku sumiiffimmi soqutiginaateqartumi (AOI) ("Area of Interest, sumiiffimmi soqutiginaateqartumi, AOI) ujarassiornikkut paasissutissat pingaaruteqartuupput tunngaviusinnaallutillu.

Kapitali 3 Uummannap Kangerluani amma Sigguup Nunaani nunami akuutissat pillugit tunuliaqutaasumik paasissutissat

Kapitalimi uani Uummannap Kangerluani aamma Sigguup Nunaani avatangiisini akuutissatigut paasissutissat pigineqartut ataatsimut isigalugit saqqummiunneqassapput. Paasissutissat pigineqartut siornatigut suliarineqartarsimasuneersuupput uanilu misissuinermi agguaqatigiisitsisumik, minnerpaaffiliisitsisumik aammalu annerpaaffiliisitsisumik naleqassutsikkut misissuisimanermit atorneqarsimasut tunngavigineqassapput.

Paasissutissat avatangiisini akuutissat pillugit katersaqarfimmi "AMDA"-mi nassaasssaapput taakkulu DCE/GINR-mit Avatangiisit Pillugit Paasissutissaateqarfimmit nutarsarnissaanut akisussaaffigineqarput. Avatangiisinit misissugassanit tigusat pingaarnerit maanna pigineqartut uilluneersuupput (*Mytilus edulis*), orsuatsiaasaneersuupput (*Flavocetraria nivalis*), nunap qaleriissaartuaneersuneersuupput, imermit tarajoqanngitsumeersuullutik (salinnikumit salinneqanngitsumillu), kanassunit (*Myoxocephalus scorpius*) aammalu qeqqussanit (*Fucus vesiculosus* og *Ascophyllum nodosum*). Misissugassatut tigusaasimasut misissoqqissaarneqarsimasut allat aamma AMDA-mi ilisimasaqarfimmiipput.

Uummannap Kangerlua aamma Sigguup Nunaa ukiut kingulliit 40-it missaani misissuiffigineqarsimapput, pingaarnertut Maarmoriliup aqerlussamik zinkimillu piiaasimanerup 1973-miit 1990-mut aatsitassarsiorfiusimanerata kingorna.

Maarmorilimmi aatsitassarsiorsimanerup kingunerisqaanik avatangiisitigut kangerlunni aatsitassarsiorfimmut qanittumi annertuumik mingutsitsisoqarpoq uanilu aqerlussaq, zink cadmiumilu annertuumik uiluni qeqqussanilu akoqalersitsisimalluni. Takussutissaq 3.2-mi AMDA-mit misissugassatigut tigusiffigisanit aatsitassarsiortoqarsimaneranit mingutsitsisiffiusimaratarfiit ersersinneqarput (Takussutissiaq 3.1).

AMDA-mit misissugassatut katersuiviusimasut Maarmoriliup aatsitassarsiorfiunerani mingutsitsivigineqarsimasut avataaneersuupput, misissugassallu katersat 159-upput aammalu nalunaarsukkat akoqassusaanik naliliinermut atugassat 8400 missaaniillutik. Ilanngussaq 2-mi AMDA-mi takuneqarsinnaavoq akoqassutsikkut naliliinerit takutikkaat akussat assigiinngitsut 60-it missaaniittut misiliutini qulingiluaasuni ersertut paasissutissiinermilu tunngavigineqarput. Cr, Ni, Cu, Zn, Cd, REE, Hg mamma Pb immikkut eqqaaneqartariaqarput akuutissanilu taakkunani immikkut itisiliisumik misissuisimanermit paasissutissat ersersinneqassapput (aamma Ilanngussaq 2).

Misissugassat katersorneqarsimasut pingajorarterutai tikingajallugit nunami Sigguup Nunaani 2022-mi misissuisimanermit aallaaveqarput. Orsuaasat, issoq, uillut, qeqqussat imerlu (salinngikoq salinnikuunngitsorlu) sumiiffinni pingasuni katersaapput (Takussutissiaq 3.3). Misissukkat tassaapput Cr-, Ni- aamma Cu naleqassusai misissornissai takutippaalu Kalaallit Nunaanni nalinginnaasumik agguaqatigiisitsinikkut tamarmik qaffasinnerusumik inissisimasut (Takussutissiaq 3.4 mamma 3.5). Zn mamma Pb Maarmoriliup eqqaani immikkut maluginiagassaapput, kisianni Sigguup Nunaani annikinnerusumik toraagassallutik. Sigguup Nunaani nunami misissuisimanermit inernerit GEUS-ip kuunni misissuisimaneranit sanilliullugit inerneri naapertuulluarput. Naatsumik oqaatigalugu, misissugassat inernisa takutippaat Cr, Ni mamma Cu aamma Sigguup Nunaani takussaasut (Takussutissaq 3.6).

Kapitali 4 Uumassuseqartut assigiinngisitaarneri amma uumassuseqassutsikkut pingaarutillit sumiiffiit illersugaasut

Kapitalimi uani avatangiisitigut uumassuseqarneq ataatsimut isigalugu sammineqassaaq. Uumasoqassuseq taassumalu assigiinngitsutigut pingasoqiusatut isumaqarnera saqqummiunneqassalluni: AOI-kkut, Kalaallit Nunaanni peqassutsimut sanillersuullugu aammalu nunarsuarmi pissutsinut sanillersuullugu.

Allattorsimaffimmut aappalaartumut nalunaarsuutit naapertorlugu peqassutsimut navianartumiittut pillugit (IUCN-ip peqassutsimut navianartumiissutsimut uuttuutai tunngavigalugit; LC (ulorianaateqannginnerpaat), annikitsuinnarmik navianartorsiortut; NT (nungutaanisssamut navianartorsiortut), navianartumut qanittumiittut; VU (mianernartumiittoq); EN (nungutaanissamut ulorianartumiittoq); aamma

CR (nungutaanissamut navianartumiittoq) nunagisami aammalu nunarsuarmut sanilliullugit allattorsimapput taakkulu Takussutissiaq 4.1-mi (uumasut) aamma Assiliartaq 4.2-mi (naasut) takuneqarsinnaapput.

Imartat avataaniittut ilanngunneqanngillat taamaallaat sinerissap qanittuaniittut miluumasut imarmiut aalisakkalu ilanngunneqarput. Miluumasut imarmiut pineqartut tassaapput qilalugaq (*Monodon monoceros*) aammalu arfivik (*Balaena mysticetus*) immikkut pingaaruteqartut. Uummannap kangerlua qilalukkanut oktoberimiit januaarimut pingaaruteqarluinnarpoq, kisianni aamma upernaakkut sikup sinaaniittarlutik.

Arfivik nalinginnaasumik AOI-mi upernaakkuinnaq takkusimaartarpoq taamaattorli nunami misissuinerup nalaani suliap massuma ingerlannerani Tasiusap Imaata kangerliumanerani arferit arlariissuit toraarneqarput imaaratarsinnaavorlu arferit ingerlaartarnerisa allanngorsimanerinik isumaqarsinnaasoq.

Kapitalip annertunerpaartaa uani nunami, tatsini aammalu imartarni timmiarussat sammineqassapput. Sigguup Nunaani masarsoqarfiit angisuut pingasut timmissanik assigiinngitsunik arlariinnik peqartarput, uani nerlerit manniliortut mamaartullu takussaallutik (Takussutissiaq 4.1). Nerlernaarsuk takussaanerpaavoq (*Branta canadensis*) tulleralugu nerleq (*Anser albifrons flavirostris*). Miteq, miteq sioraki aammalu qeerlutuut AOI-p avannarpasissuani aalajangersimasuni mamaartarput (Takussutissiaq 4.2). AOI-mi timmiaruaqarfiit arlariissuupput, malamuit (*Fulmarus glacialis*, Assiliartaq 4.3) taateraallu ilanngullugit (*Sterna paradisaea*, Assiliartaq 4.4).

Kalaallit Nunaata kitaani avannarpasissitsip 62°20 ’og 74°N akornani naasut assigiinngitsut 380-upput, taakkunanillu 170-it missaaniittut AOI-mi naasuullutik. Taakkunanit arfinillit allattorsimaffimmi aappalaartumi nalunaarsorsimapput (mianernartumiittut nungutaanissaminnillu navianartorsiortut). AOI-mi immikkut nunap naaneranik takutitsisumik nutaasumik nunap assiliortoqarpoq (angissuseq 10x10 m) immikkut sammineqarlutik nunap naaneri assigiinngitsut sisamat orpigaasat pukkitsut, orpigaasat orugaasallit, ivigaqarfik aamma ukaliusaat; Assiliartaq 4.12). Ilanngussami 4-mi nunami naanerit nunap assiliarineqarnerani periuserineqarsimasut pillugit paasissutissat itisilerlugit takuneqarsinnaapput.

Kalaallit Nunaannit inatsisit malillugit aatsitassarsiornerni ingerlatat “*Rules for field work and reporting regarding mineral resources (excluding hydrocarbons) in Greenland*”naapertorlugit ingerlanneqartarput. Sumiiffiillu pillugit malitassat ”Uumasoqarneranut pingaaruteqartuupput”, aatsitassarsiortoqassatillugulu killilersuissutaasartunik imaqarlutik. Sumiiffinni malitassat sumiiffiillu uumasoqarneranut pingaaruteqartut ataavartumik nutarteriffigineqarlutillu annertusineqartarput. Oqaaseqaasiornikkut tamanna pisarpoq, uumasoqassutsimut ilisimasat nutaat pigineqaleraangata suliarineqartartumik. Sumiiffiit nutarterneqartut WebGis-ip quppernerani NatureMap’imiipput (https://naturemap.eamra.gl).

Timmissanik illersuineq piniarnerlu pillugit Namminersorlutik Oqartussat nalunaarutaanut attuumassuteqartut sumiiffiit AOI-mi arlariiupput. Sumiiffiit pingasut timmissanik piniaqqusaanngiffiusuupput: Qeqertani (Schades Øer) timmiaqarfiit Uummannap avannaaniittoq aamma Issortusoq aamma Uigorleq (Lille Fladø) Upernavik Kujallermiittoq. Timmissanik illersuineq piniarnerlu pillugit Namminersorlutik Oqartussat nalunaarutaat naapertorlugu timmiaqarfiit tamarmik isorartussutsimik assigiinngisitaartumik (3 km tikillugu) eqqissisimatitaaffeqarput, piumasaqaateqaatinik assigiinngitsunik nassataqartut (soorlu piniarneq, ajoqusersuineq, qulaassineq) manniliornerup nalaanut atuuttunik. Taseqarpoq tarajumik Ikerasaap qeqertaani AOI-mit kujasissumiittumik aammalu Umiiarfimmi uunartumik puilasoqarluni nunamik eqqissisimatitsineq pillugu inatsisitigut illersugaasoq 100 m tikillugu angallaffigineqarnissamut illersugaasumik.

Pupiit, usugutaqarfiit aammalu uumasut qiteraleqanngitsut pillugit ilisimasat amigarneri peqqutigalugit uani nalunaarusiami taakku iserfigineqanngillat. Nalunaarusiami inerniliussaasut ilai paasissutissat pisoqalisimasut tunngavigalugit suliaapput. Pingaartumik naasoqatigiit siammarsimassusaat pineqartillugit aammalu timmiaqarfiit arlariit ukiuni nutaanerusuni misissuiffigineqarsimanngitsut eqqarsaatigalugit.

Kapitali 5 Inuit atuinerisa sunniutai

Kapitamili uani AOI-mi inuit atuinerisa sunniutaat sammineqassapput, paasineqassalluni umimmaliisimaneq, imartani pisuussutit piniarneqarneri aammalu takornariaqarneq. Kapitalimi amma immikkut qaqqap sisoornera tassaarsuaqarsinnaaneranullu aarlerinaatillit sammineqassapput tamakku kingunerissammagit inuit sumiiffinnut aaliangersimasunut ornigussinnaajunnaarsinneqarneri (Immikkoortoq 5.7).

1991-miSigguup Nunaanut 31-nik umimmaliisoqarpoq (*Ovibos moschatus*). Peqassutsip minnerpaaffianik misissuinermi 2022-mi missingiunneqarpoq uumasoqatigiit 193-ssasut, kisiannili nunaqavissut ilisimasaat takunnittarnerilu tunngavigalugit ukiut arlallit matuma siorna pisassiissuteqartarneq tunngavigalugu piniarneq ammaanneqarpoq. Ulloq manna takillugu peqassuseq qanorpiaq annertutigisoq ilisimaneqanngikkaluartoq 2022-mi umimmattassat 150-simapput.

Sineriak tamakkiusallugu aalisarneq pissaqarniarneq tunngavigalugu inuussutissarsiornerlu tunngavigalugu ingerlanneqarpoq. Nalinginnaasumik AOI-mi inuussutissarsiutigalugu aalisarneq Kalaallit Nunaata imartaanut allanut sanilliullugu killeqarpoq. Nalunaarusiami aalisarfiit pingaarnerit pineqartut eqalunnut (*Salvelinus alpinus*; Assiliartaq 5.3), saarullinnut (*Gadus morhua*, Assiliartaq 5.4) aamma qaleralinnut (*Reinhardtius hippoglossoides*; Assiliartaq 5.5) allaaserineqarput.

Kapitali 6 Kulturikkut oqaluttuassartaq kingornussarlu

Kapitalimi uani kulturikkut oqaluttuassartamik sammisaqarpoq. Uummannap Kangerluani aamma Sigguup Nunaani Assiliartaq 6.2-mi amma 6.3-mi takuneqarsinnaasutuut sumiiffiit kulturikkut pingaarutillit ersipput. Ilanngulluguttaaq Assiliartaq 6.4-mi sumiiffiit kulturikkut pingaaruteqartut Uummannap kangerluani aamma Sigguup Nunaata akornani 5 km-sut isorarhtutigisumiittut qanoq akulikitsigineri Assiliartaq 6.4-mi nalunaarsorneqarput. Akulikissutsimi nalunaarsorsimasut itsarnisarsiuunit misissuiffigineqarsimasuupput kisiannili aamma siornatigut najugaqarfigineqarsimasuusarput tamassumalu tikkuussissutigaa sumiiffimmi suliaqartoqartinnagu Kalaallit Nunaata Katersugaasiviata Allagaateqarfiatalu misissuiffigeqqaartariaqarneranik.

Kulturikkut kingornussat Kalaallit Nunaani sumi tamaani nassaassaapput, kisianni nunat ilusaasa isikkui aammalu nunap isorartussusai assigiinngitsunik isumaqarsinnaapput aammalu kulturikkut kingornussat suli nalunaarsorneqarsimanngitsut nassaassaasarput - pingaartumik ineqarfigineqarsimasut angisuut imaluunniit inoqarfiit 13-it. Nunap isorartussusai assigiinngisitaartut itsarnisarsiuunit soqutigineqarluartut - misissueqqaarnermi inerisaanialernermilu sioqqutsisumik misissuiffigineqartariaqarput ilimanaateqarluarmat kulturikkut kingornussat/ nunaqarfiit nassaassaqarfiulluarnissaat - Takussutissaq 6.1-mi takukkit.

Kapitali 7 Sumiiffiup misissuiviginerani soqutigisat qaleriissaarsinnaaneri pillugit itisiliineq

Nalunaarusiami nunap assingi assigiinngitsut atorneqartut takutippaat sumiiffinni naasut uumasullu pingaaruteqartut sumiinneri, inuit nunamik atuiffii aammalu sumiiffiit kulturikkut kingornussat sumiinneri. Tamarmik nunamik soqutiginaateqartutut nalilerneqarput aatsitassarsiorniarluni misissueqqaarnermik piiaaniarnermilu pilersaarusiornermi suliarineqartussatut nalilersuutigineqartariaqartut. Kapitalimi uani eqikkaasumik itisiliinermik imaqarpoq nunap isorartussutsikkut isikkumigut soqutiginaateqartut itisiliiffigineqarlutik misissuiffigineqartussamilu sumi qaleriiffeqarsinnaaneri ersersillugit. Misissueqqissaarnerit pingasut assigiinngitsut suliarineqarsimapput (Takussutissaq 7.1): pingaarnertut misissuiffigisaq 28-nik kortitalik, uani immikkut naasut uumasullu aammalu nunamik atuineq kulturikkullu kingornussat inissisimaffiinik ersersitsisoq (Assiliartaq 7.1 aamma 7.2), misissuinerup ilaga 19-nik kortitalik pingaarnertut uumassusilinnik paasissutissanik tulluarsorinartunik sammisalik (Assiliartaq 7.3a) aammalu misissuinerup ilaga 16-nik kortitalik paasissutissanik inuit nunamik atuineranit aammalu kulturikkut kingornussanik immakkut soqutiginaatilinnik imaqartoq (Assiliartaq 7.3b).

Pingaarnertut itisiliisumik misissuinerup Sigguup Nunaanut tunngasup takutippaa soqutigisaqarfiit arlariit qaleriiffeqarsinnaanerat. Maani uumassuseqartut pingaaruteqartut arlalissuit takussaapput, soorlu nunap naaneri, mamaarfiit/ manniliorfiit, imeqarfiit eqaloqarfiusut aammalu umimmaat.

Nunami inuit atuisuunerisa takussutissap pingaarutillip takutippaa umimmanniarnermik sinerissallu qanittuani ammassanniarnermik nipisanniarnermillu inuussutissaqarniarnermi piniarfiuneranik. Immikkut taasariaqarpoq Sigguup Nunaani sumiiffik Maligiaq/Svartenhavn-ip kitaani kujataatungaa, aammalu sumiiffik Itsakup kangerliumanera kangiata tungaaniittoq aammalu sumiiffik Tasiusap Imaata kangerliumanerata kujammut avannarpasissuata kangianiittoq immikkut taasariaapput (Assiliartaq 7.2). Misissuinerup ilagaa uumassuseqartunik imalik (Assiliartaq 7.3a) pingaarnertut itisiliinermi misissuinermut sumiiffiit assigingajappai, taamaattoq misissuinerup ilaa inuit nunamik atuineranik misissuineq avannamut kujasinnerusorlu inuit piniarfigalugu atuineranik ersersitsineranik imaqarpoq. Inuit nunamik atuinerat amerlanertigut illoqarfinnut nunaqarfinnullu qaninnerusuni ersittarpoq annerpaartaatigullu piniarfiit aalisarfiillu tassaakkajuttarput kulturikkut kingornussat nassaassaqarfiusut nalunaarsuiffigineqarsimasut.

Pingaaruteqarpoq erseqqissassallugu, sumiiffinni assigiinngitsuni misissuinerit aappalaartumik imaluunniit sungaartumik nalunaaqutserneqarsimappata pinngitsoorani isumaqanngimmat aatsitassarsiorsinnaaneq avannataatigut inuillu nunamik atuineranik annertuumik ajoqutaasussaaneranik. Tamassuma ersersiinnarpaa maannamut ilisimasavut naapertorlugit soqutigisat assigiinngitsut eqqummaariffigineqartariaqarneri. Pingaaruteqarpoq eqqummaariffigissallugu paasissutissat amigarsinnaaneri pingaartumik misissuinerit qaleriissaartut suliarinerini aammalu paasissutissat nutaanerusut suliamut ataatsimut ilanngunneqartussaatillugit. Nalilerparpulli paasissutissat inerniuliussat Sigguup Nunaanut tunngasut tutsuiginassutsikkut qajannaatsumiinnerinik.

Kapitali 8 Aatsitassarsiorneq aamma avatangiisinut sunniutit

Kapitalimi uani nutaaliaasumik aatsitassarsiorneq nunat tamalaat akornanni avatangiisinut piumasaqaatinik ingerlatsiffiussappat avatangiisitigut sunniutigisinnaasai nalinginnaanerusut immikkut isiginiarneqassapput. Assersuutit nunap sananeqaataanut attuumassuteqartut sunniutaasinnaasullu sivisussutigisinnaasai ullutsinni aatsitassarsiornermi ilimagineqartariaqartut ilagai, sulianut assigiinngitsuugaluartunut. Eqqaamaneqartariaqarpoq aatsitassarsiornissamut suliat assigiinngitsuusarmata taamaapporlu avatangiisinut sunniutaasinnaasut assigiinngitsuusarlutik. Kapitalimi sammisaq kingulliup aatsitassarsiornermi ajutoortoqaratarnerani sunniutigisinnaasai sammineqassapput.

Kapitali 9 Siunissami periarfissat paasissutissallu amigartut

Kapitalimi uani siunissami silap allanngoriartornerata AOI-mut sunniutigisinnaasaanik sammisaqassaaq Nalunaarusiami amigaatigineqartut suuneri assersuusiorfigalugit suussusersineqarsimaneri nalunaarusiamittaaq atuarneqarsinnaapput, AOI-’p iluani sumiiffiit sisamat pillugit allassimasami aatsitassarsiortoqarnissaanik pilersaarusiornerni illersugassatut eriagisassatullu eqqumaffigisassat suuneri taagorlugit DCE/Pinngortitaleriffimmik immikkut eqqumaffigineqarnissaat innersuussutigineqarput.. Sumiiffiit tassaapput: 1) Sigguup Nunaani masarsoqarfiit, 2) Sallermi timmiaqarfik, 3) Sumiiffiit arfernit neriniarfiit ingerlaarfiillu aamma 4) AOI-ip avannarpasissuani qeerlutuut mamaarfii.

1 Introduction – Regional baseline assessment (RBA) for mining activities in Uummannap Kangerlua and Sigguup Nunaa (Svartenhuk)

By Anders Mosbech[1], Katrine Raundrup[2] and Janne Fritt-Rasmussen[1]

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Mining activities (exploration, exploitation and transport) are bound to have a certain impact on nature and environment. In Greenland, as in other countries, it is often necessary to set up temporary industrial zones in connection with mining. Mining has a negative impact on nature, the original environmental conditions and occasionally cultural heritage, and it may limit other types of human use in the area. Environmental regulations and nature planning aim to ensure that the existing nature and environment are not destroyed to the detriment of current as well as future generations, while still creating the possibility of developing mining activities. Sufficient background knowledge about process technology, geochemistry, ecotoxicology, biodiversity and ecological contexts can help to predict the impacts of new mining projects and often, by planning, mitigation and regulation, largely limit any effects beyond the actual area of exploitation.

Sensible planning and the use of the best available technologies (BAT) and best environmental practise (BEP), in addition to ongoing monitoring of the impact, can substantially limit the effect of mining on nature and environment. Mining projects often have a limited life span of a few decades, and it is important to plan from the very beginning if certain valuable biodiversity areas should be left untouched, and how the mining area is to be restored at the end of the project. Long-term planning can potentially ensure that valuable biotopes are restored in the landscape when a mine is closed, even if such biotopes are to some extent created artificially. In connection with mining projects, it is important to thoroughly analyse and describe the potential environmental impact as early as possible in the planning phase. Deciding whether the activity is desirable, and the environmental impact is acceptable – locally as well as regionally and globally – is a democratic process and a political decision.

So far, area regulation of exploration activities in Greenland has been flexible. In practice, each initial investigation has been assessed based on existing knowledge, even when it was obvious that the existing knowledge was subject to significant uncertainty. It has been an important premise for this practice that exploration usually only gives rise to limited impacts on nature and environment. It has generally been possible to place disturbing activities in the least environmentally harmful places and periods so that a disturbing activity has been carried out, e.g., when vulnerable moulting geese are absent from an area or driving in connection with seismic surveys has been done when the landscape is snow covered.

In the late exploration phase and in the exploitation phase, the activities are linked to specific and delimited areas and take place over longer periods (decades). In other words, there is no or little flexibility here as to where and when the activities are to take place. The companies must describe in their Environmental Impact Assessment (EIA) report how they intend to avoid or minimise disturbances as well as all other environmental impacts. It is therefore crucial for the companies that there is sufficient data to prepare adequate and accurate EIA reports. In cases where the available knowledge has been insufficient, it has been a requirement for the companies to carry out background studies to supplement the existing knowledge to fill out the knowledge gaps.

As an aid to obtain a regional overview of nature and environmental conditions in connection with the tender for oil exploration and exploitation permits on land, the Government of Greenland prepared regional environmental assessments (Strategic Environmental Impact Assessment - SEIA) for Jameson Land (in 2012) and Disko-Nuussuaq (in 2016).

According to the same principles, Regional Baseline Assessments (RBA) of mining activities will, for selected areas of mining interest, provide:

- available knowledge of the location of vulnerable and important areas through studies of the distribution of plant and animal species as well as local knowledge of the areas.
- updated knowledge of natural background levels for selected chemical elements.
- improved public access to updated environmentally relevant knowledge and data via, e.g., NatureMap (www.naturemap.eamra.gl).

This RBA of mining activities in West Greenland is the result of a project cooperation between the Environmental Agency for Mineral Resource Activities (EAMRA), Greenland Institute of Natural Resources (GINR) and DCE – Danish Centre for Environment and Energy (Aarhus University). The purpose of the project is to provide a basis for supporting environmentally sound planning and regulation of mining activities by summarising regional background information and conducting sensitivity analyses and, subsequently, making the results operational and easily accessible. The purpose is threefold:

- To make it easier for the authorities to plan and regulate mining activities in relation to nature and the environment.
- To make it easier for locals and other stakeholders to get information on the potential impact of mining activities in the region.
- To make it easier and less costly for companies and their consultants to plan exploration activities considering the environment. The RBA will also be valuable for mining companies and holders of small-scale permits in connection with the preparation of the EIA ("Guidelines for the preparation of the EIA report [Environmental Impact Assessments] for mineral utilization in Greenland" of 2015).

The RBA for Uummannap Kangerlua and Sigguup Nunaa has compiled existing information on geology (Chapter 2, input from GEUS), biodiversity (Chapter 4 and Appendix 1), human use (Chapter 5), cultural history and archaeology (Chapter 6, input from Greenland National Museum and Archives) in the region. This report is based on published information, databases and local knowledge, and the information is supplemented with selected studies that include remote sensing analysis of vegetation (Appendix

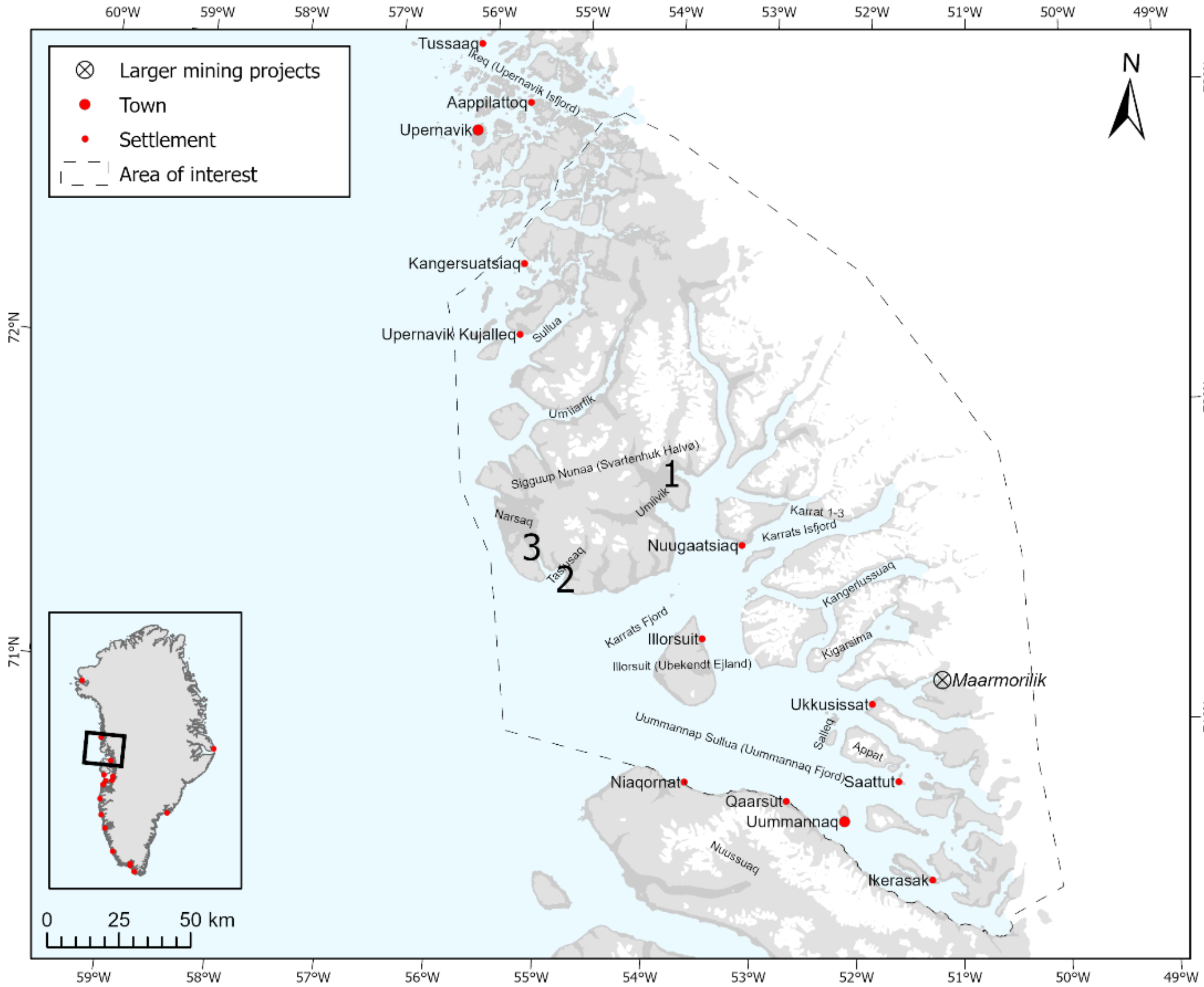
4) and chemical analyses of environmental background samples (Chapter 3, Appendix 2). The area of interest (AOI) is shown in Figure 1.1. Based on the regional information compiled, we have conducted an integrated spatial overlay analysis of overlapping interests in the region (Chapter 7). Combined with knowledge of the generic environmental footprint of modern mining activities (Chapter 8), the overlay analysis can provide important information in relation to regional planning of mining activities. The chapters in this report are intended to give an overview of current knowledge but also to include future perspectives, data gaps and recommendations (Chapter 9).

The report is not intended and does not fulfil the contents of either an Environmental Impact Assessment (EIA) or a Social Impact Assessment (SIA) of specific mining projects. It is the responsibility of the mining company to produce both the EIA and the SIA. Furthermore, aside from the data and maps presented in this report, both national and international NGOs may have their own interests in specific areas.

Two supplementary research projects were proposed as part of the RBA work: a project on blue mussels (*Mytilus edulis*) and a desktop project on waste rock - both in relation to the old mine at Maamorilik.

The first project included sampling of mussels for investigations of the current content of lead and other metals in the mussels at different distances from the old mine site. The project includes a proposal to update the guiding information to the public about locations where collection of mussels for consumption is safe in relation to lead content. The results are expected to be final by the end of 2023, and they will be disseminated in a separate report. The project is presented in Appendix 3.

The second proposed project has its focus on the fate of old waste rock deposited at a glacier next to the old Maamorilik mine and the potential release of waste rock from the glacier in a changing climate. It includes analysis of new sediment samples at the mine site to further the understanding of the current pollution from the old mine site. The project awaits final approval of funding, but fieldwork is expected to take place in 2024.



Figur 1.1. Area of interest (AOI) of the Regional Baseline Assessment for Uummannap Kangerlua and Sigguup Nunaa (Svartenhuk peninsula). The numbers (1, 2, and 3) refer to the three fieldwork sites (Site 1, Site 2, and Site 3).

Several place names are mentioned in the text. The location names used are the official names from Oqaasileriffik (the language secretariat of Greenland) at NunaGIS (https://nunagis-asiaq.hub.arcgis.com/pages/kortportal).

1.1 Participatory meeting in Uummannaq

Local knowledge is an important source of information for the RBA. A participatory meeting was held in Uummannaq on 18 July 2022. The meeting had been announced via Facebook using the GINR profile and posting specifically on Uummannaq-related pages. Five people attended the meeting where the talk focused on local knowledge about the distribution of biological resources. The conversations were based on printed maps, and details of current places primarily for fishing were given. Further, local users have made observations of muskoxen (*Ovibos moschatus*) on the west side of Illorsuit. Observations of numerous common eiders (*Somateria mollissima*) in the fjord Ukkusissat Sulluat on the east side of Sigguup Nunaa were mentioned.

Figure 1.2. Photo from the participatory meeting in Uummannaq on 18 July 2022. Photo: Janne Fritt-Rasmussen.

1.2 Fieldwork in 2022

The overall purpose of the fieldwork was to gather new and updated knowledge of importance for the environmental planning of mining activities. The Sigguup Nunaa was selected for fieldwork because it was identified as an area with nature types rare in West Greenland a relatively high biodiversity, and knowledge of the area is sparse. The fieldwork focused on birds (abundance, species), collecting baseline environmental samples for background chemical analysis and, lastly, completing vegetation analyses as ground truthing for the vegetation mapping.

The fieldwork took place between 18 July and 5 August 2022 and was conducted by David Boertmann and Janne Fritt-Rasmussen, Aarhus University, and Josephine Nymand and Katrine Raundrup, Greenland Institute of Natural Resources. In Figure 1.1 and Figure 1.3, the three visited locations are presented: Site 1 on the east coast of Sigguup Nunaa at Kangiusap Imaa (19-24 July), Site 2 on the southwest part of Sigguup Nunaa at Eqi in the bay Tasiusap Imaa (24-27 July) and Site 3 slightly further north of site 2 at the head of the fjord Afertuarsuk (27-31 July). Originally, the plans were to visit the Narsaq wetland on the west coast of Sigguup Nunaa, but as access to the area was prevented (due to difficult landing conditions such as strong swells and waves), it was decided to go to the Qaaqqut-area (Svartenhavn) instead, but also here conditions were difficult and there was no access to freshwater. Therefore, we chose to the site at the head of the fjord Afertuarsuk.

Detailed information about the bird surveys done during the fieldwork can be found in Appendix 1, while some is included in Chapter 4.3. Information on the vegetation survey can be found in Chapter 4.5, and the results from the background chemical analyses are described in Chapter 3. The following text is a short summary of our observations.

In 2022, spring was late in the major part of West Greenland, resulting in snow cover as late as at the end of June within the AOI. This may have delayed the breeding season for many birds or even forced some to abandon breeding.

This could be the explanation of the very few sightings of geese with goslings and of the missing observations of long-tailed ducks and mallards with chicks. The moulting geese were extremely shy; thus, when we were within a distance of 1500 m from them, they assembled on the lake shore and ran into surrounding land areas when we approached.

Figure 1.3. Photos from the fieldwork at Sigguup Nunaa in summer 2022. Upper left: field camp at Site 1. Upper right: view at Site 2. Lower left and right: landscapes at Site 3. Photos: Katrine Raundrup.

Canada geese (*Branta canadensis*) outnumbered the Greenland white-fronted geese (*Anser albifrons*) by far at all three sites. Only one breeding pair of Canada geese was observed (at Site 1), while breeding birds were not observed among the white-fronted geese. Long-tailed ducks were seen at all three sites with a maximum of 30 in the lakes and the wetland between Itsaku peninsula and the peak Umiviip Qaqqaa at Site 1. As a bit of a curiosity, an adult sandhill crane (*Antigone canadensis*) was observed in the wetland throughout the days at Site 2. This species is a rare visitor from the Canadian Arctic.

Muskoxen were observed at all three sites, though in low numbers (three single males at Site 1; a herd of six adults and three yearlings and two males at Site 2; three single males and a mixed herd of nine animals at Site 3). Two old antlers from caribou (*Rangifer tarandus*) were found in the Siuteqqup Sullua valley opposite the camp at Site 1.

Bowhead whales (*Balaena mysticetus*) were observed on several occasions in the Tasiusap Imaa Bay close to our camp at Site 2. Bowhead whales normally only occur in the AOI during the spring migration, but up to five animals were seen at one sighting in late July 2022. Observations of bowhead whales in the area at this time of year are unusual as they have normally migrated from their wintering quarters in the Disko Bay area towards their summering grounds in Canadian waters during spring. Thus, the 2022 observations suggest that the bowhead whale may be a more frequent summer visitor than previously known. The observations made during our fieldwork in 2022 have been summarised in a short scientific paper published in the scientific journal "Polar Research" (Boertmann et al. 2023).

During the fieldwork, several samples for background chemical analyses were collected. These included samples of blue mussels (*Mytilus edulis*), bladder wrack (*Fucus vesiculosus*), crinkled snow lichen (*Flavocetraria nivalis*), soil and freshwater (Table 1.1). The results are presented in Chapter 3 and Appendix 2.

Table 1.1. Number of vegetation analyses and number of samples for background chemical analyses.

Location	Vegetation analyses	Blue mussels and bladder wrack	Crinkled snow lichen and soil	Freshwater (filtered/unfiltered)
Site 1	38	4/1	7/7	1/1
Site 2	35	0/0	5/5	1/1
Site 3	22	4/1	5/5	1/1

Further, vegetation analyses were made at all three sites (Table 1.1). Only four vegetation types were found within the AOI: dwarf shrub heath, lichen-rich dwarf shrub heath, fen and fell field. The vegetation at the three sites was in general sparse with few copse and fen areas. The vegetation was well below knee height and was dominated by Arctic willow (*Salix arctica*), dwarf birch (*Betula nana*), arctic mountain heather (*Cassiope tetragona*), different grasses and sedges, and, interestingly, common horsetail (*Equisetum arvense*) had a broad distribution in the dwarf shrub vegetation type. No red-listed plant species (Chapter 4.5, Table 4.2) were found at the three sites.

Following the fieldwork at Sigguup Nunaa, additional work relating to a project at Maamorilik (Appendix 3) took place. At a previously abandoned bird colony at Salleq close to Uummannaq, breeding thick-billed murre (*Uria lomvia*) were observed together with black-legged kittiwakes (*Rissa tridactyla*) and razorbills (*Alca torda*). Ca. 30 murres were observed at the colony. This marks the return of breeding birds after ca. 40 years where the bird cliff has been abandoned. This observation is highly significant as recolonisation of abandoned bird colonies is extremely rare (Boertmann 2023).

1.3 References

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2 Geological setting of West Greenland from a mining perspective

By Kristine Thrane[1]

[1]Geological Survey of Denmark and Greenland

This resume gives a short overview of the geological setting of West Greenland with focus on descriptions of localities of economic interest, including specifications of enriched elements (Figure 2.1). This information provides an important understanding of the geological baseline levels in the area of interest.

West Greenland is dominated by Archaean basement gneisses (Archaean = 4,000 to 2,500 million years ago). The basement is overlain by a several kilometres thick succession of Palaeoproterozoic metasediments (Palaeoproterozoic = 2,500 to 1,600 million years ago). The metasediment is called Karrat Group and can be divided into several formations comprising basinal turbidite units, lava flows and tuffs and a carbonate platform in the southern part of the area.

The Archean basement and the Palaeoproterozoic metasediment are intruded by the large Palaeoproterozoic Prøven batholith in the most northerly part of the area of interest, as well as Palaeoproterozoic dolerite dykes. During the Palaeoproterozoic Rinkian orogenesis, the basement and cover were subject to folding and thrusting, and the rocks were variably affected by high temperature-low pressure metamorphism.

Much later, during the Cretaceous-Tertiary, regional rifting and basin development took place and formed the Nuussuaq Basin, west of the mainland. Sedimentary rocks are exposed on the eastern part of Sigguup Nunaa, and on the western side of Qeqertarsuaq and the southwestern part of Upernivik Ø. The sedimentary rocks are assumed to continue below the later Tertiary volcanic province of, mafic lavas and basalts. The genesis of the province of plateau basalts is related to a mantle plume. Today, the volcanic rocks cover Sigguup Nunaa and Ubekendt Ejland. There are minor units of down-faulted Cretaceous sediments. Source rocks and promising reservoirs for oil and gas are documented in the Cretaceous sedimentary rocks, just as oil seeps and bitumen have been found in surface outcrops at Sigguup Nuna.

The Karrat Group hosts several zinc and lead occurrences and showings, including the historic mine the Black Angel at Maarmorilik, where 11.2 million tons of ore were extracted in the period 1973-90. The massive shalerite-galena-pyrite ores are hosted by calcitic and dolomitic marbles and pelite schists. An additional 2.6 tons are still left in large pillars within the mine, grading 12.3% Zn, 4% Pb and 29 ppm Ag. A number of similar galena-sphalerite-pyrite occurrences and showings are known from the carbonate outcrops elsewhere in the region. Also at Kangerluarsuk, sediment-hosted zink and lead mineralisations have been identified. A horizon of massive, brown shalerite assaying 41% Zn exists along with Cu and Ni anomalies.

A rare-earth element (REE) mineralisation has been discovered at Niaqornakavsak. The mineralisation occurs in a 1.5 km long amphibolite horizon in the lower Karrat Group. The Y+REEO concentrations reach up to 2.6 wt % REE.

Gold anomalies have been found in quartz veins in the Karrat Group and in heavy mineral concentrates from eastern Sigguup Nunaa.

2.1 References

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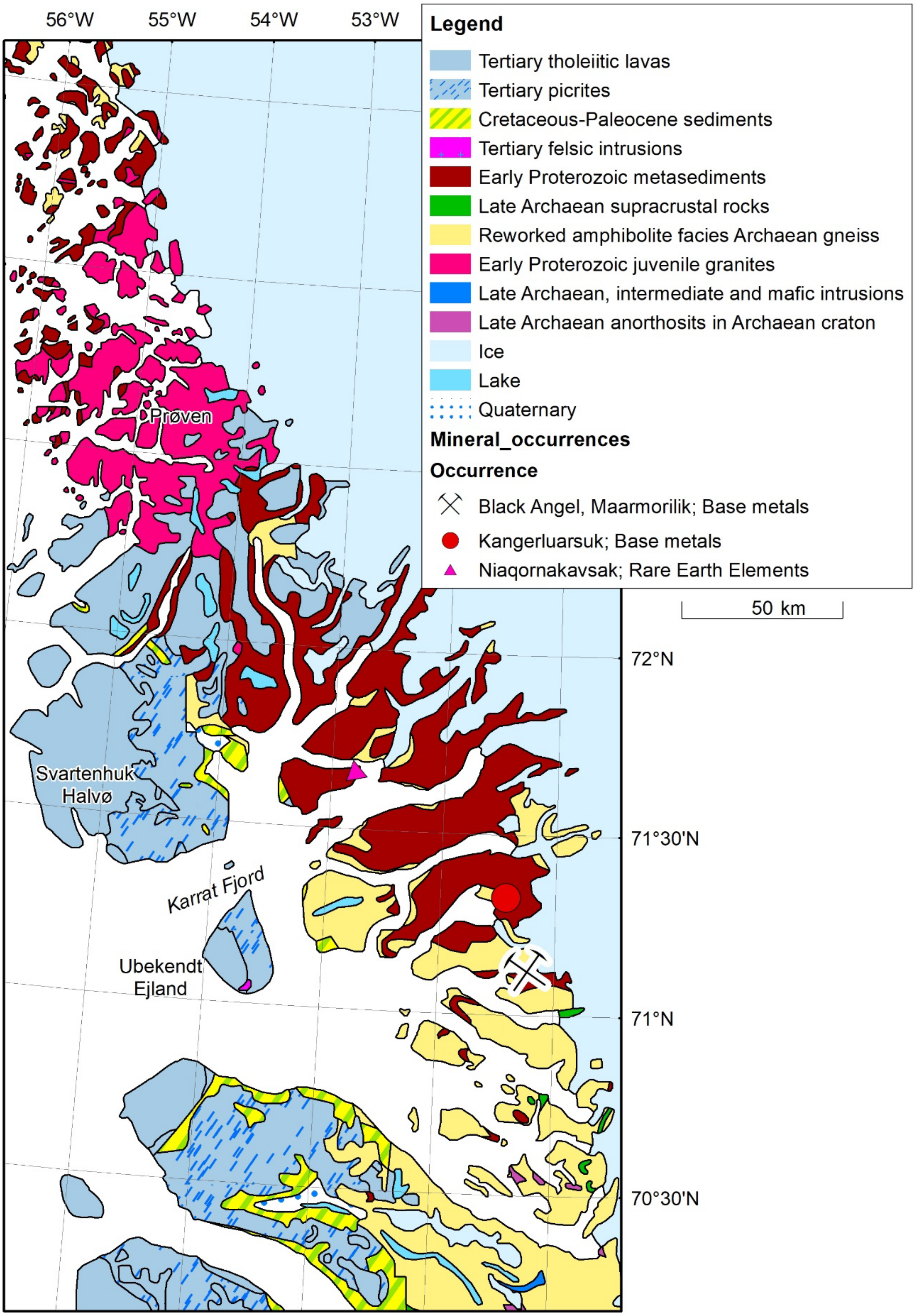

Figure 2.1. Geological map with major lithological units and mineral occurrences. Source: The Greenland Mineral Resources Portal (www.greenmin.gl).

3 The environmental chemistry of Uummannap Kangerlua & Sigguup Nunaa

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3.1 Introduction

This chapter gives an overview of the environmental chemistry data available from the Uummannap Kangerlua and Sigguup Nunaa area. The data derive from different projects conducted in the area over time, including fieldwork executed in relation to the present RBA (Figure 3.1). All data presented in this chapter are stored in the environmental chemistry database "AMDA", maintained by the DCE/GINR Environmental Datacenter on behalf of EMARA. However, in Section 3.5 element concentration maps based on stream sediment samples collected by GEUS are also presented for comparison.

3.2 Overview of available environmental samples analysed for the Uummannap Kangerlua and Sigguup Nunaa area

The environmental chemistry of the area has been investigated for the past almost 40 years, mostly in relation to the location where the former Maarmorilik lead and zinc mine operated from 1973 to 1990. The environmental chemistry data include measurements of element concentrations in, e.g., water, sediment, lichens, mussels, seaweed and fish samples. The work involved collection of baseline samples and, for the Maarmorilik area, monitoring samples during and after the mining operation. In addition, dedicated baseline sampling and subsequent studies of element concentrations in sample types from Sigguup Nunaa were completed in 2022 as part of the present RBA. Here, samples were collected at three localities on the south and eastern part of the peninsula to determine the background concentrations of elements and thereby improve the baseline data available for the RBA area (see the Section 3.5 for details).

Figure 3.1 and Table 3.1 provide an overview of AMDA samples within the area of interest which have been analysed for element concentrations and are of sample types considered relevant for the RBA. The present chapter and associated appendices are based exclusively on these samples. However, the AMDA-database and the accompanying physical sample bank of frozen and dried samples contain additional unanalysed samples that are stored for the future and can potentially be analysed for elements of interest in specific projects.

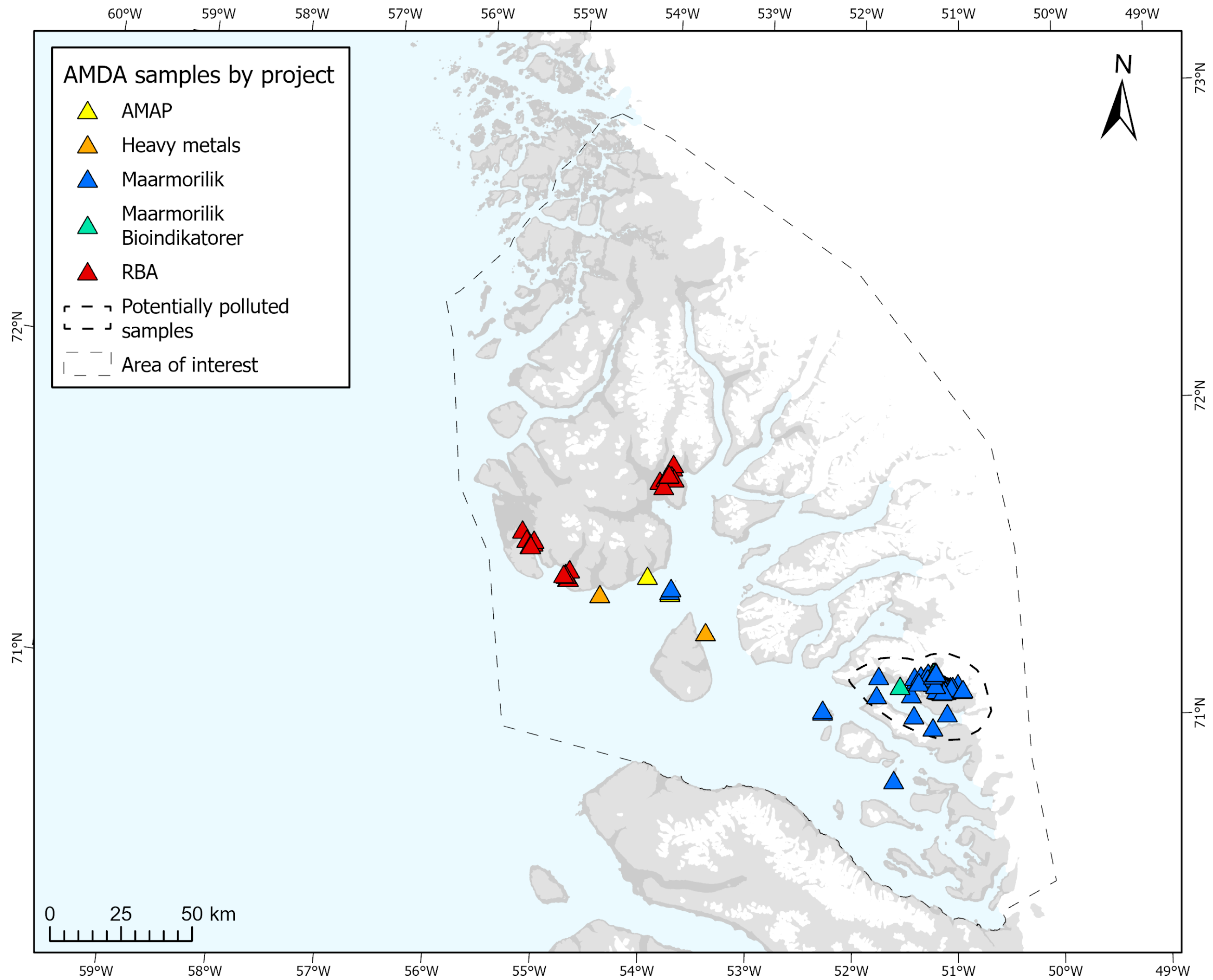


Figure 3.1. Locations of sites for collection of samples within the area of interest that can be found in AMDA and, which have been analysed for element concentrations, and are of sample types relevant for the RBA (blue mussels, seaweed, sediment, freshwater, shorthorn sculpin, crinkled snow lichen). The map corresponds to the samples listed in Table 3.1.

As the environmental chemistry data from the area of interest consist of data as far back as 1987 and onwards, sampling procedures, chemical analysis methods and sample types have changed over the years. This must be kept in mind when assessing and using the data. The chemical analyses include AAS (Atomic Absorption Spectroscopy) and, more recently, ICP-MS (Inductively Coupled Plasma Mass Spectrometry) and pXRF (portable X-Ray Fluorescence) analyses. Overall, the major types of environmental samples and data available are of blue mussels (*Mytilus edulis*), crinkled snow lichens (*Flavoicetraria nivalis*), sediments, soil, freshwater (filtered and unfiltered), shorthorn sculpin (*Myoxocephalus scorpius*) and seaweed (*Fucus vesiculosus* and *Ascophyllum nodosum*). These sample types are dominant by number and directly relevant for the RBA. Element analyses of other matrices like, e.g., marine mammals are also available in the AMDA-database but not regarded relevant for the RBA.

Seaweed and blue mussels are sessile and can accumulate elements from the surrounding seawater. They thus reflect the water quality over longer time spans. Seaweed tips are used as proxies for the year-to-year contamination (reflecting the element accumulation during the growing season), whereas blue mussels may show accumulations up to a period of 10-15 years (Theisen 1973). The element accumulation in seaweed is considered only to reflect the dissolved elements in the seawater (Rainbow 1995), whereas blue mussels can accumulate elements in both the dissolved and particulate phase (Rigét et al. 1997; Søndergaard et al. 2011b). Blue mussels are widely distributed in Greenland, except in the northern parts of East Greenland (Wenne et al. 2020), and they are internationally well-established monitoring organisms due to their role as suspension feeders, concentrating contaminants in their tissue due to filtration of large volumes of water.

For freshwater, the measured element concentrations in filtered samples act as a proxy for the dissolved elements (here defined as elements that can pass through a 0.45 µm filter). Hence, unfiltered freshwater samples also contain particles in suspension. In connection with water sampling, parameters like pH, temperature, electrical conductivity and redox potential (Eh)/oxygen have sometimes also been measured.

Lichens are generally abundant in the Arctic. The crinkled snow lichen, *Flavocetraria nivalis*, is the preferred species for monitoring in Greenland as it is found in most parts of the country (Søndergaard et al. 2020). Lichens are used as a monitoring organism for dust deposition due to their large surface area, lack of roots and long lifespan. Their ability to accumulate dust and air pollutants from mining activities have been reported in several studies (Naeth and Wilkinson 2008; Søndergaard et al. 2011b; Søndergaard et al. 2013; Søndergaard et al. 2020). With continuous pollution, element concentrations in lichens have been found to increase with exposure time. Therefore, transplantation of lichens is often used for monitoring, typically regarding short-term exposure to dust to assess year-to-year temporal variations in dust deposition.

Shorthorn sculpin (*Myoxocephalus scorpius*) is a highly common species in the fjords of Greenland, it is relatively stationary at the seafloor (Muus 1990) and easy to catch. Hence, it has been a key monitoring organism for measuring bioaccumulation of contaminants in the marine environment near mine sites (Søndergaard et al. 2020). Another fish species, Arctic char, should also be included in environmental monitoring programs if present in the rivers near the mine sites.

Besides the AMDA-samples, knowledge about the environmental chemistry of the area is also available from geological surveys (see Chapter 2 Geology), in particular from the systematic stream sediment samples collected during these surveys (see Section 3.5).

Table 3.1. Environmental chemistry data from Uummannap Kangerlua and Sigguup Nunaa in the AMDA database. Sample types, years, total number of samples and analysed elements are listed for each project. The category "seaweed" contains two types of brown fucoid macroalgae (Fucus vesiculosus and Ascophyllum nodosum). Similar sample types collected in different years at one location may have been analysed for different elements. Consequently, the number of concentration records for a specific element might be smaller than the reported number of samples in the sample type category. The analyses are conducted by use of ICP-MS, AAS or pXRF. The number of analysed samples are divided into total number within AOI ("Total"), samples within the potentially polluted region around the Maarmorilik mine site ("Polluted") and samples outside that region ("Baseline"). The locations of the different samples and the potentially polluted region around Maarmorilik are shown in Figure 3.1

Project name	Sample types	Elements	Dry matter %	Sampling years	No. of samples		
						Polluted	
AMAP	Blue mussel	Cd, Hg, Pb, Se	d.m.%	1995	0	28	28
	Sediment	As, Hg		1996	0	2	2
Heavy metals	Sediment	As, Hg		1987	0	3	3

Maarmorilik	Blue mussel	Ag, Al, As, Au, Ca, Cd, Co, Cr, Cu, Fe, Hg, Mg, Ni, Pb, Se, Zn	d.m.%	1989, 1998-2000, 2002, 2007-8, 2010-12	262	17	279
	Capelin	Pb	d.m.%	1989-90, 1997, 2002	92	0	92
	Crinkled snow lichen	Ag, Al, As, Au, Ca, Cd, Cr, Cu, Fe, Hg, Mg, Ni, Pb, Se, Zn	d.m.%	1999, 2002, 2006-8, 2010-11	169	11	180
	Rough periwinkle	Ag, As, Cd, Co, Cr, Cu, Fe, Hg, Ni, Pb, Se, Zn		2012	8	1	9
	Seaweed	As, Cd, Cu, Pb, Zn	d.m.%	1988, 1998, 2000, 2002, 2007-8	247	11	258
	Sediment	Ag, Al, As, Ba, Bi, Ca, Cd, Ce, Co, Cr, Cu, Fe, Hg, K, La, Mg, Mn, Mo, Nb, Nd, Ni, P, Pb, Pr, Rb, S, Sb, Se, Si, Sn, Sr, Th, Ti, U, V, W, Y, Zn, Zr		2012, 2022	23	1	24
	Shorthorn sculpin	Pb	d.m.%	1998, 2000, 2002, 2005, 2007-8, 2012	108	28	136
Maarmorilik Bioindicators	Shorthorn sculpin	Ag, As, Cd, Co, Cr, Cu, Fe, Hg, Ni, Pb, Se, Zn	d.m.%	2012	28	7	35
RBA	Blue mussel	Ag, Al, As, Au, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Hf, Hg, Ho, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Pd, Pr, Pt, Rb, Re, Ru, Sb, Sc, Se, Sm, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr		2022	0	8	8
	Crinkled snow lichen	Ag, Al, As, Au, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Hf, Hg, Ho, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Pd, Pr, Pt, Rb, Re, Ru, Sb, Sc, Se, Sm, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr		2022	0	17	17
	Freshwater	Ag, Al, As, Au, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Hf, Hg, Ho, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Pd, Pr, Pt, Rb, Re, Ru, Sb, Sc, Se, Sm, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr		2022	0	6	6
	Seaweed	Ag, Al, As, Au, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Hf, Hg, Ho, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Pd, Pr, Pt, Rb, Re, Ru, Sb, Sc, Se, Sm, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr		2022	0	2	2
	Soil	Ag, Al, As, Au, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Hf, Hg, Ho, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Pd, Pr, Pt, Rb, Re, Ru, Sb, Sc, Se, Sm, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr		2022	0	17	17

3.3 Data from areas with former mining activities

Until now, the major mining activity in the Uummannap Kangerlua and Sigguup Nunaa area has been related to the exploitation activities at the Maarmorilik mine. This section summarises the activities in the Maarmorilik area and is primarily based on the reports '*Evaluation of local contamination sources from the former mining operation in Maarmorilik*' (Johansen et al. 2010a) and '*Environmental monitoring at the former lead-zinc mine in Maarmorilik, northwest Greenland, in 2009*' (Johansen et al. 2010b). Further environmental monitoring reports exist from 1974 and onwards, e.g., Bondam and Asmund (1974), Asmund (1975), Asmund et al. (1976), Cooke (1978), Asmund (1980), Asmund (1986), GMU and GGU (1988), Asmund (1991), Dahl (1994), Asmund and Riget (1994), GMU (1994), Riget et al. (1994a), Riget et al. (1994b), Asmund (1995), Riget et al. (1995), Riget et al. (1996), Johansen et al. (1997), Johansen et al. (1998), Johansen et al. (1999), Møller et al. (2002), Johansen et al. (2003), Johansen et al. (2006), Johansen et al. (2008), Schiedek et al. (2009), Johansen et al. (2010b) and Gustavson et al. (2014). Besides these monitoring reports, several scientific articles treat the Maarmorilik mine site. Relevant examples are, but not limited to, Søndergaard et al. (2019), Hansson et al. (2019), Søndergaard et al. (2014), Søndergaard et al. (2013), Søndergaard et al. (2011a), Søndergaard et al. (2011b) and Larsen et al. (2011).

The Maarmorilik mine is situated at the junction of the Qaamarujuk and Affalikassaa fjords east of Ukkusissat in the Uummannaq district of central West Greenland (Figure 3.2). In 1971, Greenex A/S obtained a 25-year exploitation concession for mining the lead/zinc occurrence (galena and sphlerit) at Maarmorilik (Bondam and Asmund 1974, Thomassen 2003). The mine opened in 1973 and operated until 1990. In 2003, Black Angel Mining Ltd. obtained an exploitation licence. No mining has taken place since. A marble quarry was situated in the area in the 1930s.

In the period from 1973-1990, ores containing lead and zinc were mined from underground. The primary ore was the 'Black Angle' mountain, located 600 m above the sea level. The processing plant was situated across the Affarlikassaa Fjord. A cable car was used for transporting the mined material from the tunnels on the mountain face to the processing plant, from where a lead and zinc concentrate was shipped to Europe for further processing.

The mining included ore crushing on site as well as transport of concentrate. Particularly the crushing resulted in significant amounts of zinc and lead-containing dust that was spread into the surroundings. Waste rock was dumped at six locations outside the mine on the mountain side and finally reached the fjord. Up until 1985, the waste rock was dumped outside the mine without any regulation, but from 1985 only waste rock with less than 0.1% lead was allowed to be dumped outside the mine. A total of approximately 3 million tons waste rock was generated.

Tailings were deposited in the Affarlikassaa Fjord. It was estimated that about 8 million tons of tailings were deposited in the fjord and that almost all of it settled here. A part of the waste rock was moved from the mountain side and dumped on top of the tailings after the mine closure.

The mining activities resulted in severe pollution of the fjord systems close to the mine, with high levels of dissolved lead, zinc and cadmium in the water, and high levels of lead in blue mussels and seaweed. The main reasons for the spread of the pollution were the discharge jet of tailings suspended in seawater (during mining in 1973-1990), the tailings deposited at the Affarlikassaa and, finally, the waste rock dump that reached the coast.

Environmental studies have been conducted since 1972, and the report by Johansen et al. (2010b) compiles the latest monitoring from 2009. The references given at the start of this section contain information about the remaining monitoring reports. The environmental monitoring included sampling of seawater, sediments, lichens, blue mussels, seaweed, shrimps and fish. Lichens were sampled close to the mine and west of the mine. Lichens were also transplanted to monitor temporal (year-to-year) spreading of elements in the environment through dust. The monitoring in 2009 shows no changes in the spreading of elements by dust compared to 1996 (the year when the transplantation of lichens was undertaken). In samples from 2009, elevated concentrations compared to background levels were measured in lichens, indicating that dust still spreads place from the mine site to the surroundings, the main sources likely being the waste rock dumps and residues from the camp area.

To estimate the spreading of pollutants in the marine environment, mainly blue mussels and seaweed were used as biomonitors. Besides sampling of resident mussels, also transplanted mussels were used to assess temporal variations in element dispersion (year-to-year, 1992-2009). Elevated concentrations of lead and zinc in blue mussels and seaweed have been found in the fjord system near the mine, and the assessments indicate that no significant decrease has occurred since around the year 2000. Therefore, collection of mussels for human consumption is not recommended in an area extending to approx. 15 km north of the mine. For more details, see Appendix 3. In summer 2022, mussels in three different size groups were sampled at 10 of the previous monitoring stations along the pollution gradient from the mine. The fieldwork is described in Appendix 3, and the results are expected to be published in a note and a scientific paper in 2023.

Table 3.2 presents summary statistics of AMDA data collected in the area marked as potentially polluted due to mining activities (Figure 3.1). The table includes concentration data of relevant elements for up to seven different sample types (blue mussels (*Mytilus spp*.), lichens (*Flavocetralis nivalis*), sediments, rough periwinkle (*Littorina saxatilis*) and seaweed (*Fucus vesiculosus* and *Ascophyllum nodosum*), capelin (*Mallotus villosus*) and shorthorn sculpin (*Myoxocephalus scorpius*)). For comparison, Greenland median concentration values for the different elements and sample types under unpolluted conditions are also reported in the table. The Greenland median values were calculated in connection with the RBA of South Greenland and represent unweighted medians of all unpolluted samples from Greenland in the AMDA-database at the time (see Fritt-Rasmussen et al. (2023) for details). The Greenland median values were not updated in connection with the current RBA as the amount of new data in AMDA since the last calculation is very limited on a national scale. As further reference, Table 3.2 also includes guideline values from the literature to the extent that these exist (see Table 3.3 for a compilation of literature guideline values).

It is evident from Table 3.2 that the Pb and Zn concentrations in some of the sample types exceed the Greenland median values of unpolluted samples and the literature guideline values, demonstrating the severity of the pollution. However, it is important to bear in mind that the table integrates data from many years and a relatively large area around the mine site. Thus, for several of the elements and sample types, significant spatial and temporal trends in concentration levels occur. These gradients are not reflected in the table, and we refer to the different monitoring reports for more detailed insights into the historic and present levels and extent of the pollution.

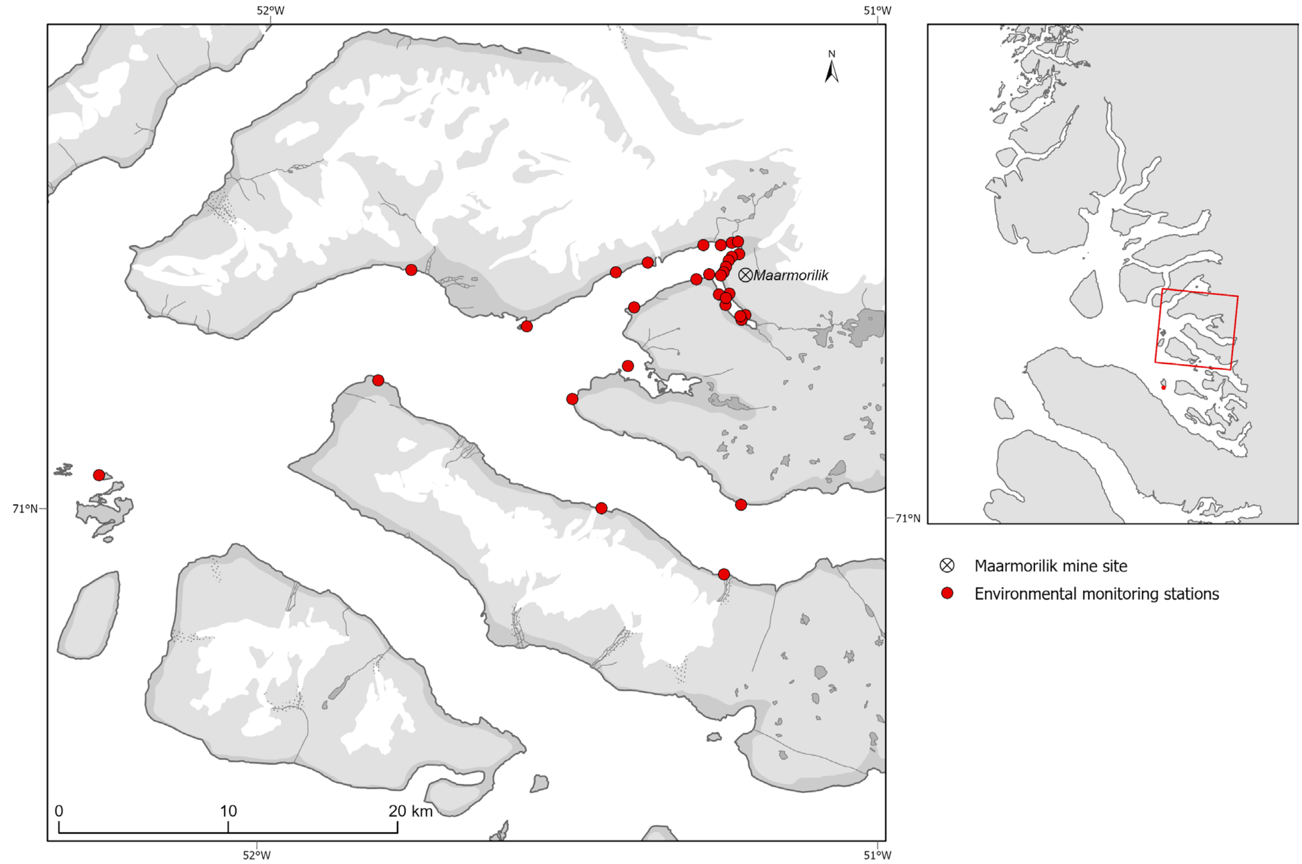


Figure 3.2. The Maarmorilik area, showing the locations of the mine site and the systematic sampling stations used for the environmental monitoring. Adapted from Johansen et al. (2010b).

Table 3.2. Concentrations of the elements Cd, Cr, Cu, Hg, Ni, Pb and Zn in AMDA samples taken in the potentially polluted area around the Maarmorilik mine (see Figure 3.1 and list of samples in Table 3.1). For comparison, Greenland median concentration levels in unpolluted AMDA samples from Fritt-Rasmussen et al. (2023) are reported as are relevant guideline values to the extent that these exist (see Table 3.3 for a compilation of literature guideline values).

Element	Sample type		Min.	Median	Max.	No. of samples	GRL median	Guideline values
Cd	Blue mussel	mg/kg	2.16	3.59	11.77	18	2.736	
	Crinkled snow lichen	mg/kg	0.08	0.39	6.47	36	0.088	
	Rough periwinkle	mg/kg	1.52	6.04	12.71	8		
	Seaweed	mg/kg	2.24	2.50	2.76	2	1.340	
	Sediment	mg/kg	<DL	3.43	16.00	23	0.146	
	Shorthorn sculpin	mg/kg	0.15	0.94	4.33	28	0.996	0.026[b]
Cr	Blue mussel	mg/kg	1.1	2.6	3.9	18	1.058	
	Crinkled snow lichen	mg/kg	0.4	1.1	2.8	36	0.329	
	Rough periwinkle	mg/kg	0.3	2.5	4.8	8		
	Sediment	mg/kg	<DL	<DL	76.6	23	66.775	70-560[a]
	Shorthorn sculpin	mg/kg	<DL	0.007	0.023	28	0.008	
Cu	Blue mussel	mg/kg	6.78	8.97	11.77	18	7.366	
	Crinkled snow lichen	mg/kg	0.59	1.15	3.43	36	0.762	
	Rough periwinkle	mg/kg	33.24	66.20	99.86	8		
	Seaweed	mg/kg	9.83	10.87	11.90	2	1.970	
	Sediment	mg/kg	3.66	25.00	491.00	23	20.440	35-51[a]
	Shorthorn sculpin	mg/kg	0.57	1.39	15.26	28	1.595	
Hg	Blue mussel	mg/kg	0.08	0.11	0.26	18	0.090	
	Crinkled snow lichen	mg/kg	0.011	0.036	0.081	36	0.034	
	Rough periwinkle	mg/kg	0.046	0.123	0.237	8		
	Sediment	mg/kg	<DL	<DL	6.00	23	0.029	
	Shorthorn sculpin	mg/kg	0.02	0.12	0.50	28	0.047	0.035[b]
Ni	Blue mussel	mg/kg	1.88	3.00	4.58	18	1.475	
	Crinkled snow lichen	mg/kg	0.12	0.61	1.98	36	0.441	
	Rough periwinkle	mg/kg	2.47	6.22	12.59	8		
	Sediment	mg/kg	13.52	34.00	50.51	23	34.240	
	Shorthorn sculpin	mg/kg	0.01	0.03	0.18	28	0.004	
Pb	Blue mussel	mg/kg	0.42	6.44	1197.10	245	0.694	1.3[c]
	Capelin	mg/kg	0.01	0.02	0.04	20		
	Crinkled snow lichen	mg/kg	0.31	7.73	917.40	169	0.665	
	Rough periwinkle	mg/kg	5.90	14.73	210.90	8		
	Seaweed	mg/kg	0.28	1.71	18.80	247	0.120	
	Sediment	mg/kg	12.10	149.00	1507.00	23	14.125	30-83[a]
	Shorthorn sculpin	mg/kg	<DL	0.08	16.09	136	0.007	
Zn	Blue mussel	mg/kg	10.51	31.31	730.71	245	75.699	63[c]
	Crinkled snow lichen	mg/kg	5.67	28.53	947.77	169	19.247	
	Rough periwinkle	mg/kg	92.27	180.80	481.81	8		
	Seaweed	mg/kg	8.64	62.01	368.83	247	13.978	
	Sediment	mg/kg	27.00	716.00	2378.50	23	69.105	150-360[b]
	Shorthorn sculpin	mg/kg	25.19	45.44	79.75	28	33.705	

a) Bakke et al. (2010) – Norwegian sediment quality criteria; classification "Good".

b) OSPAR (2014) – Assessment criteria used in the CEMP data assessment for fish.

c) OSPAR (2014) – Assessment criteria used in the CEMP data assessment for mussels.

3.4 Baseline environmental chemistry data

AMDA samples from outside the potentially polluted area around the former Maarmorilik mine (see Section 3.3 and Figure 3.1 and Table 3.1) are considered unpolluted and may be used to give an indication of baseline values for the area of interest. Besides the environmental sampling in the vicinity of the former Maarmorilik mine area, other baseline environmental samples were collected (see Figure 3.1). In Appendix 2, we provide summary statistics on the concentration levels for approx. 60 different elements across nine different sample types for these unpolluted samples. In total, this baseline dataset is based on 159 samples and approx. 8400 individual element measurements. Cr, Ni, Cu, Zn, Cd, REE, Hg and Pb are considered particularly relevant regarding the mineral activities in the area of interest. Thus, for these elements detailed maps of individual measurements are presented in Appendix 2 Figures A2.1-8. The maps include only unpolluted samples, which is why there are no dots in the Maarmorilik area. For each sub-map, the Greenland median concentration level in unpolluted AMDA samples from Fritt-Rasmussen et al. (2023) is also reported for the purpose of comparison (see explanation in Section 3.3). As a further reference, Table 3.3 compiles guideline values from the literature for the relevant elements and sample types. However, it was not possible to find guideline values for all the involved sample types and elements. There is a large variation between the concentrations found in the baseline samples from the area of interest (Appendix 2 Figures A2.1-8.). Overall, Cr, Ni and Cu seem elevated in the sediment samples compared to the Greenland median concentration and the guideline values, particularly for the Siggu Nunaa area (see further in Section 3.5). In most of the samples, the concentrations measured in the mussels are higher than the guideline values. For the filtered freshwater, none of the sample values are elevated compared to the guideline values.

Table 3.3. The environmental chemistry of Uummannap Kangerlua and Sigguup Nunaa.

	Cr	Ni	Cu	Zn	Cd	REE	Hg	Pb
Crinkled snow lichen								
Sediment (mg/kg[a])	70-560	30-46	35-51	150-360	0.25-2.6		0.15-0.63	30-83
Blue mussel (mg/kg[b])			6	63	0.96		0.09	1.3
Seaweed								
Freshwater (filtered) (µg/l[c])	3	5	2	10	0.1	2[d]	0.05	2
Freshwater (unfiltered)								

a) Bakke et al. (2010) – Norwegian sediment quality criteria; classification “Good”.

b) OSPAR (2014) – Assessment criteria used in the CEMP data assessment for mussels.

c) MRA (2015) Greenland Water Quality Criteria (GWQC).

d) de Boer et al. (1996), safety levels for each individual REE for drinking water in the Netherlands, for ΣREE an estimated value would be 32 µg/L.

3.5 Baseline data from Siggu Nunaa – fieldwork 2022

Almost one third of all unpolluted AMDA samples from the area of interest origin from the fieldwork conducted at Siggu Nunaa in 2022 as part of the present RBA project. These samples were collected to increase the rather limited number of baseline samples from the area of interest in general, and Siggu Nunaa in particular. As these data are not presented anywhere else, a more detailed treatment is given here.

Samples of lichens, soil, blue mussels, seaweed and freshwater (filtered and unfiltered) were collected at three localities at Siggu Nunaa. The overall sampling localities and the sampling sites for specific sample types are depicted in Figure 3.3. The sampling procedure followed Bach et al. (2022). All samples were analysed by means of ICP-MS, and concentrations of approx. 60 elements are reported in Appendix 2, Table A2.2. For the most relevant elements (Cr, Ni, Cu, Zn, Cd, REE, Hg and Pb), box plots of the measurements are presented in Figure 3.4 and 3.5 for all the sample types at the three overall sites. In these box plots, the Greenland median values from Fritt-Rasmussen et al. (2023) are given for comparison (see explanation in Section 1.2.1 in Fritt-Rasmussen et al. (2023)).

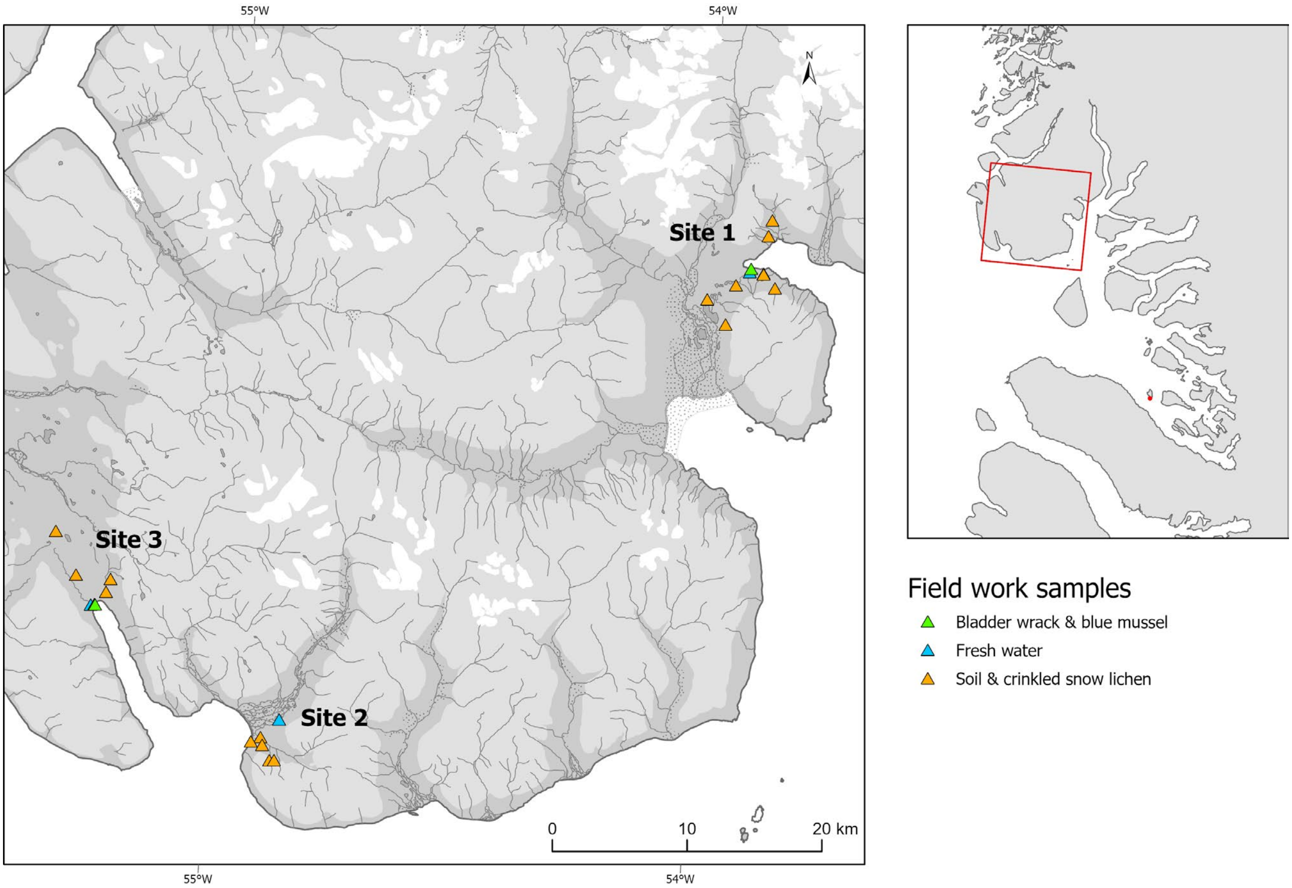
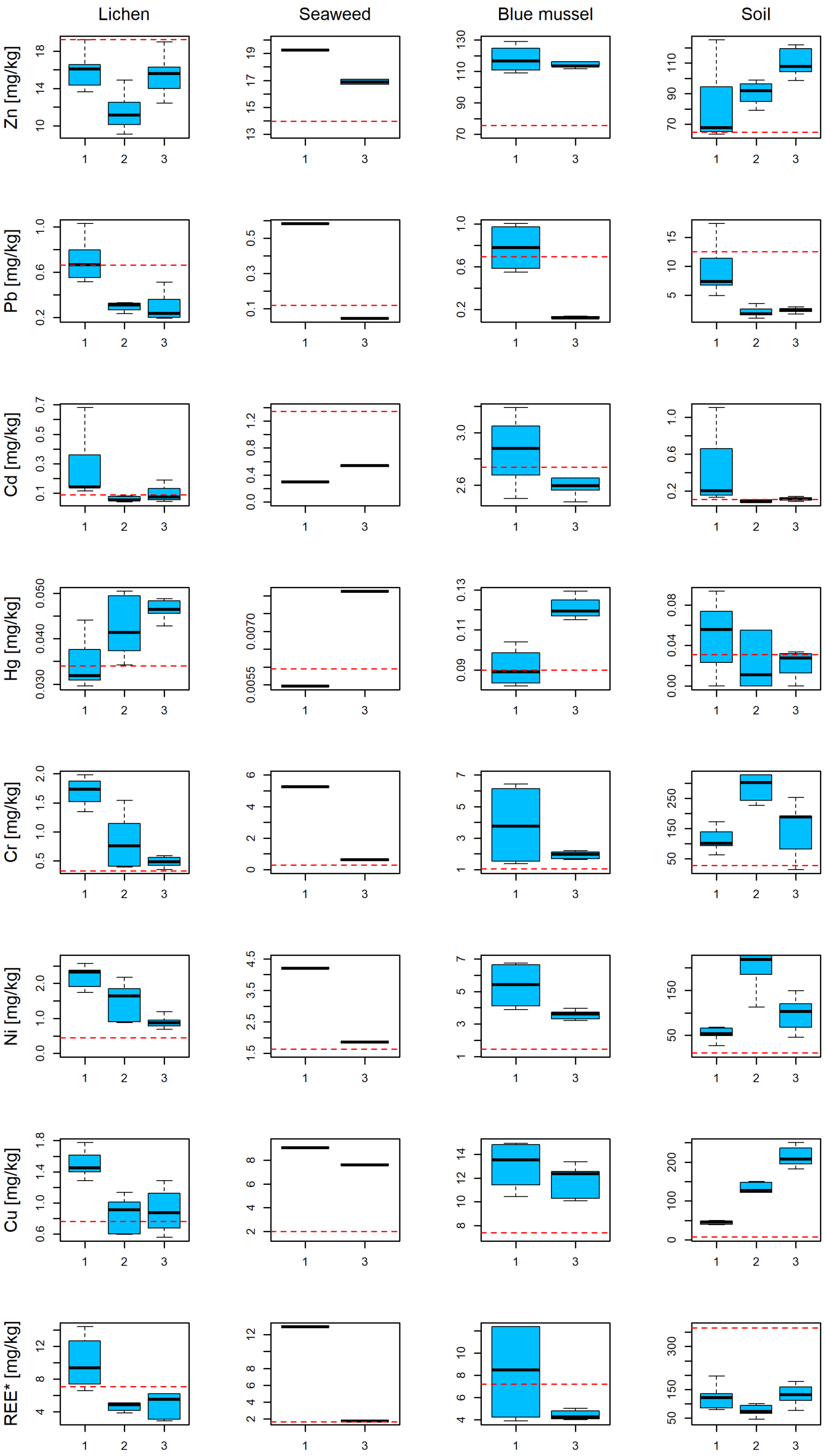


Figure 3.3. Sites for environmental sample collection during the fieldwork in summer 2022 at Siggu Nunaa.

For the biota and soil samples, Cr, Ni and Cu measurements were all generally higher than the Greenland median values (Figure 3.4). When comparing the soil samples to the available guideline value intervals (Table 3.3) for Cr and Ni, the measurements exceeded the lower and upper limits of the given guideline value range, respectively. For the remaining elements (Zn, Pb, Cd, Hg and REE), the results vary between sites and sample types. Zn and Pb are of major importance in the Maarmorilik area but apparently less relevant for Siggu Nunaa. The same tendency is seen for the freshwater samples (Figure 3.5), where the Cr, Ni and Cu measurements were all higher than the Greenland median (but still below the guideline values), and the Zn, Pb, Cd, Hg and REE results were below the Greenland median, though with variations between sites.

Figure 3.4. Boxplots of concentrations of Zn, Pb, Cd, Hg, Cr, Ni, Cu and REE in samples of lichen, seaweed, mussels and soil collected as baseline data during fieldwork in summer 2022 at Siggu Nunaa. The numbers on the x-axis refer to the site numbers in Figure 3.3. At site 2, mussels and seaweed were not present. The dashed red lines represent the Greenland median values from Fritt-Rasmussen et al. (2023). *Sum of the individual median concentrations of 17 REEs, except Pm.



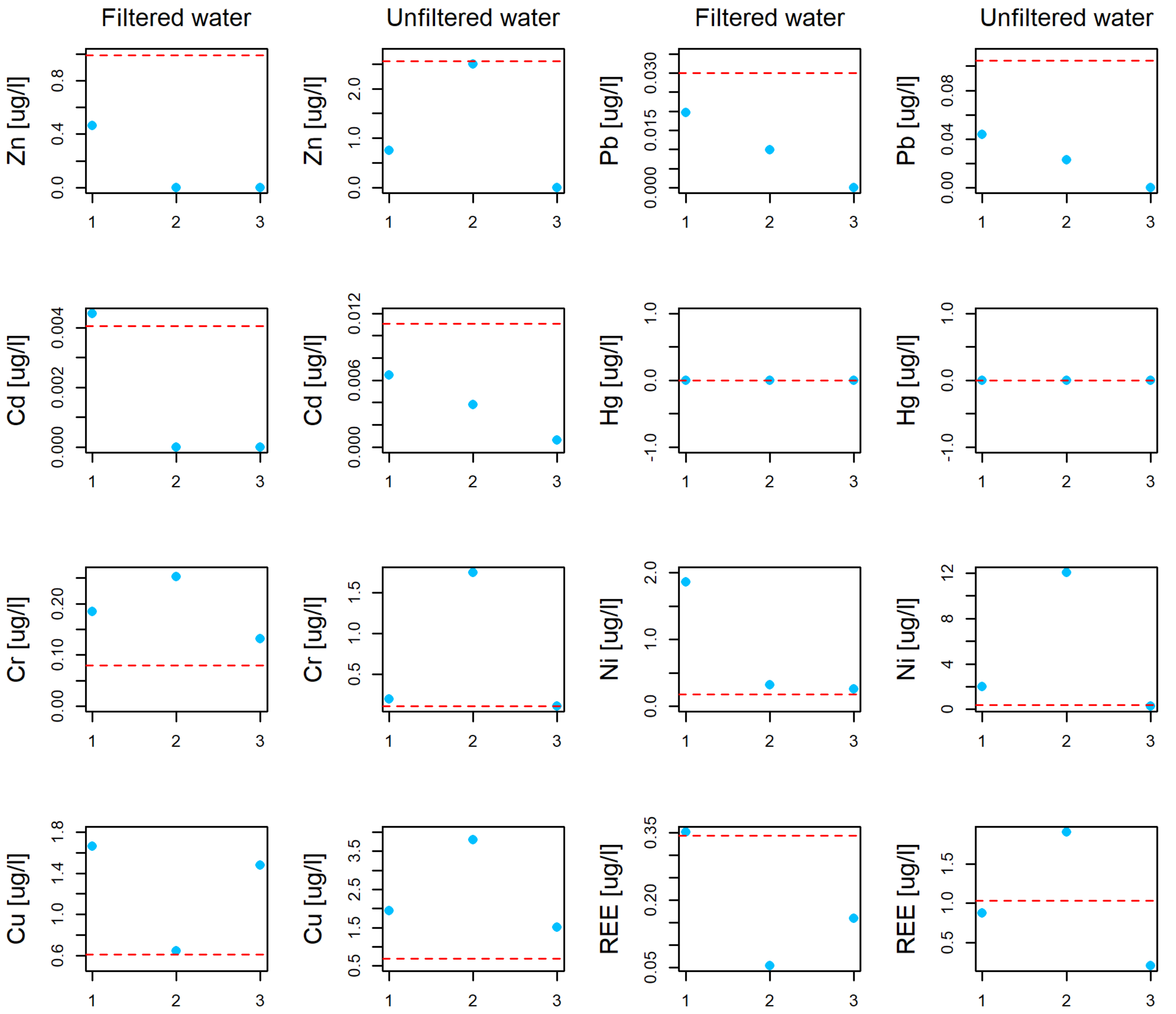


Figure 3.5. Boxplots of concentrations of Zn, Pb, Cd, Hg, Cr, Ni, Cu and REE in freshwater samples (filtered and unfiltered) collected as baseline data during fieldwork in summer 2022 at Siggu Nunaa. The numbers on the x-axis refer to the site numbers in Figure 3.4. The dashed red lines represent the Greenland median values from Fritt-Rasmussen et al. (2023). REE is calculated as the sum of the individual median concentrations of 17 REEs, except Pm.

3.6 GEUS stream sediment data

Apart from AMDA data, another important source of information on the environmental chemistry of the area of interest is the *Geochemical Atlas of Greenland – West and South Greenland* (Steenfelt 2001a). This atlas contains element concentrations measured in stream sediment samples collected by GEUS during different geological surveys. The data can be browsed and downloaded freely from The Greenland Mineral Resources Portal (www.greenmin.gl). The geochemical data from the stream sediment samples are interpreted to represent the surrounding catchment area and are therefore a good exploration tool. A description of sampling procedures, analysis methods and data processing are provided by Símun Dalsenni Olsen, GEUS, as follows:

"Stream sediment samples were collected from 1979 to 1998 with as even a coverage as possible from low-order streams and with a sampling density of mostly around 1 sample per 30 km². The 0.1 mm grain size fractions of 500 g samples were analysed for major and trace elements by up to five different methods: X-Ray Flourenscence Spectrometry, Instrument Neutron

Activation, Inductively Coupled Plasma, Atomic Absorption Spectrometry, and Delayed Neutron Counting. The final consistent dataset, 'Batch 2005', contains data from 7122 samples, analysed for up to 43 elements (Steenfelt 2001a). The data is chosen after calibration, careful quality control, and elimination of analytical bias (see Steenfelt 1999, 2001b for details on data selection and calibration). In 'Batch 2005', values below detection limit are indicated by the digit 0. Major elements are given on a volatile free basis. Before 1997, sample sites were originally marked on topographic maps at the scale 1:100,000 and their positions were later digitised and later again corrected, when a new topographic reference was introduced around year 2000. From 1997 onwards, GPS was used to determine sample positions."

Within the area of interest, there are data on 617 GEUS stream sediment samples collected between 1989 and 1998. Based on these samples (and an additional 393 samples in a 100 km buffer zone around the aera of interest), we have produced interpolated maps of the most relevant elements (Figure 3.6). The element concentrations were interpolated in a grid with a cell size of 250 m using Empirical Bayesian Kriging in ArcGIS Pro 3.0.2 (Esri 2022) with multiplicative skewing data transformation (with empirical base function) and a K-Bessel semi-variogram model. The maps include the elements Cu, Zn, Ni and Cr. It was not possible to produce maps for Pb, Hg and Cd as data on these elements were missing. It is important to note that data from the potentially polluted area around Maarmorilik are not excluded in the maps in Figure 3.6.

Overall, there is a good correspondence between the area of interest baseline data from AMDA (Figure 3.4 and Figure 3.5, Appendix 2) and the GEUS stream sediment data (Figure 3.6). Both datasets indicate relatively high background values of Cu, Ni and Cr in Siggu Nunaa. The GEUS data indicate high concentrations of Zn at Maarmorilik but also further north in the bottom of Kangerluarsuk Fjord outside the polluted area.

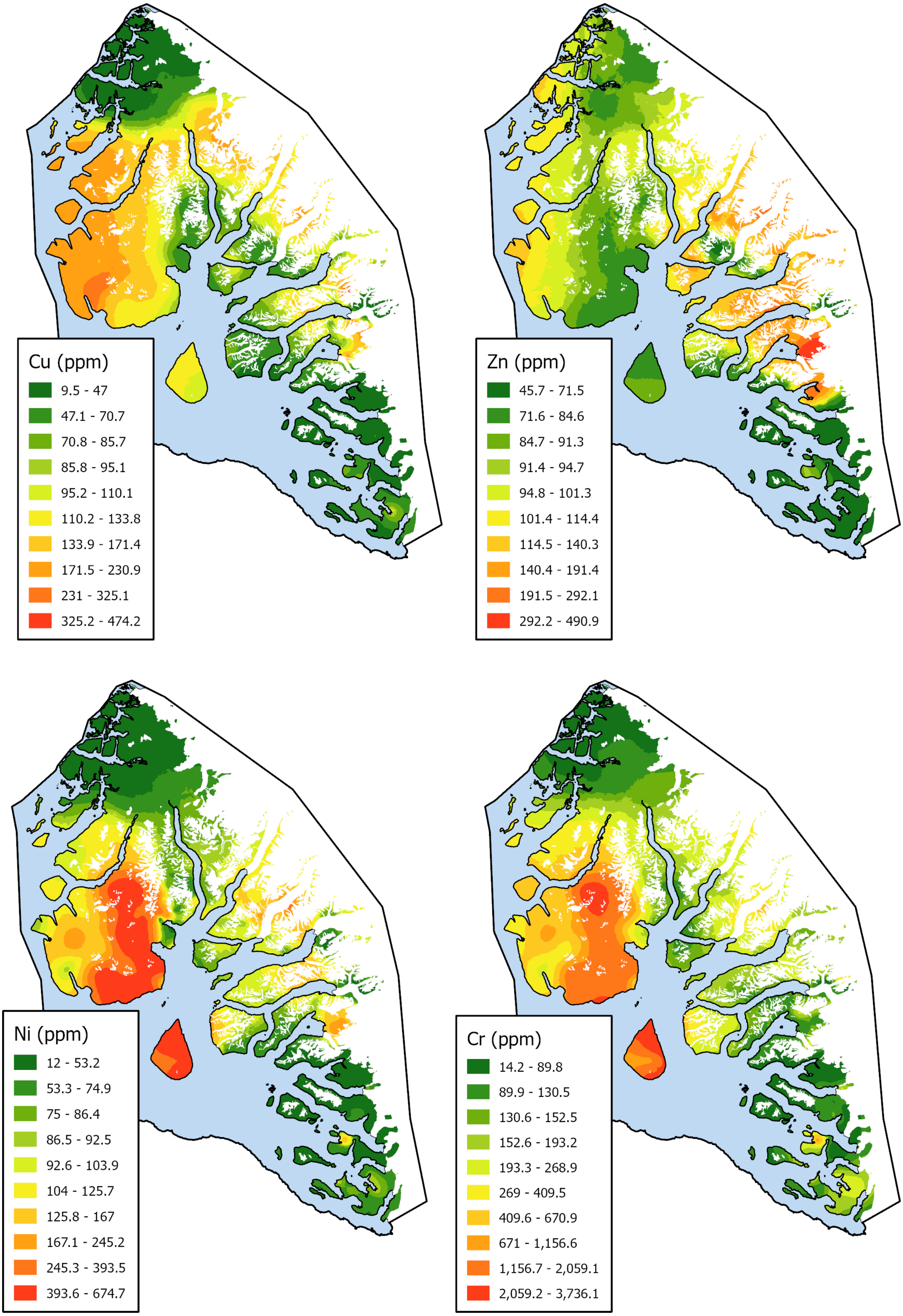


Figure 3.6. Interpolated maps of concentrations of Cu, Zn, Ni and Cr in stream sediment samples based on data from Steenfelt (2001a).

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4 Biodiversity and biologically important and protected areas

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4.1 Introduction

The area north of Nuussuaq peninsula and south of Upernavik (i.e., the Area of Interest, AOI) is located in high Arctic west Greenland. The average annual temperature is -1 °C, and the average annual precipitation is 190 mm. The biodiversity of vascular plants is low, while wetland areas on Sigguup Nunaa hold a high diversity of birds, including moulting and breeding geese.

This chapter gives an overview of the biological environment of the AOI, including a presentation of the regularly occurring fauna as well as the significance of the populations at three different scales: AOI, Greenland and global scale. Furthermore, the threat status according to the red list (summarised based on the IUCN threat categories: LC, least concern; NT, near threatened; VU, vulnerable; EN, endangered; and CR, critically endangered) at national level is presented. Table 4.1 summarises this information for the fauna and Table 4.2 for the flora.

As the offshore areas are not part of the RBA, only marine mammals and fish occurring in the coastal environment are included. Information on the offshore areas can be found in the strategic environmental impact assessments for Disko West (Boertmann & Mosbech 2020) and Baffin Bay (Boertmann & Mosbech 2017).

Information on protected areas, description of vegetation mapping as well as biologically important areas is presented. Due to lack of specific knowledge of distribution and diversity, fungi, bryophytes, and invertebrates are not included in this report.

For location names mentioned in the text, please refer to Figure 1.1, the species-specific figures in this chapter as well as Oqaasileriffik (the language secretariat of Greenland) at NunaGIS (https://nunagis-asiaq.hub.arcgis.com/pages/kortportal.

4.2 Mammals

4.2.1 Terrestrial mammals

There are seven naturally occurring land mammals in Greenland of which only two are found within the AOI: Arctic fox (*Vulpes lagopus*), and Arctic hare (*Lepus arcticus*).

The fox and hare are found throughout the area, but their numbers are unknown. The hare is a valued game animal (open-quota hunting from August to April), while the fox is hunted mainly as it is a vector for rabies with open-quota hunting from mid-September to mid-May. Both have a favourable conservation status and are assessed as "least concern" (LC) on the Greenland red list (Boertmann and Bay 2018).

Caribou (*Rangifer tarandus*) were found in the AOI until the 1960s. By using the trading and hunting statistics from Upernavik (to which the AOI belonged) as a proxy for the actual number of animals, a peak in numbers occurred around the 1850s, followed by a steep decline. Since 1966, no caribou have been killed within the AOI (Meldgaard 1986).

Muskoxen (*Ovibos moschatus*) were introduced to Sigguup Nunaa in 1991 (see Chapter 5.2 and Figure 5.2) and are thus not naturally occurring in the area. The most recent survey from 2002 estimated a population of 193 animals (Cuyler et al. 2019). Since then, the Greenland Government has assessed the population to have increased and combined with local knowledge, quota-based harvesting was implemented several years ago. In 2022, the annual hunting quota was 150 animals, though the current population size remains unknown.

4.2.2 Marine mammals

Several marine mammals occur in the waters of the AOI. There are five seals (including walrus*, Odobenus rosmarus*), six whales as well as polar bear (*Ursus maritimus*). Most of the whales and hooded seal (*Cystophora cristatus*) occur mainly in offshore waters and are of less importance to this report. Walrus is primarily found in offshore waters, but during winter and spring may be found in the waters west of Sigguup Nunaa, i.e., in the western part of the AOI (Hansen et al. 2022). Some seal species occur frequently in the coastal waters and in the fjords. This applies to ringed seal (*Pusa hispida*), harp seal (*Pusa groenlandica*) and bearded seal (*Erignathus barbatus*). Among the whales, especially minke whale (*Balaenoptera acutorostrata*), fin whale (*Balaenoptera physalus*) and humpback whale (*Megaptera novaeangliae*) are often observed in the fjords in summer, while in winter narwhal (*Monodon monoceros*) and white whale/beluga (*Delphinapterus leucas*) occur.

The Uummannaq fjord is an important area for narwhal in late autumn and early winter (October – January), but they are also found at the edge of the fast ice in Uummannaq in spring. The animals within the AOI belong to the 'Somerset Island stock' that spend the summer around Prince Regent Inlet and adjacent waters in Canada. They migrate to Baffin Bay during autumn. Some of these animals move into the Uummannaq fjord system and stay there between October and December. The most recent survey of narwhal in Baffin Bay is from March-April 2012, where the number of animals was estimated to approx. 18.000, but the number of animals staying in the Uummannaq region is unknown. However, in the 1990's up to 1000 animals were caught in some years, but the annual hunting quota is now 154 per year for the Uummannaq region (Hansen and Nielsen 2022).

Bowhead whale is usually a spring visitor in the outer parts of Uummannaq Fjord, but in July 2022 several were observed in the bay Tasiusap Imaa in southwestern Sigguup Nunaa during the RBA-field work (Boertmann et al. 2023; see also Chapter 1 and Appendix 1 for more information on the field work that took place in summer 2022).

Polar bear is mainly a winter visitor and most frequent in the northernmost part of the AOI (Born & Laidre 2017), particularly when the West Ice reaches the coast.

4.3 Birds

The field work in 2022 had a focus on bird surveys (see Appendix 1 for further information).

The most abundant birds in the terrestrial environment of the AOI are the passerines. Snow bunting (*Plectrophenax nivalis*), Lapland bunting (*Calcarius lapponicus*), northern wheatear (*Oenanthe oenanthe*), common redpoll (*Carduelis flammea*) as well as raven (*Corvus corax*) breed commonly in the area. They are all widespread in Greenland, have a favourable conservation status, and seen from a conservational point of view, the region is of low importance for the populations. Most of the passerines, except for the ravens and a few snow buntings, leave Greenland for the winter.

During the field work in 2022, snow bunting, northern wheatear and common redpoll were recorded in unexpectedly low numbers, and only Lapland bunting was common at all three surveyed sites. This could be a result of a very late spring, resulting in, e.g., that Lapland buntings fledged chicks two to three weeks later than usual.

Table 4.1. Mammals and birds in the AOI including their habitat (F, Freshwater; M, Marine; T, Terrestrial), and national as well as global red list status (IUCN threat categories: LC, least concern; NT, near threatened; VU, vulnerable; EN, endangered; DD, data deficient; NE, not evaluated). Furthermore, the occurrence in the AOI (B, breeder; W, winter visitor; S, summer visitor; SP, spring visitor), the importance of the AOI to the population in summer and winter (L, low; M, medium; H, high; 0, does not occur; ?, unknown), and the importance of the AOI for the international population. *Assessed as the combined populations from North America, Greenland, and Eurasia. **Endemic subspecies. Data based on Boertmann and Bay (2018). The current red list classification according to IUCN can be found at www.iucn.redlist.org.

			Red list status			Importance of AOI to population		Importance of population to global population
Species	Scientific name	Habitat	Greenland	International	Occurrence	Summer	Winter	
Mammals								
Polar bear	*Ursus maritimus*	M (T)	VU	VU	W	0	L	L
Walrus	*Odobaenus rosmarus*	M	VU	NT	W	0	L	L
Hooded seal	*Cystophora cristata*	M	LC	VU	S	0	L	L
Bearded seal	*Erignathus barbatus*	M	LC	LC	S, W	0	L	L
Harp seal	*Pusa groenlandica*	M	LC	LC	S	0	L	L
Ringed seal	*Pusa hispida*	M	LC	LC	S, W	M	M	M
Bowhead whale	*Balaena mysticetus*	M	NT	LC	SP (S)	L	L	L
Minke whale	*Balaenoptera acutorostrata*	M	LC	LC	S	L	0	L
Fin whale	*Balaenoptera physalus*	M	LC	VU	S	L	0	L
Humpback whale	*Megaptera novaeangliae*	M	LC	LC	S	L	0	L
White whale	*Dephinapterus leucas*	M	VU	LC	W	0	M	H
Narwhal	*Monodon monoceros*	M	NT	LC	W	0	M	H
Birds								
Red-throated diver	*Gavia stellata*	F (M)	LC	LC	B	L	0	L
Great northern diver	*Gavia immer*	F (M)	NT	LC	B	L	0	L
Northern fulmar	*Fulmarus glacialis*	M	LC	LC	B	H	0	H
Great cormorant	*Phalacrocorax carbo*	M	LC	LC	B	M	0	M
Greenland white-fronted goose	*Anser albifrons flavirostris*	F, T	EN	LC*	B	H	0	H
Snow goose	*Anser caerulescens*	F, T	LC	LC	B	L	0	L
Canada goose	*Branta canadensis*	F, T	LC	LC	B	H	0	M
Mallard**	*Anas platyrhynchos conboschas*	F, M	LC	LC	B	M	0	M
Common eider	*Somateria mollissima*	M	LC	NT	B	M	0	L
King eider	*Somateria spectabilis*	M	LC	LC	S	H	L	H

Harlequin duck	*Histrionicus histrionicus*	F (M)	LC	LC	B	L	0	L
Long-tailed duck	*Clangula hyemalis*	F, M	LC	VU	B	M	0	M
Red-breasted merganser	*Mergus serrator*	F, M	LC	LC	B	L	0	L
Peregrine falcon	*Falco peregrinus*	T	LC	LC	B	L	0	L
Gyrfalcon	*Falco rusticolus*	T	NT	LC	B, W	L	L	L
Ptarmigan	*Lagopus mutus*	T	LC	LC	B, W	L	L	L
Ringed plover	*Charadrius hiaticulus*	T	LC	LC	B	L	0	L
Purple sandpiper	*Calidris maritima*	T	LC	LC	B	L	0	L
Red-necked phalarope	*Phalaropus lobatus*	F (M)	LC	LC	B	M	0	M
Arctic skua	*Stercorarius parasiticus*	M	LC	LC	B	L	0	L
Sabine’s gull	*Larus sabini*	M	NT	LC	B	L	0	L
Iceland gull	*Larus glaucoides*	M	LC	LC	B	L	0	L
Glaucous gull	*Larus hyperboreus*	M	LC	LC	B, W	L	0	L
Kittiwake	*Rissa tritridactyla*	M	VU	VU	B	M	0	M
Thick-billed murre	*Uria lomvia*	M	VU	LC	B	L	0	L
Razorbill	*Alca torda*	M	LC	LC	B	L	0	L
Atlantic puffin	*Fratercula arctica*	M	VU	VU	B	L	0	L
Northern wheatear	*Oenanthe oenanthe*	T	LC	LC	B	L	0	L
Raven	*Corvus corax*	T	LC	LC	B, W	L	L	L
Redpoll	*Achantis flammea*	T	LC	LC	B	L	0	L
Lapland bunting	*Calcarius lapponicus*	T	LC	LC	B	L	0	L
Snow bunting	*Plectrophenax nivalis*	T	LC	LC	B	L	0	L

One passerine species, Arctic redpoll (*Acanthis hornemanni*) does not breed within the AOI but is a winter visitor from the northern part of Greenland.

Rock ptarmigan (*Lagopus mutus*) is usually rather common and occurs throughout the AOI. Ptarmigan may leave the area for the winter, and migrants from the north move through the AOI in spring and autumn. During the field work in summer 2022, rock ptarmigan was less abundant than expected.

Two shorebirds breed in terrestrial habitats in the AOI: purple sandpiper (*Calidris maritima*) and common ringed plover (*Charadrius hiaticula*). None of these are common, but they are widespread in Greenland, and seen from a conservational point of view the AOI is of low importance to the population in Greenland. Unexpectedly, sandpiper was not observed during the field work in 2022, though the visited habitats seemed optimal for this species. The late spring may have forced the breeding birds to give up their breeding attempts.

Two birds of prey breed in the AOI, peregrine falcon (*Falco peregrinus*) and gyrfalcon (*Falco rusticolus*). Peregrine falcon is probably rather common, and the species is also widespread in most of Greenland. The population is thriving and has a favourable conservation status. Peregrines are migratory, leaving Greenland for the winter. Breeding peregrines use the same nesting cliff from year to year. During the nesting period they are sensitive to disturbance (Christensen et al. 2016). Gyrfalcon breeds in low numbers in the AOI. Gyrfalcons are stationary, and the winter population is supplemented with birds from northern parts of Greenland and Arctic Canada. The Greenland population is assessed as "near threatened" (NT) on the Greenland red list due to a very small population (Boertmann and Bay 2018). Seen from a conservational point of view, the AOI is of no particular significance to the population. Breeding gyrfalcons often use the same nest year after year, and they are very sensitive to disturbance while nesting. None of the two falcon species was observed during the field work in 2022.

White-tailed eagle (*Haliaeetus albicilla*) is a rare summer visitor in the AOI as its northern distribution limit is around the Disko Bay area (Boertmann 2002). In 2022, feathers from an immature bird were found at Sigguup Nunaa, though, and Egevang & Boertmann (2012) report an observation from the same area in 2010.

During the breeding time, several bird species are associated with freshwater habitats: great northern diver (common loon, *Gavia immer*) is found in large lakes, and due to a small population in Greenland it is assessed as "near threatened" (NT) on the Greenland red list. Another diver, red-throated diver (*Gavia stallata*), breeds at small lakes and ponds near the coast and is rather common. Both divers leave Greenland for the winter. The two species were both observed during the 2022-field work. Red-throated diver bred at all tree study sites, while great northern diver overflew the study sites on their way from breeding sites elsewhere to their marine foraging areas.

Mallard (*Anas plathyrhynchos*), long-tailed duck (*Clangula hyemalis*), harlequin duck (*Histrionicus histrionicus*) and red-necked phalarope (*Phalaropus lobatus*) all breed near freshwaters in the AOI. Harlequin duck is often seen at rivers in low numbers, while the other species are more abundant at lakes and ponds. Red-necked phalaropes leave Greenland for the winter, while the other three species spend the winter in coastal waters of southwest Greenland.

Mallard is common and widespread; long-tailed duck breeds here and there in low numbers. Note that long-tailed duck is assessed as "vulnerable (VU)" on the global red list (BirdLife International 2018). Both mallard and long-tailed ducks were observed at all three study sites during the field work in 2022. Red-necked phalarope was one of the most common birds observed at all three study sites in 2022. Harlequin duck was only observed at one of the sites and is apparently rare in the AOI.

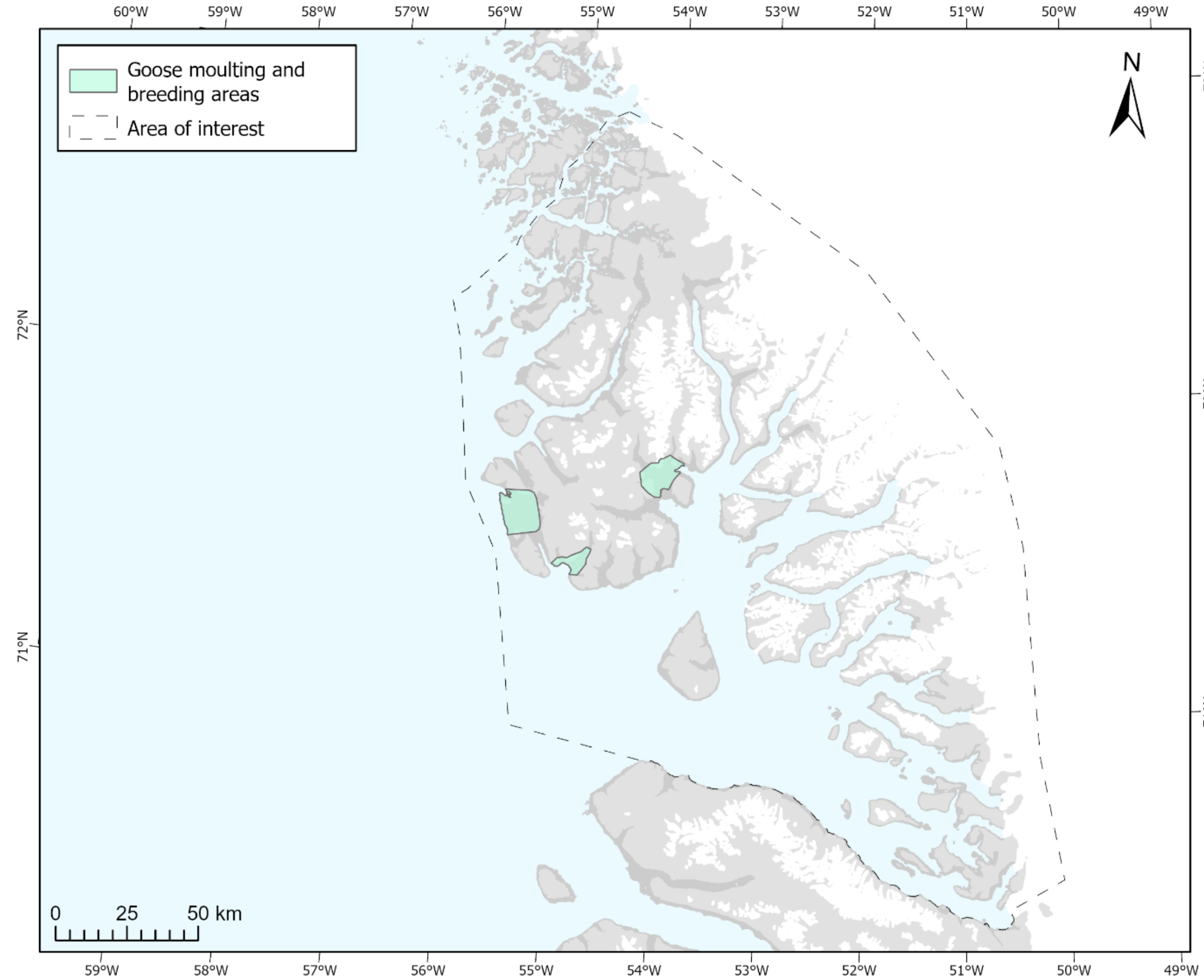

Figure 4.1. Three areas with moulting and breeding geese in the AOI. The areas correspond to three large wetlands on the Sigguup Nunaa. These areas are the goose moulting and breeding areas indicated on the map.

Geese are among the most significant species in the inland areas of the AOI. They are primarily found in the large wetlands of Sigguup Nunaa, where thousands of geese both breed and moult (Figure 4.1). The most numerous species is Canada goose (*Branta canadensis*) of which 4400 individuals were counted in the two important wetlands surveyed in 2022. These were almost all non-breeding moulting birds, and only a few family flocks were observed. Similarly, 375 moulting Greenland white-fronted geese (*Anser albifrons flavirostris*) were counted in these areas. Both species breed here, but family flocks are usually very shy and avoid areas with many moulting birds. Greenland white-fronted goose has an unfavourable conservation status due to a very small and decreasing population (n = approx. 20,000 in spring 2021, Fox et al. 2021) and is therefore assessed as "endangered (EN)" on the Greenland red list (Boertmann & Bay 2018).

The third goose species breeding and moulting in the area is snow goose (*Anser caerulescens*), which was seen in low numbers (n = 14, all non-breeders) in the two wetlands during the field work in summer 2022. Furthermore, light-bellied brent geese (*Branta bernicla hrota*) occur in the AOI as migrant visitors in spring and autumn when they move between wintering sites in Ireland and breeding grounds in Arctic Canada and northwest Greenland.

The two wetland areas Tasiusaq and the area between the Itsaku peninsula and the peak Umiviip Qaqqaa (the southern and eastern markings in Figure 4.1, respectively) surveyed in 2022 are extremely important for geese. A third area, the Narsaq plains, was not surveyed in 2022, but data from previous surveys in the 1990s indicate that this area is of equal importance. The other parts of the AOI are predominantly alpine with restricted distribution of wetlands, but both Canada and white-fronted geese are likely to occur in these wetlands, albeit in low numbers.

Underlining the high value of one of these wetlands is, e.g., the breeding of tundra swans (*Cygnus columbianus*) from 1990 to 1998 in the wetland between the Itsaku peninsula and the peak Umiviip Qaqqaa. During this period, a pair of tundra swans raised young almost every year. Tundra swan breeds in the Canadian Arctic, and the species has, apart from this breeding pair, only been observed a few times in Greenland. Another rare visitor in Greenland is sandhill crane (*Antigone canadensis*), which was observed in the other important Tasiusaq wetland in July 2022.

King eiders (*Somateria spectabilis*) breeding in high Arctic Canada assemble in late summer in some specific fjord areas to moult, and the birds become (like the geese) flightless for three weeks. The straits and fjords in the northernmost part of the AOI and the long narrow fjord Umiiarfik are very important as moulting areas for king eiders (Figure 4.2).

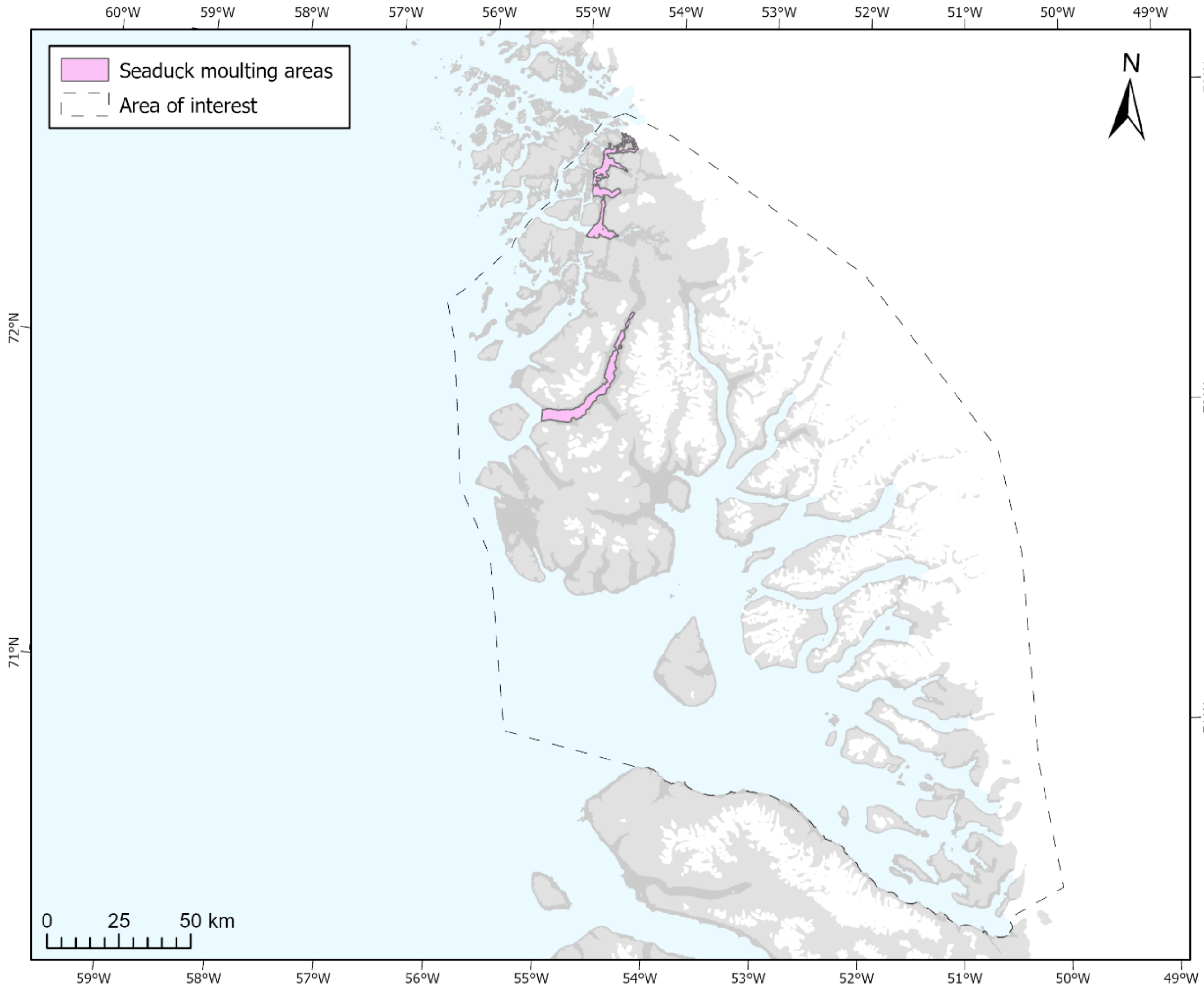

Figure 4.2. Important moulting areas for common eider, king eider and other seaducks (after Boertmann et al. 2022a).

There are numerous breeding colonies of seabirds in the AOI (Boertmann et al. 1996; see Figure 4.13 for a map of all colonies). Most colonies only have a limited number of birds (< 100 pairs), but there are some colonies, which hold very high numbers of breeding birds. The largest colonies are those of northern fulmar (*Fulmarus glacialis*), where tens of thousands of birds nest on steep cliff faces (Figure 4.3). Another species breeding in very large colonies is Arctic tern (*Sterna paradisaea*), where large colonies are found on some of the islands, especially Schades Øer (Qeqertat; Figure 4.4).

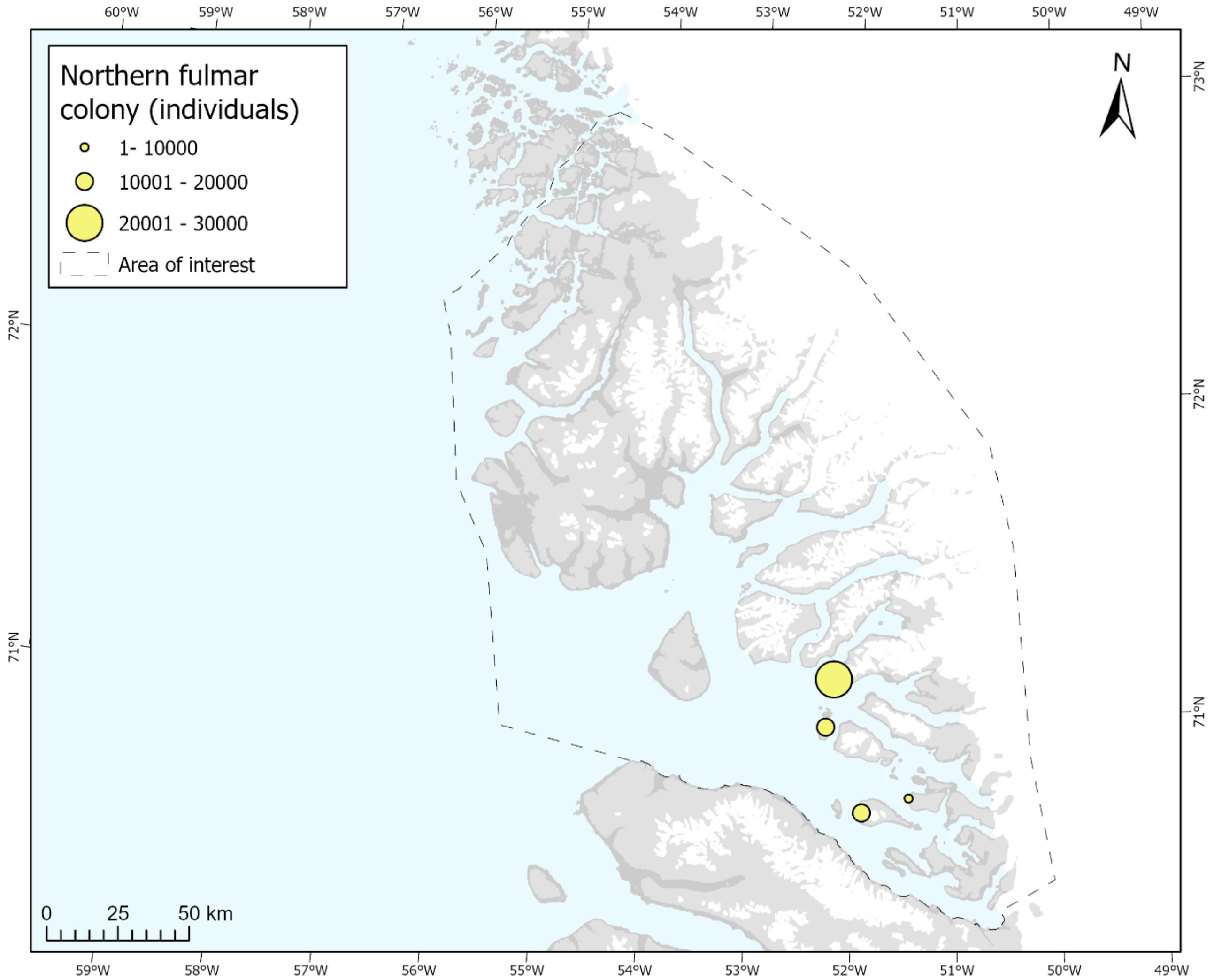

Figure 4.3. Northern fulmar colony locations and sizes in numbers of breeding individuals. Data from The Greenland Seabird Colony Register maintained by DCE and GINR.

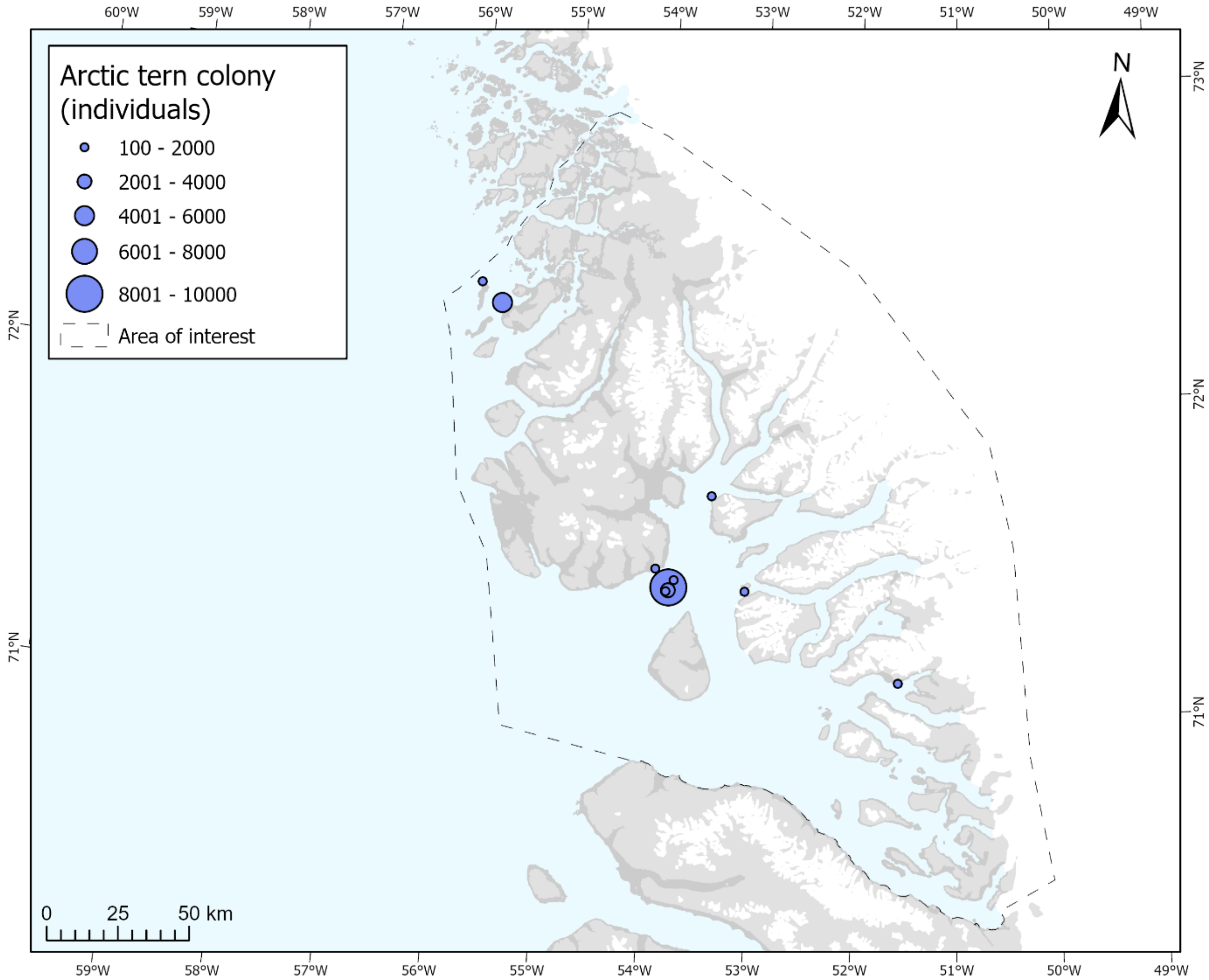

Figure 4.4. Arctic tern colony locations and sizes in numbers of breeding individuals. Data from The Greenland Seabird Colony Register maintained by DCE and GINR.

The widespread colonial species include black guillemot (*Cepphus grylle*) and the large gull species glaucous and Iceland gulls (*Larus hyperboreus* and *L. glaucoides*), but great cormorant (*Phalacrocorax carbo*), common eider (*Somateria mollissima*, figure 4.5) and razorbill (*Alca torda*, figure 4.6) also breed at many sites. In the early to mid-1900s, there were large colonies of kittiwakes (*Rissa tridactyla*, Figure 4.7) and one very large colony with thick-billed murre (*Uria lomvia*) at the island of Salleq. These colonies subsequently declined, the latter to extinction. However, some of these colonies seem to have recovered recently; thus, the field work in 2022 revealed that kittiwakes were again present in high numbers at Salleq, and that thick-billed murres had returned to the site after decades of absence, though in low numbers (n = 30 birds in early August) so far.

The rare gull species Sabine's gull (*Larus sabini*, Figure 4.8) was found breeding among Arctic terns at Schades Øer in 2010, and Atlantic puffin is known from a few colonies on the westernmost coasts e.g., at Sigguup Nunaa (Figure 4.9).

Non-colonial seabirds breeding in the AOI include Arctic skua (*Stercorarius parasiticus*) and red-breasted merganser (*Mergus serrator*) (the latter also occurs at lakes and rivers inland).

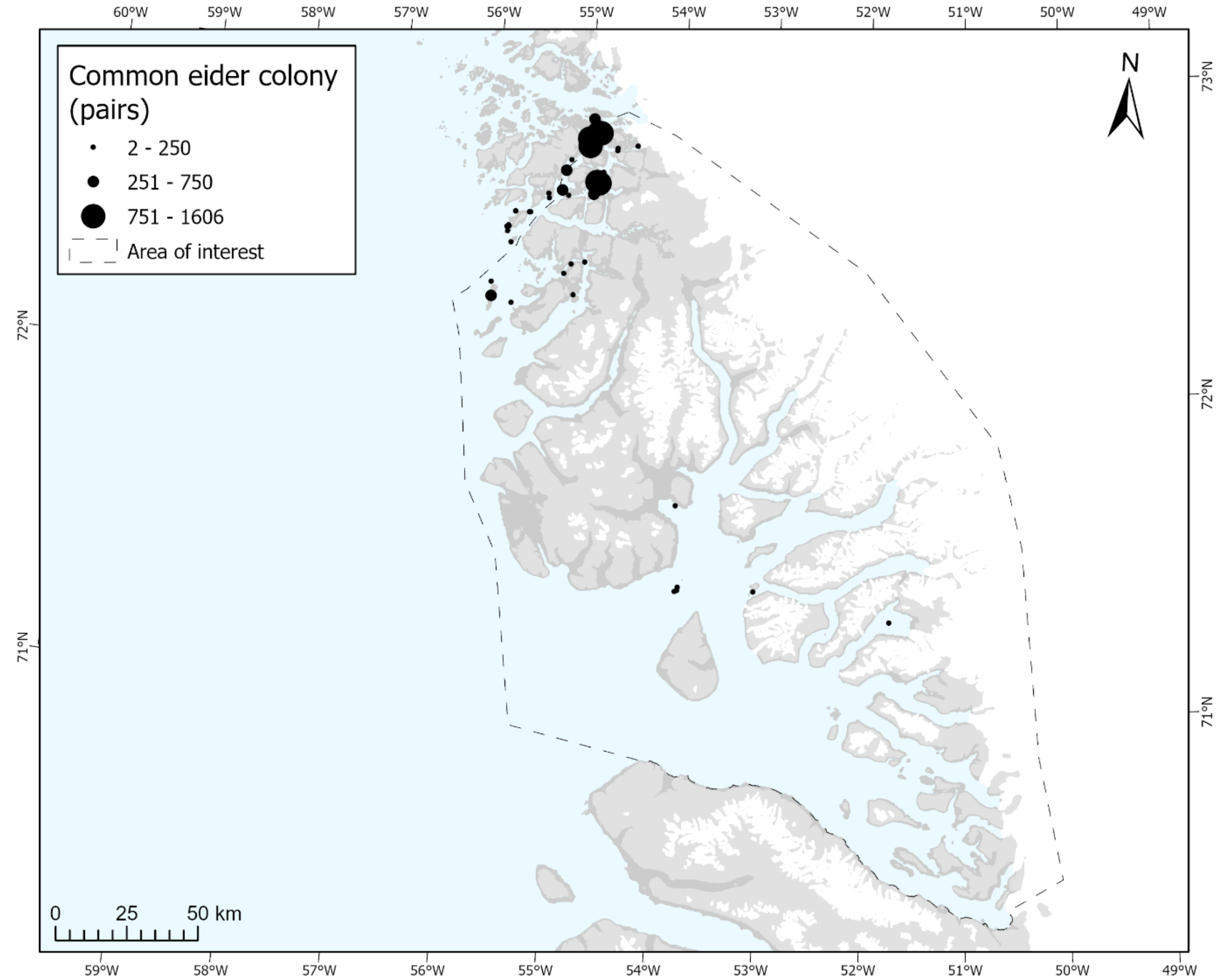

Figure 4.5. Common eider colony locations and sizes in numbers of breeding pairs (nests). Data from The Greenland Seabird Colony Register maintained by DCE and GINR.

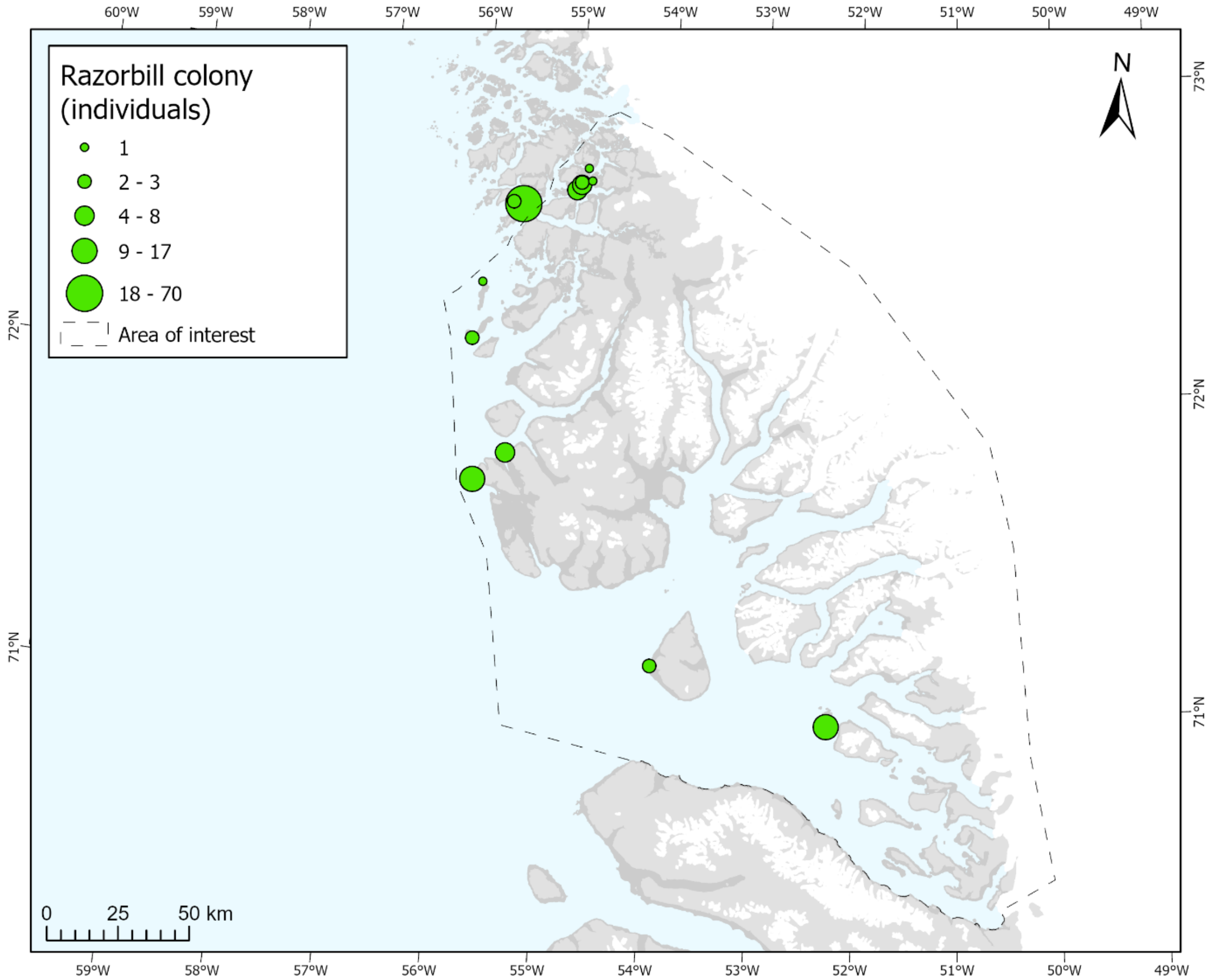

Figure 4.6. Razorbill colony locations and sizes in numbers of breeding individuals. Data from The Greenland Seabird Colony Register maintained by DCE and GINR.

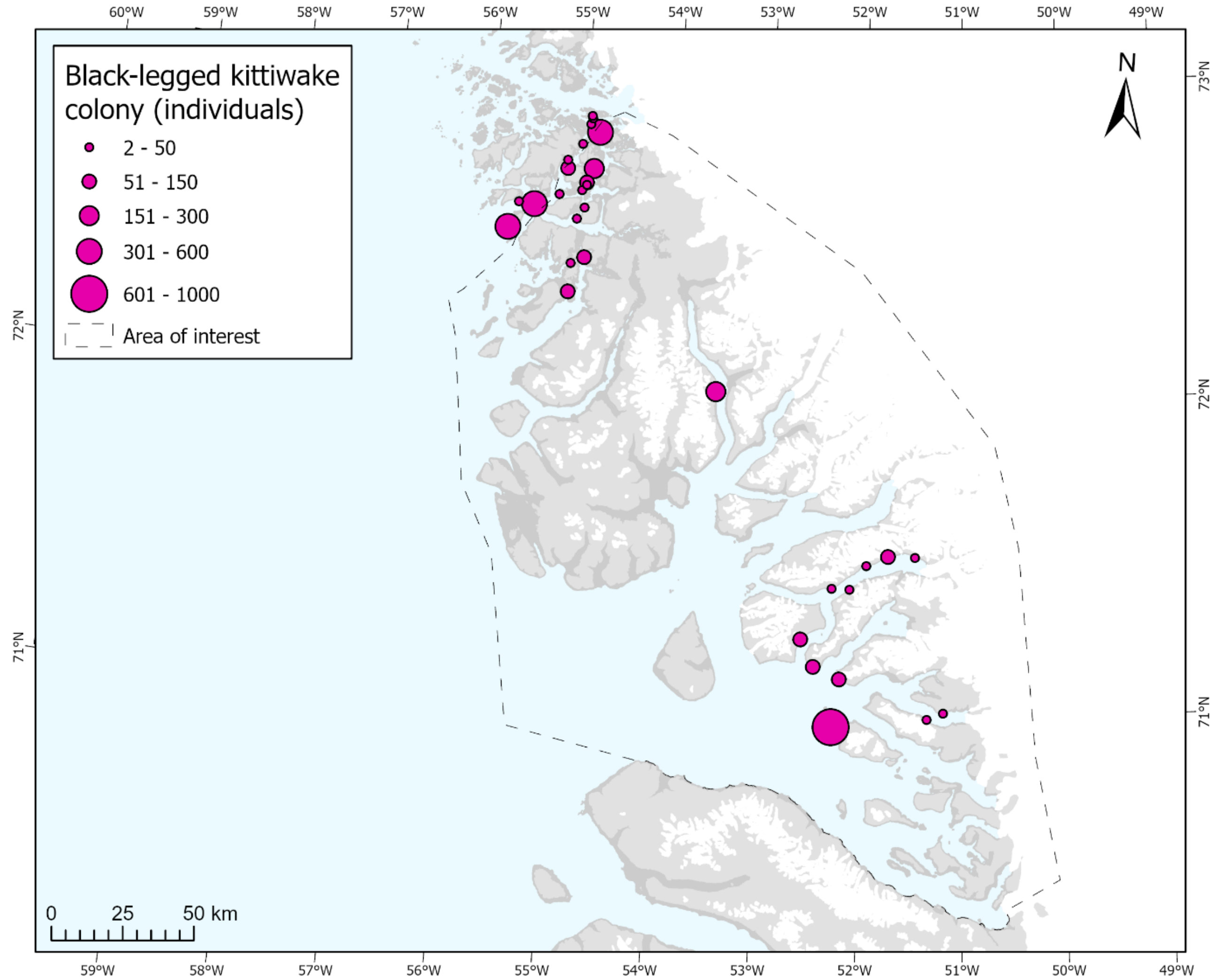

Figure 4.7. Black-legged kittiwake colony locations and sizes in numbers of breeding individuals. Data from The Greenland Seabird Colony Register maintained by DCE and GINR.

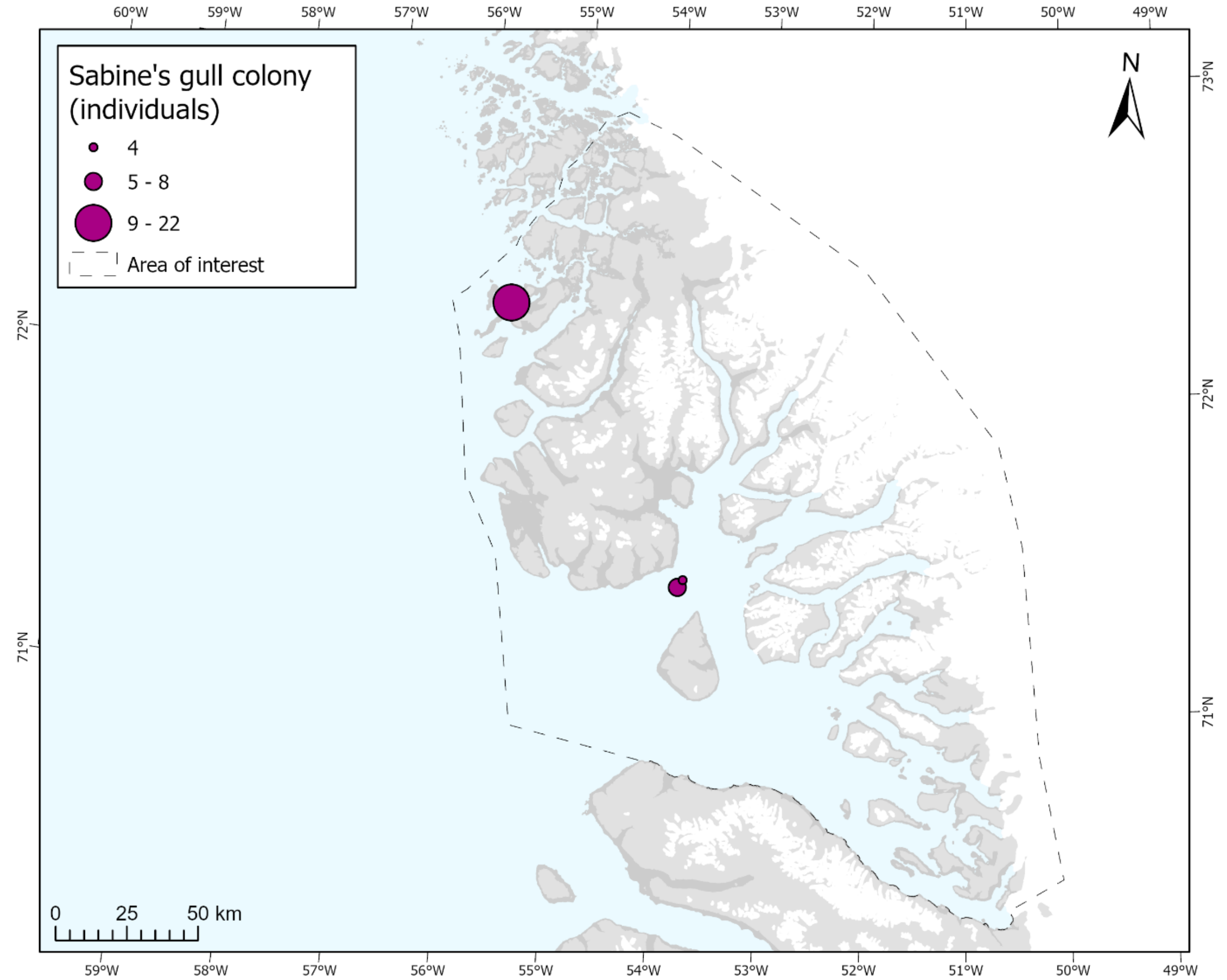

Figure 4.8. Sabine's gull colony locations and sizes in numbers of breeding individuals. Data from The Greenland Seabird Colony Register maintained by DCE and GINR.

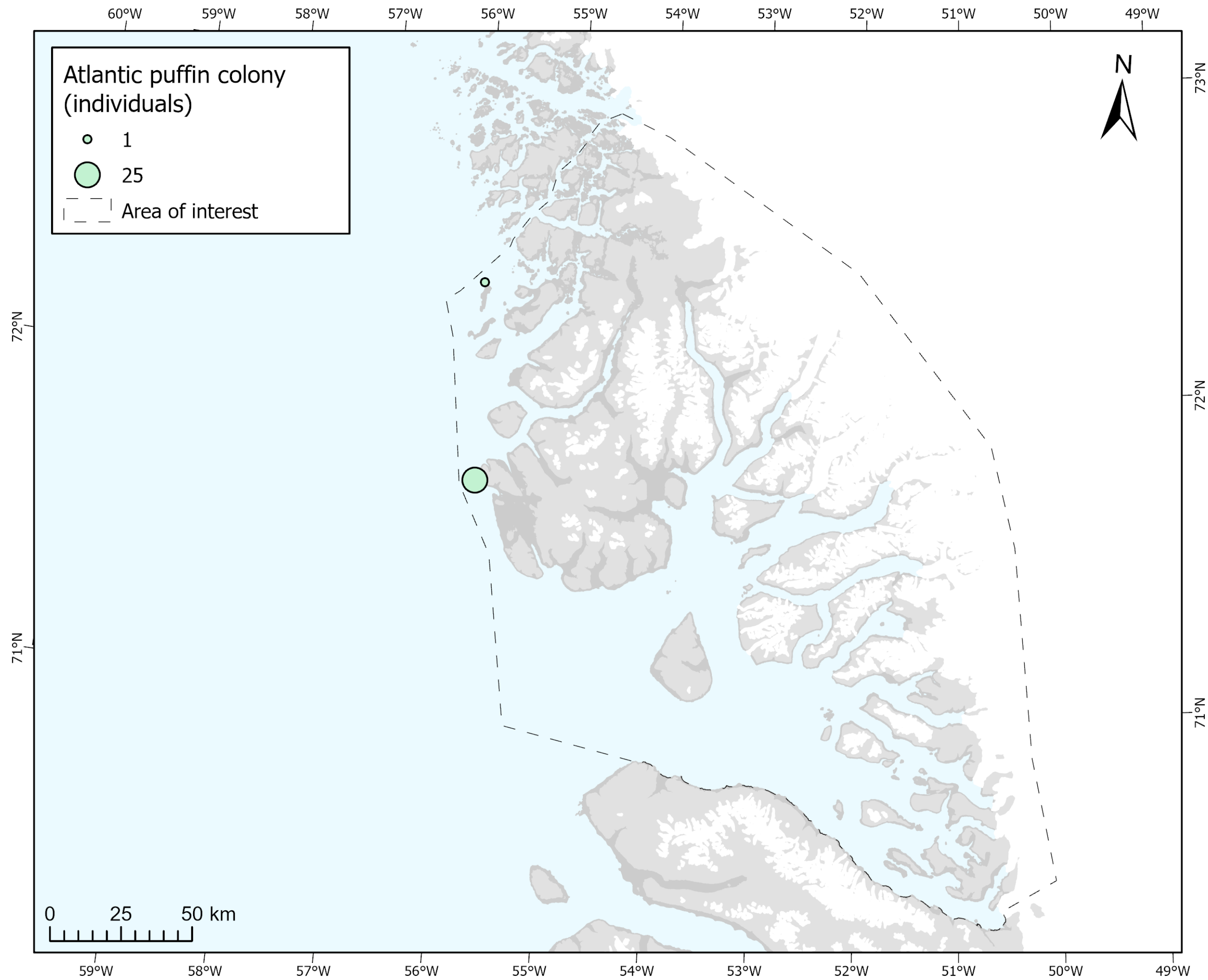

Figure 4.9. Atlantic puffin colony locations and sizes in numbers of breeding individuals. Data from Greenland Seabird Colony Register.

4.4 Fish and shellfish

West Greenland waters are in general rich in fish and shellfish, though within the AOI less so. Within the AOI, two marine fish species spawn in spring in the shallow coastal waters. These are capelin (*Mallotus villosus*) and lumpsucker (*Cyclopterus lumpus*). The capelin spawning areas are found along many coasts of Ummannaq fjord and in the straits and fjords north of Sigguup Nunaa (Petersen 1993a, Petersen 1993b, Olsvig & Mosbech 2003). Lumpsucker fishing areas are few (Olsvig & Mosbech 2003): in southern Uummannaq Fjord and in the strait of Sullua near Upernavik Kujalleq. Petersen (1993a and 1993b) do not mention lumpsucker in his review of fishing and hunting in waters close to Upernavik and Uummannaq. Arctic char (*Salvelinus alpinus*) is an important species for subsistence.

A review of relevant fish species, including maps of catches, which may also be used as proxies for their relative occurrence, are found in Chapter 5 "Human use".

4.5 Vegetation

4.5.1 Red listed plant species

Almost 380 taxa of vascular plants are known from West Greenland between 62°20′ and 74°N (Fredskild 1996). Of these, approximately 170 can be found in the AOI. Six of these taxa are red listed (vulnerable and near threatened) on the Greenland Red List 2018 and have been found within the AOI (Table 4.2; Boertmann and Bay 2018). None of these taxa are unique to the AOI, but all of them have their West Greenland northern distribution limit within the AOI.

The distribution of the historically known observations of red listed plants is shown in Figure 4.10. The figure is based on digitisation of maps reporting and analysing herbarium specimens (Fredskild 1996) collected primarily between 1962 and 1996 in the Greenland Botanical Survey. Both dots (the observations) and a buffer zone (3.5 km radius, cut off by the coastline and 800 m altitude) around each observation point are shown on the distribution map as the geographical precision of the dots is low.

Table 4.2. Red listed taxa of vascular plant species in the AOI according to the Greenland Red List (Boertmann and Bay 2018). The IUCN categories (NT: near threatened, VU: vulnerable) as well as the vegetation type, in which they are found, are shown.

Species	Author	Red list status	Veg. type
Braya novae-angliae	(Rydb.) Th.Sør.	VU	Fell field
Festuca groenlandica	(Schol.) Frederiksen	NT	Dwarf shrub heath
Ledodendron vanhoeffeni	(Abromeit) Dalgaard & Fredskild	VU	Dwarf shrub heath
Myriophyllum spicatum ssp. *exalbescens*	L.	NT	Lake
Poa flexuosa	Sm.	NT	-
Puccinellia rosenkrantzii	Th. Sør.	VU	-

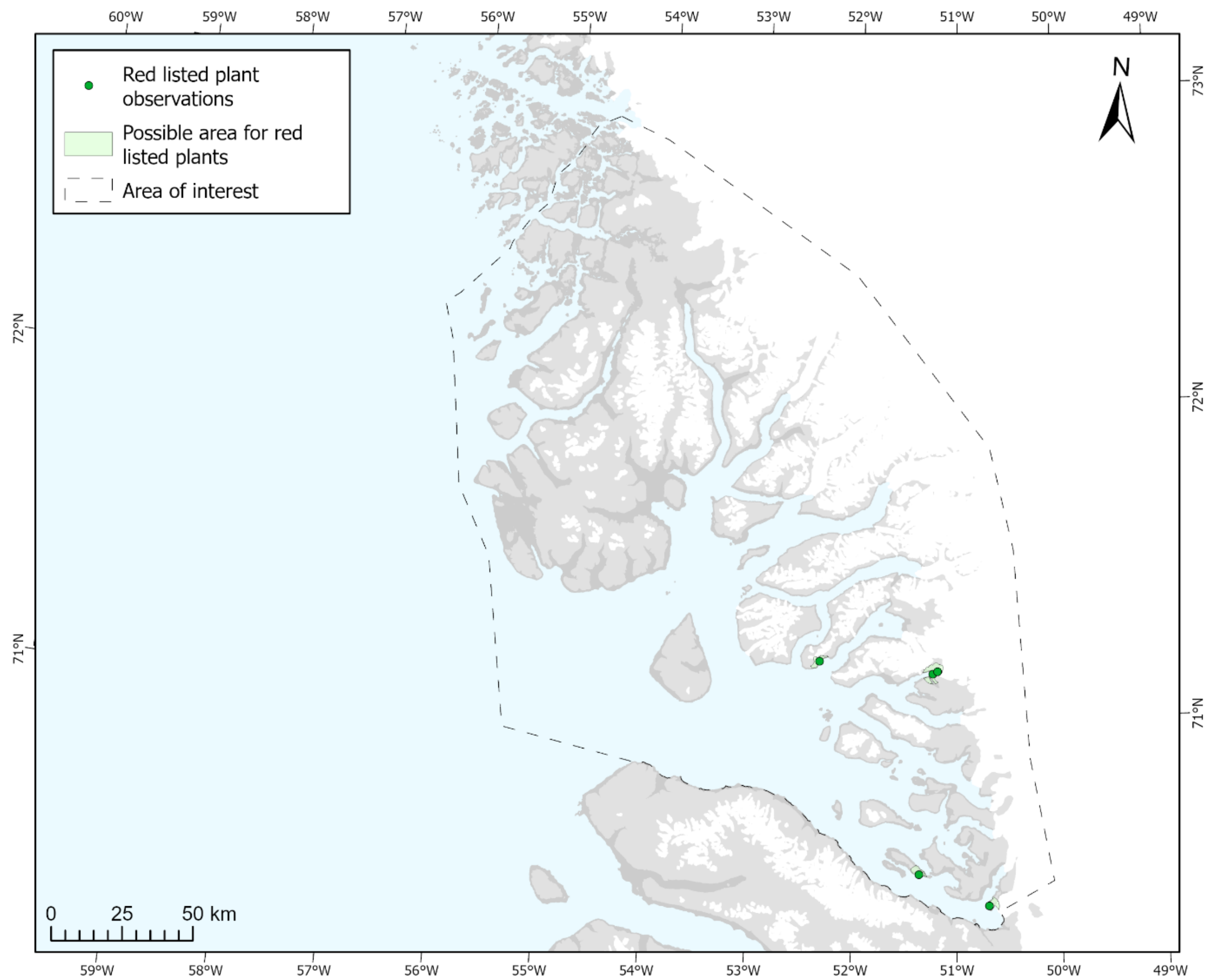

Figure 4.10. Distribution map of observations of red listed (vulnerable and near threatened) plants in the AOI. The geographical precision of the individual observations is fairly low; thus, a buffer zone (with a 3.5 km radius, cut off by the coastline and 800 m altitude line) of each observation is included in the map (possible area for the red listed plants). Please see the webGIS for details.

4.6 Vegetation mapping

A large part of the 2022 field work done was related to getting ground truthing points to validate an updated satellite-based vegetation map (Figure 4.12). The methods used for making the vegetation map are described in the paper by Rudd et al. (2021) and in Appendix 4.

When referring to vegetation mapping, it is important to note that mapping of vegetation types/classes will not reveal the distribution or occurrences of red listed or any other specific species. Red listed species may occur in vegetation types not identified by the method used here, and due to the scale of the mapping (10 m x 10 m), e.g., the vegetation types "snow patch" and "herb slope" are not included. These types often have a very limited distribution, and at the scale of this vegetation mapping, they are not distinguishable.

Vegetation analyses were undertaken to classify the vegetation types. A total of 95 analyses with just below 70 species were done during the field work in 2022. The types were classified based on species composition, but the classification also included information on, e.g., height of vegetation, slope, and soil moisture. Four broad vegetation types were classified: dwarf shrub heath (34 analyses), lichen-rich dwarf shrub heath (30 analyses), fell field (27 analyses) and fen (only 4 analyses; Table 4.3 and Figure 4.11). In addition, bare rock and soil as well as snow/ice and water are indicated on Figure 4.12.

Table 4.3. Field observations of the dominant species of the different vegetation types at Sigguup Nunaa. Please see Figure 4.10 for examples of species and vegetation types.

Vegetation type	Dominant species
Dwarf shrub heath	*Salix arctica, Vaccinium uliginosum, Equisetum arvense*
Lichen-rich dwarf shrub heath	*Vaccinium uliginosum, Salix arctica, Betula nana, Cassiope tetragona*
Fell field	*Salix arctica, Dryas* sp., *Vaccinium uliginosum*
Fen	*Carex bigelowii, Carex saxatilis*

In general, the vegetation within the AOI is relatively homogenous, which is also indicated by the few vegetation types found at the three sites visited in 2022. As is evident from the vegetation map (Figure 4.12), the most dominant vegetation type is fell field, which covers ca. 32% of the ground. The two shrub heaths cover ca. 17% (dwarf shrub heath) and 11% (lichen-rich dwarf shrub heath), while fen only covers 0.5%. The remainder is bare rock or soil (with a maximum NDVI of less than 0.07).

Lichen-rich dwarf shrub heath is mainly found on south facing slopes, whereas the distribution of dwarf shrub heath showed no preference related to compass orientation. Christensen et al. (2016) mention the northernmost copse in Greenland, which is found in the inland on a south facing slope just north of the Sigguup Nunaa. This vegetation type was not found at any of the three sites visited during field work in 2022.

See Appendix 4 for more information on the classification model and procedures regarding the vegetation mapping.

Figure 4.11. Examples of vegetation types and characteristic species found at Sigguup Nunaa. *Papaver radicatum* in a lichen-rich dwarf shrub heath, *Dryas* sp. in a fell field and *Pyrola grandiflora* in a dwarf shrub heath. Photos: Katrine Raundrup.

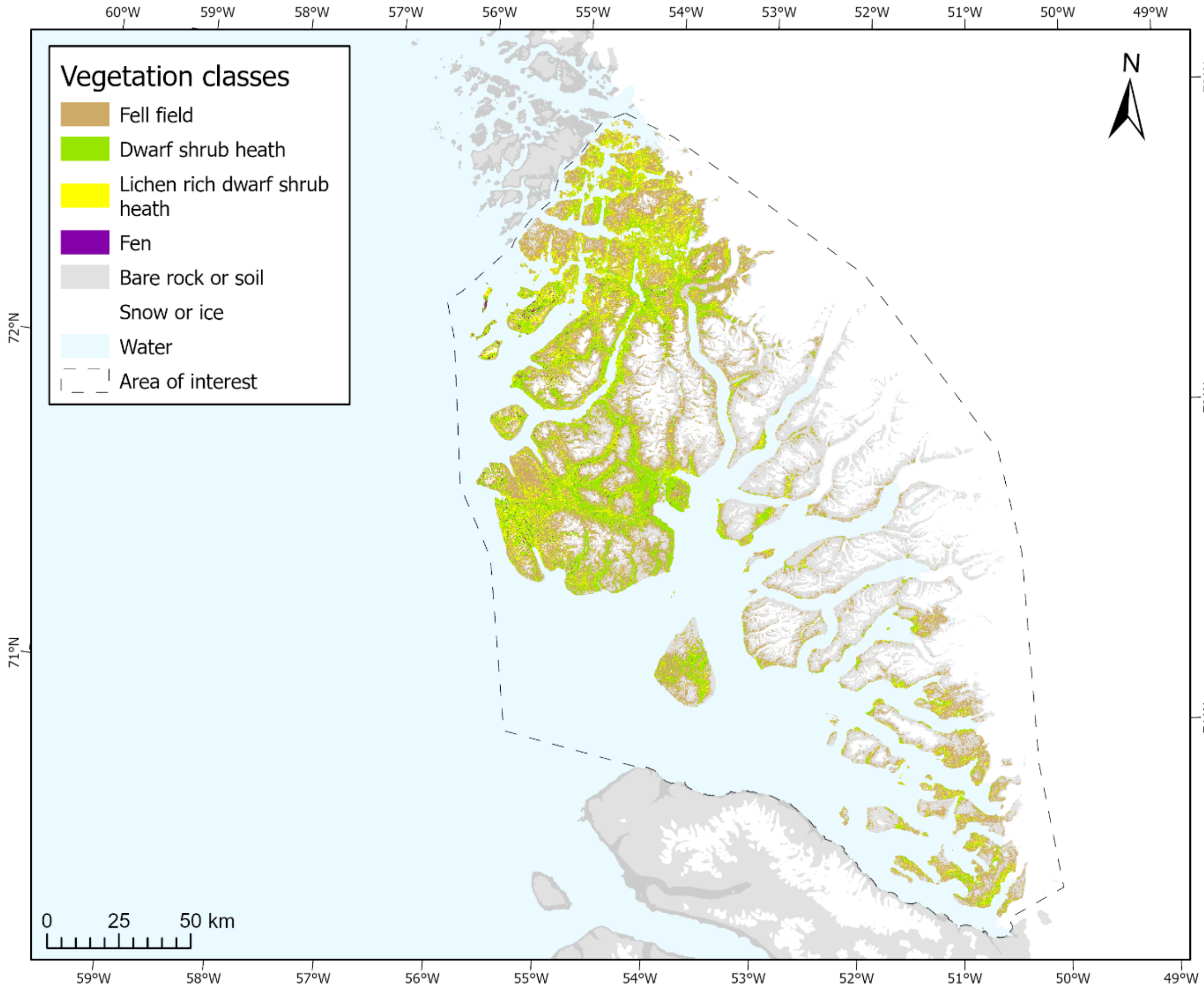

Figure 4.12. Vegetation map of the AOI. For method description consult Appendix 4.

4.7 Protected and regulated areas

There are several types of protected areas in Greenland. They fall within the legislation related to the Nature Protection Act, the Bird Protection Order, the Ramsar Convention and UNESCO's World Heritage List. Of these different types of protected areas, several areas related to the Bird Protection Order are present within the AOI. These include three so-called bird protection areas, defined based on seabird breeding colonies at the Qeqertat-islands (Schades Øer) in the northern Uummannaq fjord, the islands of Issortusoq and Uigorleq (Lille Fladø) west of Upernavik Kujalleq (Egevang & Boertmann 2012). However, according to the Bird Protection Order, all seabird colonies have a number of protection zones of varying radii (up to 3 km) in relation to different stressors (e.g., hunting, disturbance, over-flight) during the breeding season. Thus, each of the 190 seabird colonies presently known within the AOI has protection zones according to the Bird Protection Order. Further, two salt lakes on the island Ikerasak in the southern part of the AOI and one homothermic spring in Umiiarfik are protected as nature types under the Nature Protection Act with restrictions on activities within a 100 m zone.

By Greenlandic law, mineral resources activities are exempt from the different types of protection mentioned above. Instead, mineral resources activities are regulated through the *Rules for field work and reporting regarding mineral resources (excluding hydrocarbons) in Greenland* (Anon 2000; hereafter "field rules”), containing a number of so-called “Areas Important to Wildlife” with restrictions on mineral activities. The field rules and the associated Areas Important to Wildlife are continuously updated and extended through memos as new biological knowledge becomes available (see e.g., Johansen et al. 2022a), and the regulated areas are displayed on the WebGIS site NatureMap (https://naturemap.eamra.gl).

Within the AOI, several Areas Important to Wildlife with different restrictions on mineral resources activities occur on NatureMap. In the northern part of the AOI, there are two important seaduck moulting areas (Figure 4.2; Boertmann et al. 2022a) and three large wetlands on the Sigguup Nunaa are identified as important goose breeding and moulting areas (Figure 4.1; Boertmann et al. 2022b). Further, during the period 15 April to 15 September, protection zones are defined in the field rules for the 190 seabird colonies within the AOI in relation to:

Disturbance, including boat travel at speeds above 3 knots (200 m or 1000 m depending on the species breeding).

Over-flight by fixed-wing plane or helicopter (500 m or 3000 m depending on the species breeding).

Over-flight by drones (100 m for all colonies).

In addition, the three bird protection areas of the bird protection act mentioned above are also included in the field rules as no go areas during the seabird breeding season. All these different seabird colony protection zones are shown in Figure 4.13 (see also Johansen et al. 2022a, 2022b). To a large extent, they correspond to the protection zones in the Bird Protection Act, but at present the field rules and the Bird Protection Act are not completely aligned, and GINR and DCE have advised that the Bird Protection Act be updated to reflect the latest version of the field rules with regard to seabird colony protection zones.

Finally, the “Areas Important to Wildlife” also include an offshore walrus winter and spring concentration area, which only marginally overlaps the extreme western part of the AOI (Hansen et al. 2022).

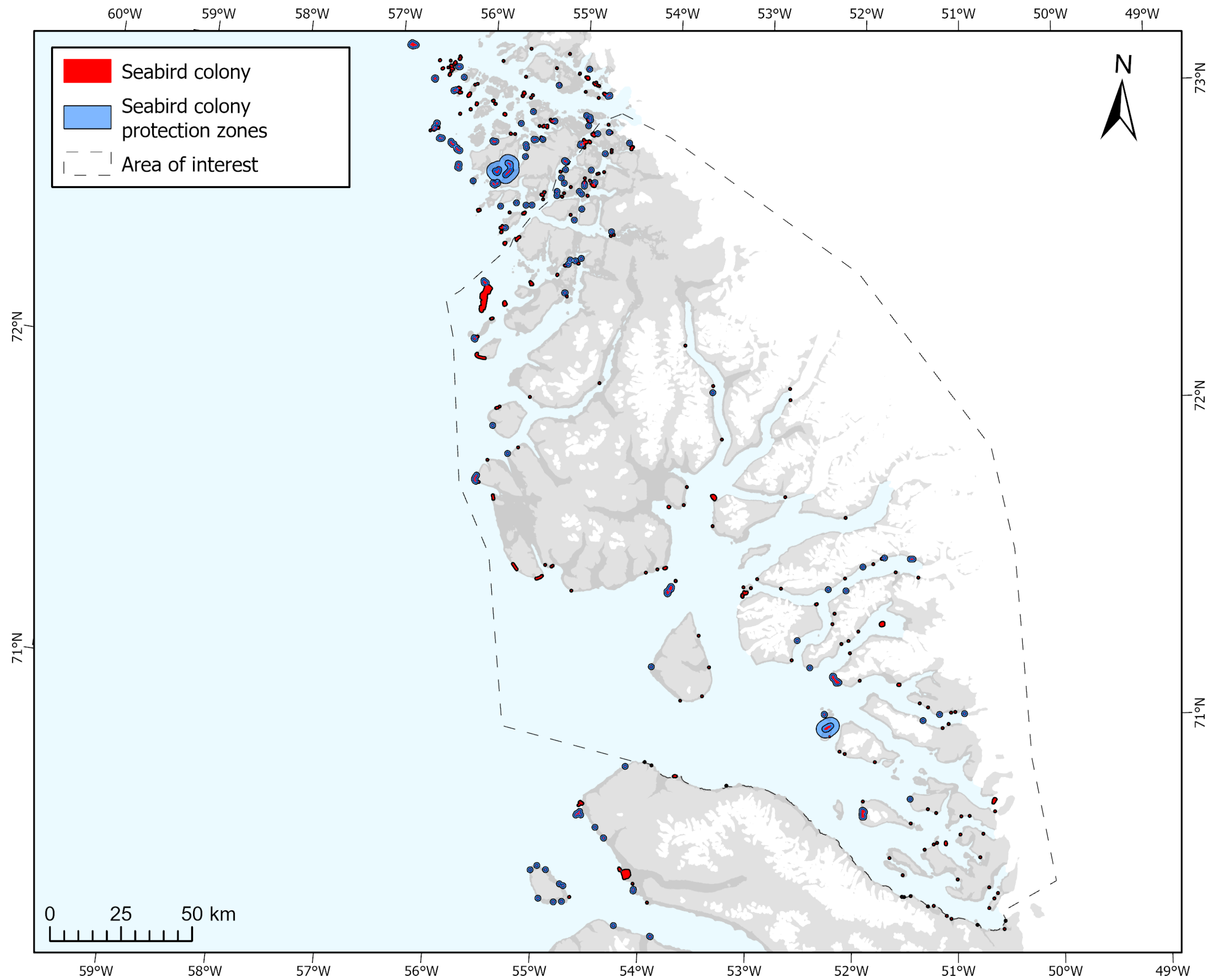

Figure 4.13. The distribution of seabird breeding colonies in the AOI and their associated protection zones in relation to the field rules for mineral resources activities. Please refer to the WebGIS for better visualisation of the colony locations.

4.8 Biologically important areas

In 2016, a report on ecological and biological important areas in West and Southeast Greenland was published (Christensen et al. 2016). The report provides an overview of important areas for ecosystems and species, and identifies three types of important areas:

- Species-specific core areas. These are hot spots critical for specific species. They may be areas containing relatively large numbers of individuals, migration corridors or other types of important areas.
- Important habitats, nature types or other ecosystem components. These include areas with high biological productivity, areas that are biologically unique and/or possess e.g., high biodiversity.
- Ecological and biological valuable areas. These are identified as areas where the species-specific core areas and important habitats, nature types or ecosystem components are particularly close.

The report identifies 23 ecological and biological valuable areas. Two of these partially overlap the AOI of this report (Figure 4.14). Area 5 covers the land areas between Upernavik Isfjord and northern Sigguup Nunaa, and Area 6 covers most of Sigguup Nunaa as well as marine areas. Only the southern part of Area 5 is included in the AOI. Among others, it holds a high diversity of seabirds including the rare Sabine's gull. There are several eider duck colonies along both the outer coast and in the fjords. Furthermore, it is an important area for moulting king eiders.

Area 6 is known as the northernmost breeding, moulting and staging area for the Greenland white-fronted goose. The northern part of the area is an important moulting area for king eiders. The area also houses the population of introduced muskoxen.

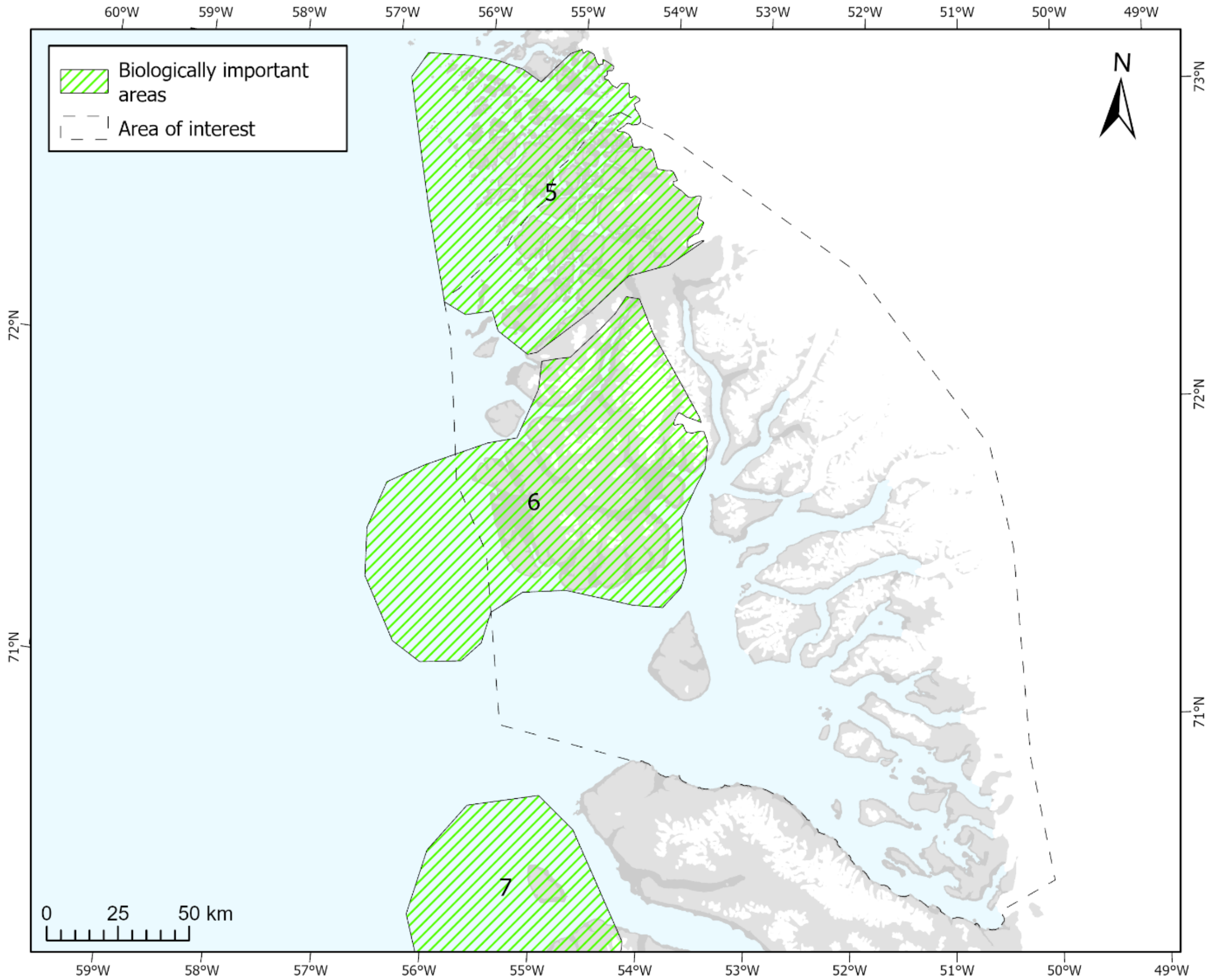

Figure 4.14. The two ecological and biological important areas are located in the AOI and marked as 5 and 6 in the report by Christensen et al. (2016).

The Christensen et al. (2016) report concludes that the 23 ecological and biological valuable areas identified can be regarded as a network, which, if protected against actual threats, could safeguard a representative part of important habitats, ecosystems, and species in West and Southeast Greenland. However, the report recommends that while further strategic work related to nature protection should focus on these 23 areas, there may also be a need for protection of certain species-specific core areas outside of the 23 ecological and biological valuable areas.

4.9 References

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5 Human use

By Katrine Raundrup[1], Debora Hansen Kleist [1] and Karl Zinglersen[1]

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5.1 Introduction

The area of interest is relatively sparsely populated with 1447 people living in Uummannaq, 255 people in Saattut, 234 in Ikerasak, 207 in Upernavik Kujalleq, 153 in Ukkusissat and 139 in Kangersuatsiaq (numbers per 1 January 2022, www.stat.gl) giving a total of 2435 within the AOI. The AOI is located in Avannaata Komminia, the northernmost municipality in Greenland. Two settlements (Illorsuit and Nuugatisaq) were closed after the tsunami catastrophe in 2017 (see chapter 5.7 on Landslides and tsunami risk).

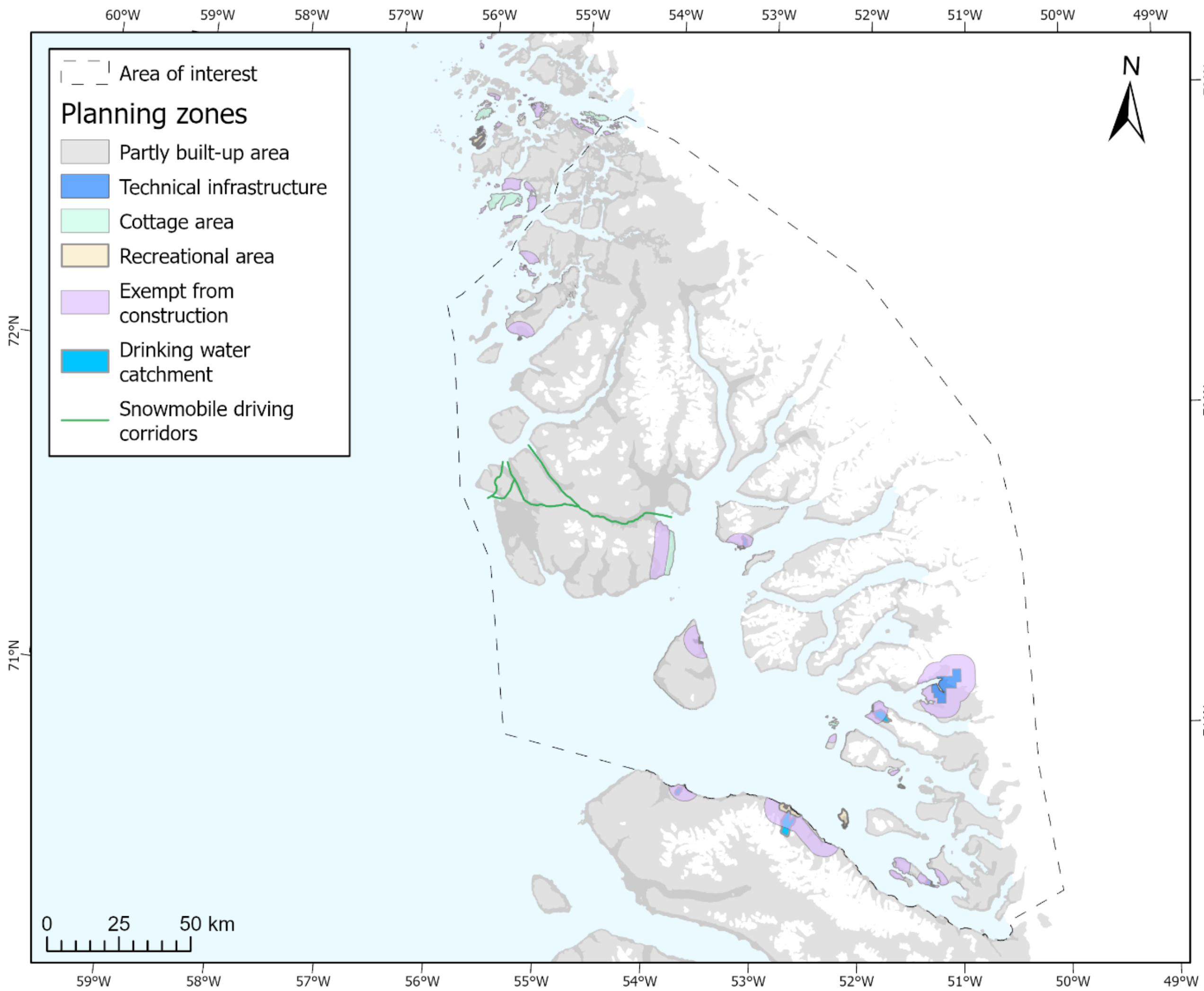

Figure 5.1. Municipality plan for the AOI with planning zones as well as snowmobile driving corridors. Reference: https://kommuneplania.avannaata.gl/en/

In this chapter, the human use of land and marine resources as well as tourism in the AOI is described.

The municipality plan for the entire Avannaata Kommunia can be found at https://kommuneplania.avannaata.gl/en/. It includes maps of e.g., recreational areas, area allotments, technical infrastructure and snowmobile driving corridors all of which are summarized in Figure 5.1. The municipality plan is implemented through the Law on Planning and Land Use with the aim to protect nature, allocate areas between human use and nature, advance development, and involve the inhabitants. The municipality has the obligation to establish a complete plan and assessment of land use, natural and economic resources in the region, as well as goals for the development of businesses and population. The plan, valid for a specific period (the Avannata Kommunia plan is valid from 2018-2030), must include (and not disagree) with the national sector plans and interests such as conservation zones, infrastructure for energy and transport, and other vital societal interests. The authorities and organizations at the national level are obliged to inform the municipality of their plans and interests affecting the municipality level. The municipality plan provides the basis for the municipality to regulate and administer requests from organizations and citizens for area allotments and activities involving land use in inhabited and uninhabited places (Anon. 2010).

Land use and activities related to mineral activities is regulated through the Mineral Resources Act by the Mineral License and Safety Authority concerning permits to and inspection of facilities etc. on the basis of other relevant acts and regulations and through hearings with relevant authorities (Mineral Resources Act, §3, govmin.gl).

The only larger technical infrastructure mentioned in the Municipality plan from the AOI is the former Maamorilik mine (also called the Black Angel) located ca. 55 km northeast of Uummannaq (blue marking in Figure 5.1). The mine was active between 1973 and 1990 and the mined resources included e.g. lead and zinc. Please see Chapter 3.2 for more information.

During winter dog sledging is an alternative way of getting around on the sea ice. There are ca. 1900 sledge dogs in in Uummannaq (number form 2021, www.stat.gl).

Snowmobile driving corridors follow major valley systems on Sigguup Nunaa (green markings in Figure 5.1) while a coastal stretch on the southeastern side of the peninsula has been laid out as a cottage area.

5.2 Muskox introduction

As mentioned in chapter 4.2 caribou (*Rangifer tarandus*) were found in the AOI until the 1960's. For the next ca. three decades there were no large herbivores in the area. In 1991, 31 muskoxen (*Ovibos moschatus*) were introduced on the northwest coast of the Sigguup Nunaa (Clausen 1993). The muskoxen were moved from the Kangerlussuaq population (which itself is an introduced population started in the 1960's with animals from East Greenland). The most recent survey (minimum count) made by the Greenland Institute of Natural Resources is from 2002 and gave an estimate of 193 animals (Cuyler et al. 2019). Since then, the Greenland Government has assessed the population to have increased and combined with local knowledge quota-based harvesting was implemented several years ago by the authorities. In 2022 the annual hunting quota was 150 animals, though the current population size remains unknown.

Most of the animals killed during the annual hunt are from the north and western parts of Sigguup Nunaa (Figure 5.2). Hunting quotas are set by the

Government of Greenland and the most recent can be found at www.sullissivik.gl (in Greenlandic and Danish only).

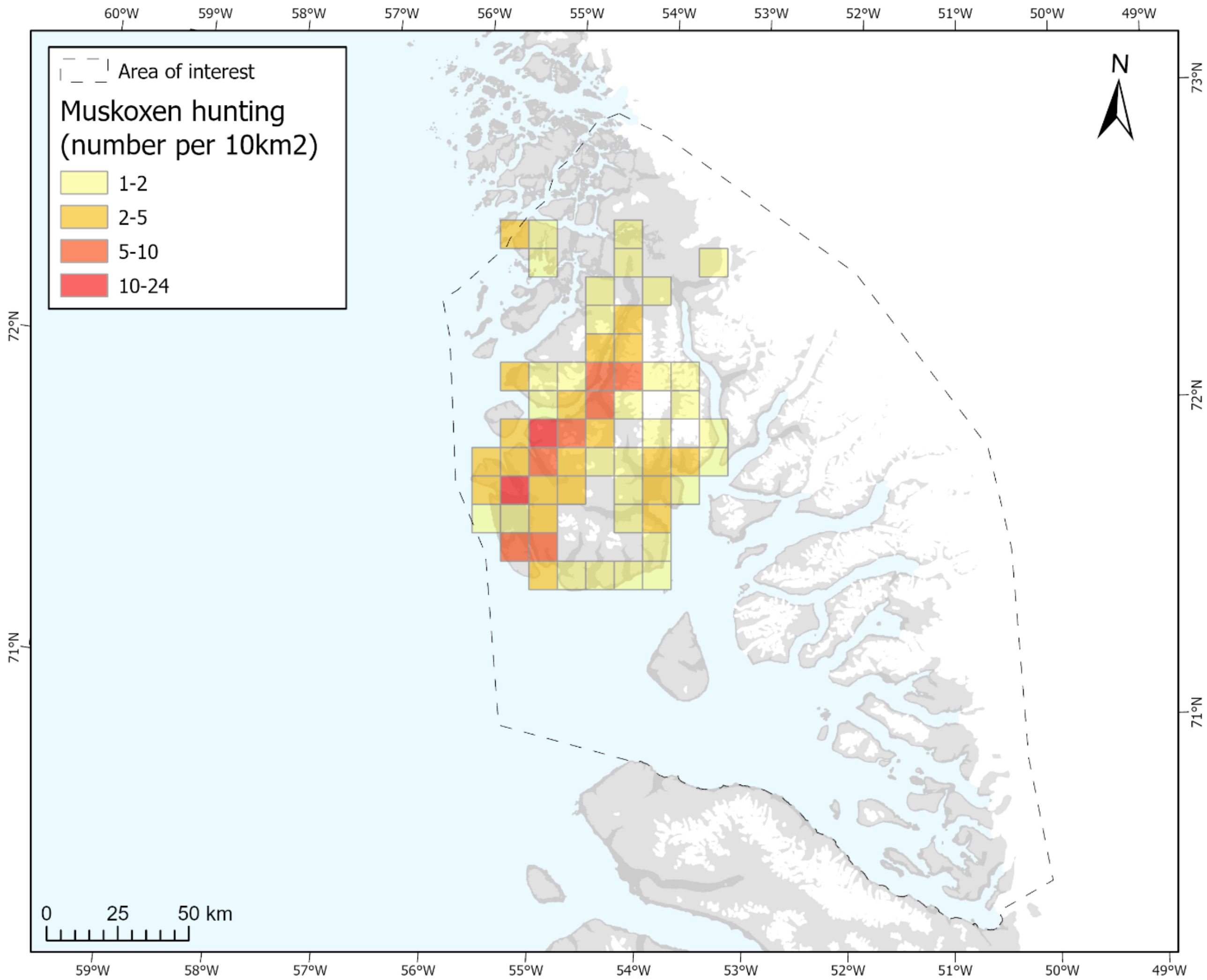

Figure 5.2. Muskox hunting (number per 10 km^2) at Sigguup Nunaa from 2005-2016.

5.3 Coastal fishing

Long stretches of the coastline have fishing resources for both private as well as commercial use. In general, the commercial fishing in this area is limited compared to other Greenlandic waters. In the following, the important areas for fishing Arctic char (*Salvelinus alpinus*), Atlantic cod (*Gadus morhua*) and Greenland halibut (*Reinhardtius hippoglossoides*) are presented. Furthermore, subsistence fishing for capelin (*Mallotus villosus*) and lumpsucker (*Cyclopterus lumpus*) is presented based on input from the interviews made for the mapping of the oil spill sensitive atlas (Olsvig & Mosbech 2003). These data are thus somewhat out-dated, and more recent information about the use of these resources may provide a different image of the relative use.

Aside from the mentioned species, there is commercial fishing for snow crab (*Chionoecetes opilio*) in the northernmost part of the AOI, though mainly outside the AOI around Upernavik.

5.3.1 Arctic char

There are relatively few rivers with Arctic char (*Salvelinus alpinus*) in the entire Uummannaq fjord complex (Petersen 1993a, Olsvig & Mosbech 2003, Figure

5.3). At Sigguup Nunaa most of the larger rivers and lakes are expected to have Arctic char or function as catchment areas. Arctic char spawns in freshwater, and the young fish stay in freshwater for some years before they migrate to the marine environment. Some lakes and rivers have non-migrating char. All Arctic char winter in freshwater, and this period is thus crucial for their survival (Christensen et al. 2016).

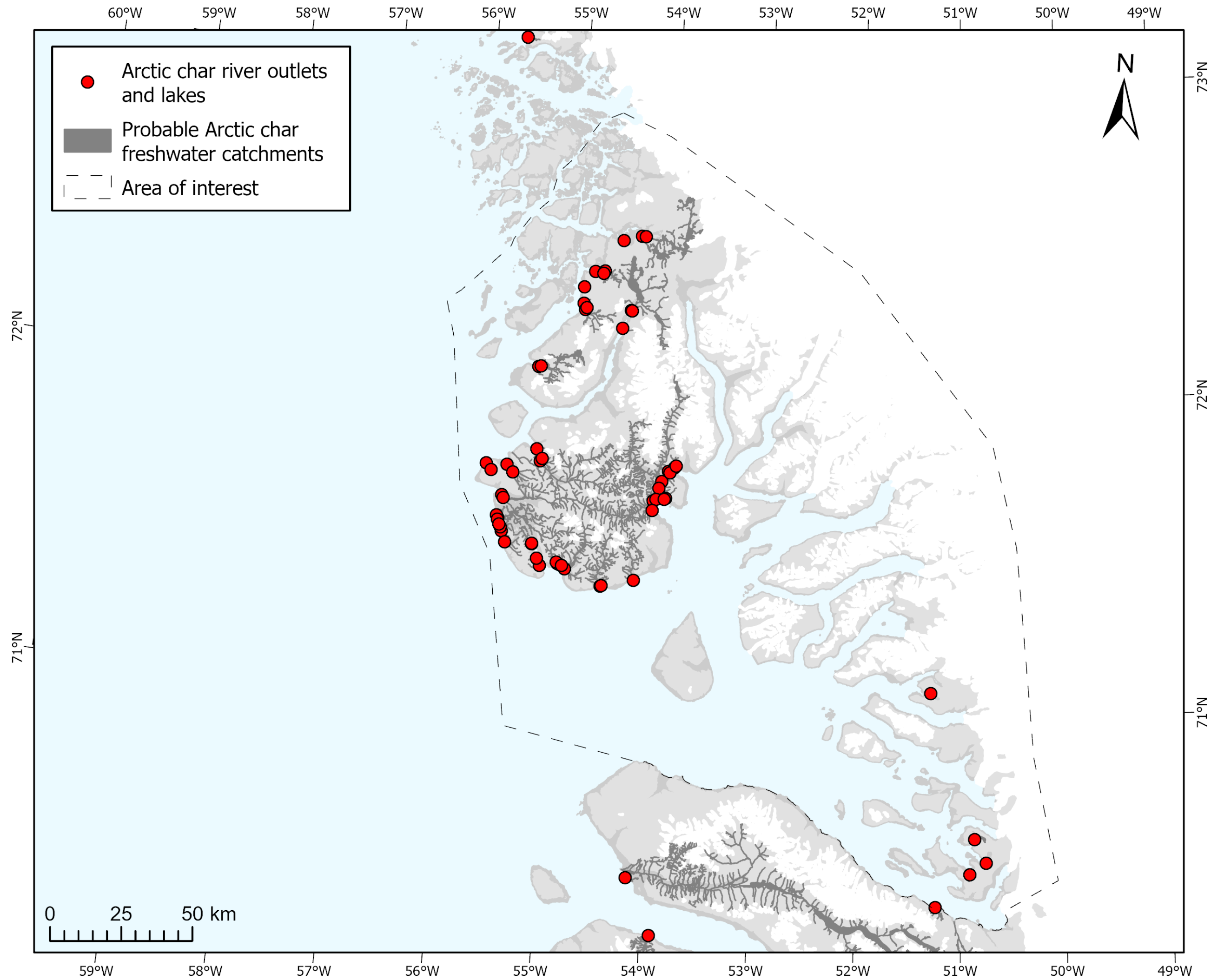

Figure 5.3. Arctic char rivers as well as relevant catchment rivers and lakes.

5.3.2 Atlantic cod

Atlantic cod fishery only occurs in the fjord systems/coastal areas. In general, the fishery for this species is of low economic importance to the area (Figure 5.4). The catches in the northern part of the AOI likely reflect catches by fishermen from Upernavik or nearby settlements, i.e., outside the AOI.

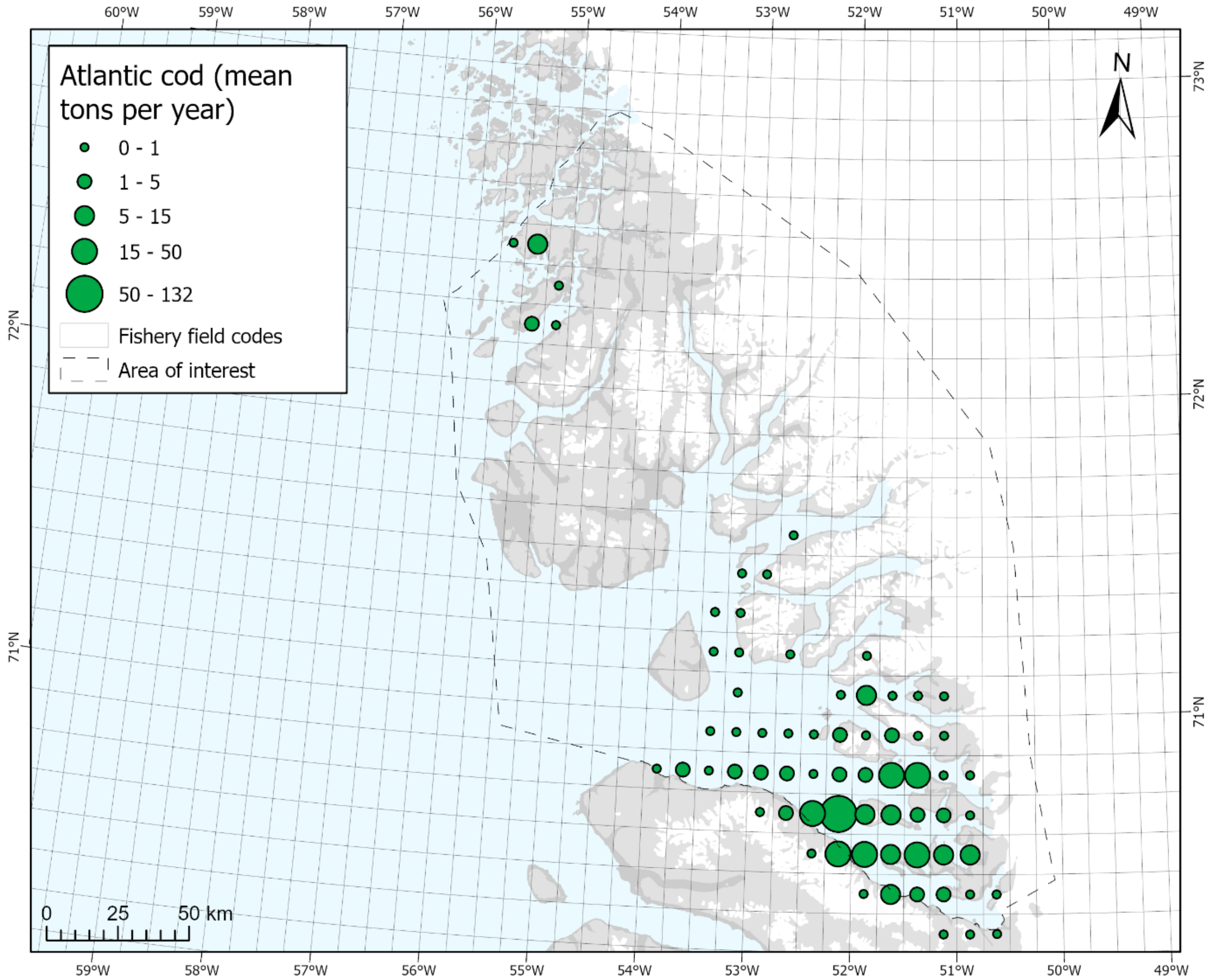

Figure 5.4. Average catches of Atlantic cod in tons per year (2014-2019). The squares refer to the individual fishery field codes (statistical catch squares). The individual dots are centered in each of the relevant squares and thus do not necessarily refer to the specific catch position within the field code area.

5.3.3 Greenland halibut

Greenland halibut fishey mainly occurs in the fjord systems (Figure 5.5). The fishery for halibut is of high importance to the area. Most catches are from waters around Uummannaq and elsewhere in the southern part of the AOI. The catches in the northern part of the AOI likely reflect catches by fishermen from Upernavik or nearby settlements, i.e., outside the AOI.

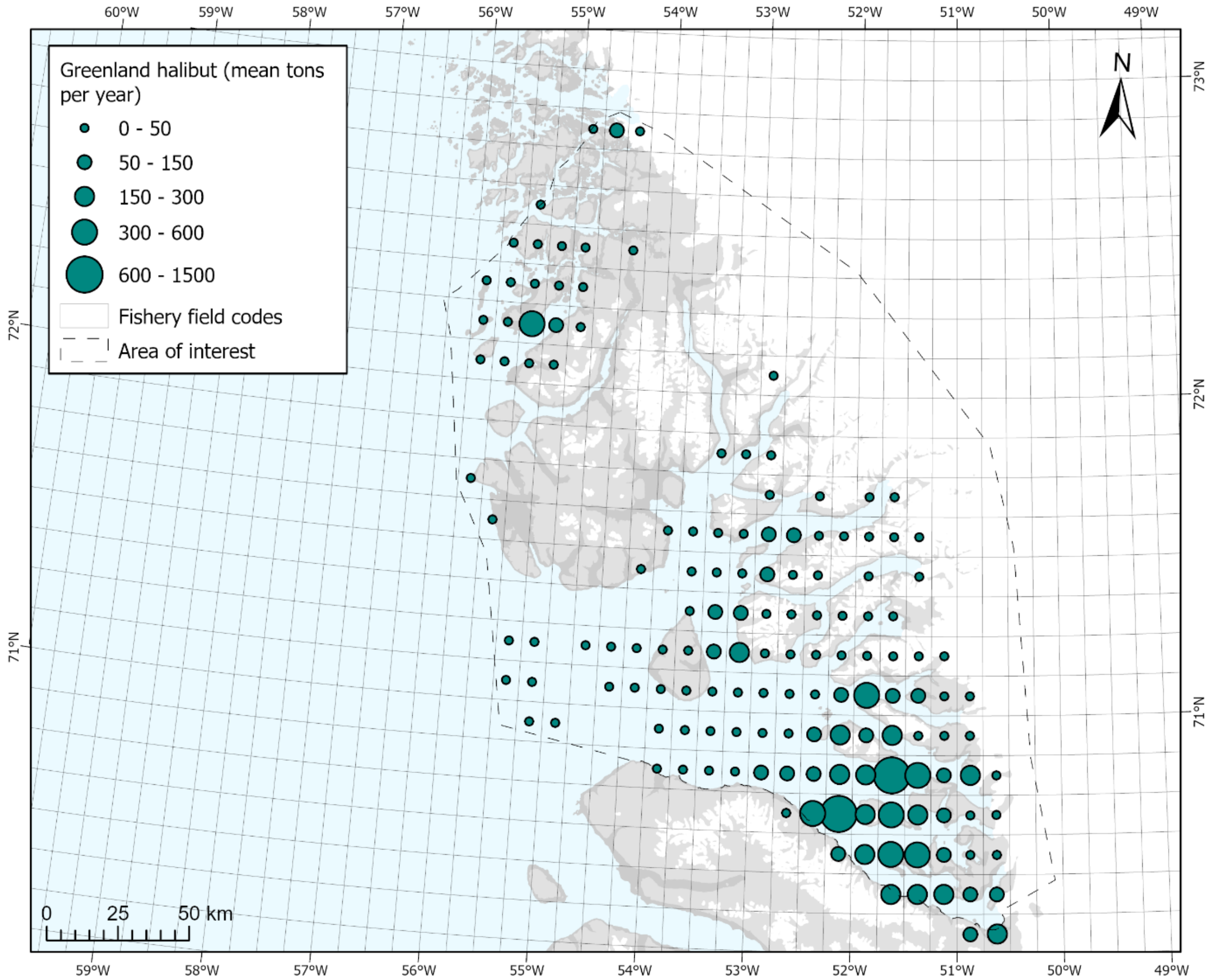

Figure 5.5. Average catches of Greenland halibut in tons per year (2014-2019). The squares refer to the individual fishery field codes (statistical catch squares). The individual dots are centered in each of the relevant squares and thus do not necessarily refer to the specific catch position within the field code area.

5.3.4 Capelin and lumpsucker

The fisheries for capelin and lumpsucker are small and only for private subsistence. The data presented in Figure 5.6 are based on interviews with users of the area and may thus reflect both catches and distribution. High relative abundance may thus indicate large fishery, but it also reflects areas where the species is present but not necessarily fished (data from Olsvig & Mosbech (2003), Stjernholm et al. (2011) and Clausen et al. (2012)).

Capelin spawns in shallow waters in spring (May – June) and during that time, the species is sensitive to disturbance. The capelin fishery takes place on the southern coast of Sigguup Nunaa as well as in the northernmost part of the AOI (Figure 5.6 left).

Lumpsucker fishery is mainly directed at females with roe (March – June) and almost exclusively takes place in the northernmost part of the AOI (Figure 5.6 right).

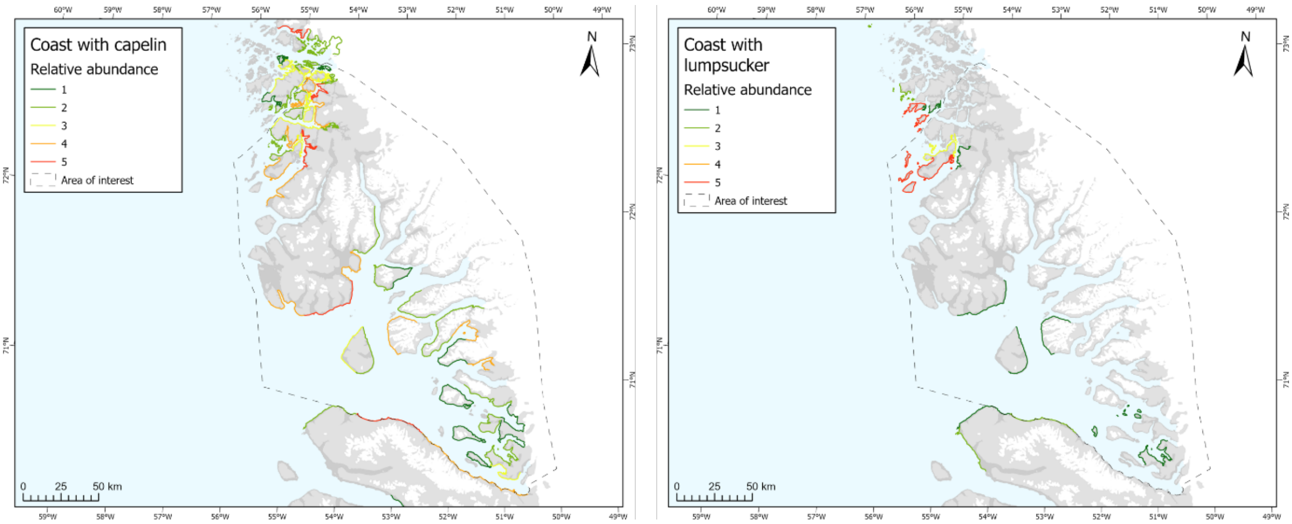

Figure 5.6. Coast sections with capelin (left) and lumpsucker (right). Data are based on interviews with users of the area and may thus reflect both catches and distribution. High relative abundance may thus correspond to large fishery but also reflects areas where the species is present but not necessarily fished. Data from Olsvig & Mosbech (2003), Stjernholm et al. (2011) and Clausen et al. (2012).

5.4 Tourism

Tourism is an increasing industry in the Arctic including Greenland, but the number of visitors decreases the further north on the west coast you are (especially north of Ilulissat). The number of tourists visiting Uummannaq by cruise ship from 2016-2021 is plotted in Figure 5.7 (www.stat.gl). There was no cruise ship tourism in 2020 and 2021 due to the global pandemic. For comparison, data from Upernavik (north of the AOI) and from Ilulissat (in Disko Bay) are presented. The number of cruise ship tourists is far lower in this part of Greenland than in South Greenland where a total of ca. 92,000 people visited Qaqortoq during the same period.

Land-based tourism is low, but with Uummannaq as a hub for both short hikes and boat transfers elsewhere within the AOI.

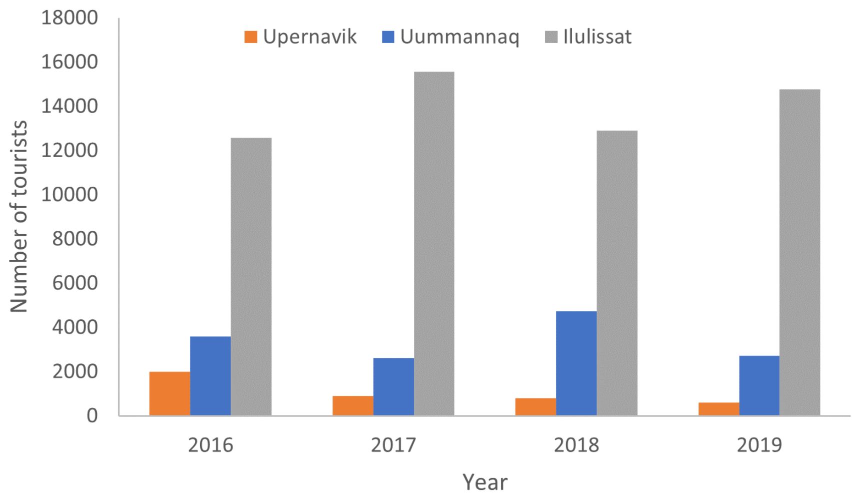

Figure 5.7. Number of cruise ship passengers visiting Uummannaq in 2016-2019. For comparison data from Upernavik and Ilulissat are presented as well. There were no cruise ship passengers in 2020 and 2021 due to the Covid-19 pandemic.

5.5 Oil spill sensitivity

An extract of the data from the Oil Spill Sensitive Atlas published in 2004 (Mosbech et al. 2004) combined with rankings published in Stjernholm et al.

(2011) and Clausen et al. (2012) is shown in Figure 5.8. The classification of sensitivity is based on a variety of parameters primarily related to the biological resources of the area as well as human use of the resources. Accordingly, areas that are sensitive to oil spill are areas with, e.g., specific coastal types, archeological remains, a high density and/or diversity of biological resources as well as areas important for fishing and hunting. The Oil Spill Sensitivity Atlas from 2004 included community consultation, thus incorporating information of local use of the area.

The sensitivity ranking ranges from red, corresponding to extreme sensitivity, yellow, which is high sensitivity, to green and blue representing moderate and low sensitivity, respectively.

In the AOI Ummannaq island, Salliaruseq (Storø), the coastlines east of Salliaruseq, the eastern coast of Illorsuit and part of the coastline in the northern part of the area are ranked as being extremely sensitive in case of an oil spill. The coastlines of Appat, Appatsiaat Qaqqarsui and the peninsula in between, as well as the west and northwest coast of Sigguup Nunaa along with several stretches of coast in the northern part of the AOI, are ranked as high sensitivity areas. The remaining coastline is ranked as having either moderate or low sensitivity.

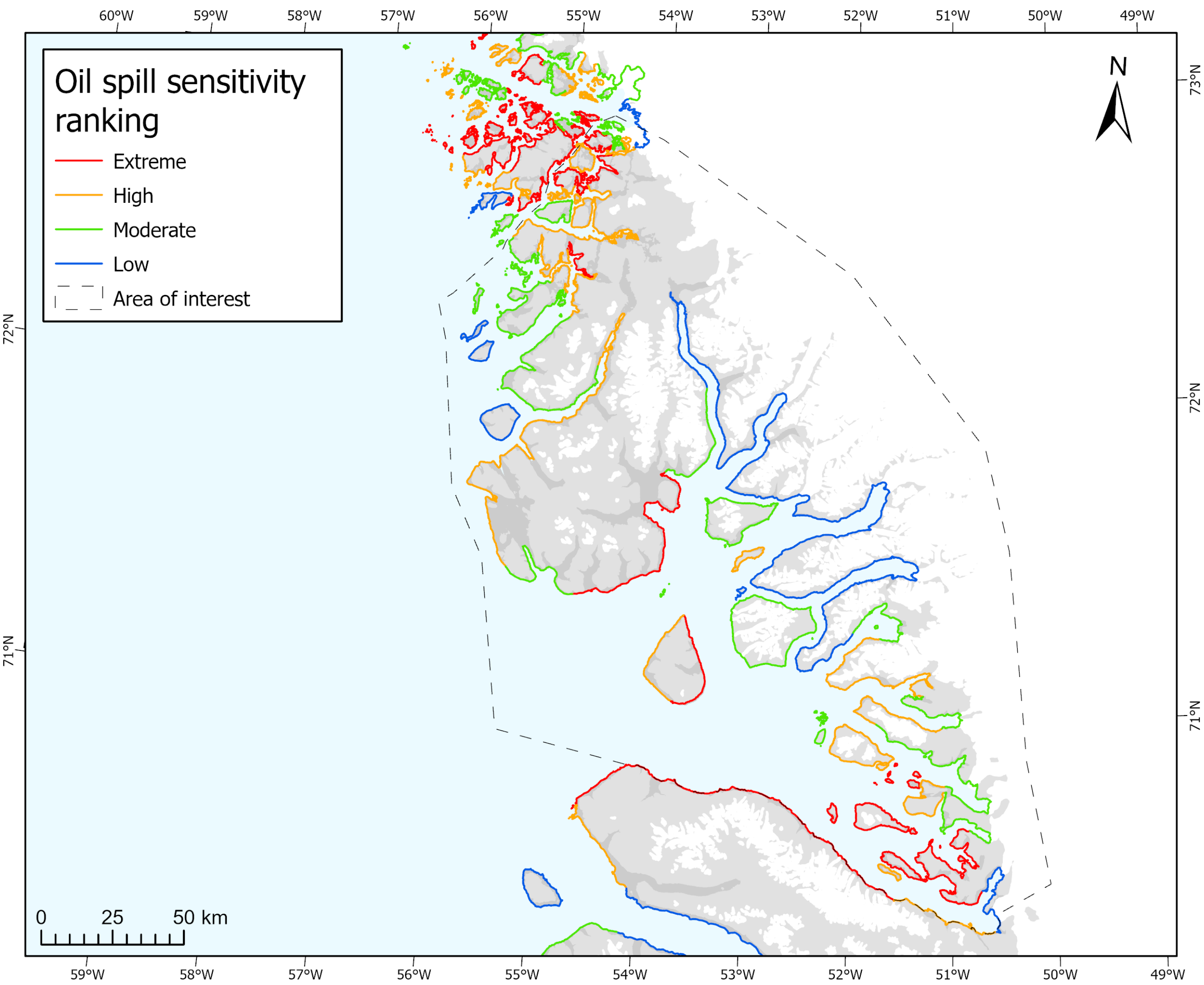

Figure 5.8. Oil spill sensitivity ranking along the coast in the AOI. Data from Stjernholm et al. (2011) and Clausen et al. (2012).

5.6 Landslides and tsunami risk resulting in reduced human access to specific areas

Quality assurance/Commenting: Marie Kløve Keiding (GEUS), Eva Mätzler (Government of Greenland)

Uummannap Sullua (Uummannaq Fjord) contains areas where there is a high risk of landslides. If the mountainside is connected to the sea, there is a risk of a cascading event, i.e., that a landslide can trigger a tsunami. The tsunami can travel long distances and thus pose serious risk to people and equipment in the vicinity.

The Geological Survey of Denmark and Greenland (GEUS) has carried out surveys and a screening study for areas of potential risk in Greenland, including several sites in Uummannap Sullua and Sigguup Nunaa. The main reason for the many unstable mountain areas is assumed to be connected to the geological composition of the region combined with the thawing of permafrost. The region is dominated by the Karrat Group, which generally contains metamorphic sediments that overlay and are folded together with Archaic gneiss, and volcanic basalts in the Svartenhuk Formation, a part of the Nuussuaq Basin. Both involve unstable mountainsides.

On 17 June 2017, a rock avalanche along the north side of Karrat Fjord triggered a tsunami that hit the two nearby settlements of Nuugaatsiaq and Illorsuit with loss of life and major material damages (Anon. 2018, Strzelecki & Jaskólski 2020, Svennevig 2020). The area around and in the two settlements was closed to activities related to mineral exploration and extraction by the Government of Greenland due to the risk of new landslides (Anon. 2017, Figure 5.9).

GEUS estimates that there is still a high risk of serious landslides in this area (Anon. 2021) and that these have the potential of triggering major and catastrophic floodings. A large unstable slope, Karrat 3, has been identified. The specific runup height depends on the proximity to the slide as well as on the local topographical and bathymetric conditions. The Government of Greenland installed a monitoring system in Karrat Fjord during summer 2022, and further developments of the monitoring towards an early warning system is ongoing.

In spring 2022, GEUS observed that an area further south of Karrat Fjord, Kigarsima at the Kangerluarsuk fjord, was in motion (Anon. 2022a, 2022b). The area is estimated to have a high probability of landslides within an unknown number of years as well as the potential to trigger a tsunami with a possible high risk of serious consequences for nearby settlements. Especially the settlements of Niaqornat, Qaarsut and Ukkusissat and coastal areas in this area may be at risk. GEUS estimates that the probability of a landslide is significantly higher for Kigarsima than for Karrat 3, but that the consequences of a tsunami are minor here than at Karrat 3 due to lower runup height (Anon. 2022a). The Government of Greenland is planning to install a monitoring system in Kangerluarsuk fjord during summer 2023.

In addition to the specifically mentioned areas, the screening study by GEUS based on satellite data and questionnaires identified several of different degrees of unstable mountain slopes in Greenland, including many within the study area (Anon. 2018, Svennevig 2019). Maps of these areas are currently not publicly available, but like the other reports on the risks of landslides and tsunamis in the area, they can be requested from the Government of Greenland.

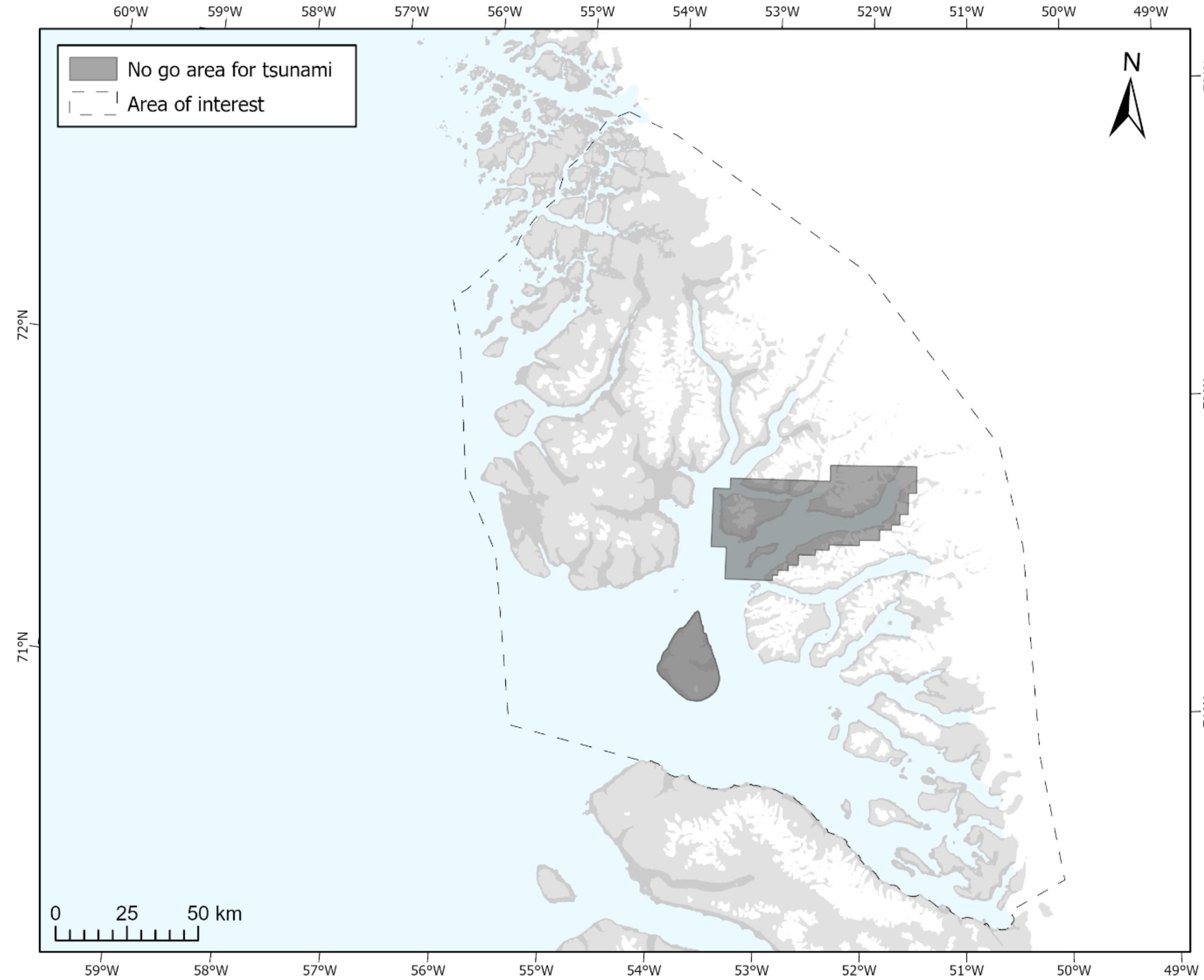

Figure 5.9. Shaded areas are no-go areas due to the risk of tsunamis within the AOI.

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6 Cultural history and heritage

By Christian Koch Madsen[1]

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Greenland's cultural history (Figure 6.1) begins with the arrival of small, highly mobile populations of Arctic hunter-gatherers crossing from Ellesmere Island into northwest Greenland ca. 4,500-4,200 years ago (Figure 6.1). These Paleo-Inuit peoples were the Saqqaq and Independence I cultures. Between ca. 2,500-500 BCE, these highly mobile peoples spread throughout Greenland, opportunistically taking advantage of every available resource as they moved with the seasons. By 800 BCE, an influx of new people migrating from the North American Arctic, the Greenlandic Dorset, emerges in Greenland with a noticeably different material culture than the preceding pioneer Paleo-Inuit groups, but settling in many of the same places previously occupied by Saqqaq and Independence I peoples. The Greenlandic Dorset thrived in Greenland for about seven centuries before disappearing around the year 0 CE, leaving the country unpopulated for the next eight centuries. Around 800 CE, the Late Dorset culture appeared in northwest Greenland and thrived until about 1300 CE. The Saqqaq, Independence I, Greenlandic Dorset and Late Dorset peoples all shared similar cultural traits, settlement patterns and a specialised microblade stone tool technology that is part of the North American Arctic Small Tool tradition (ATSt).

Around year 1,000 CE, a small population of Icelandic Vikings arrived in Southwest Greenland. The years that followed were marked by a rapid transition of this society to Christianity and the establishment of two settlements (*Vestribyggð* and *Eystribyggð*) that built their economies around farming, hunting and a lucrative trade in walrus and narwhal ivory and other exotic goods with mainland Europe over the next 450 years. These medieval Greenlandic Norse populations inevitably met the Thule culture Inuit who migrated into Greenland from Canada ca. 1,200 CE and quickly spread up and down the country's coasts within a few centuries. The Thule culture Inuit are the direct ancestors of Greenland's present-day Inuit population. The Thule culture Inuit brought new and highly sophisticated developments in sea mammal hunting and ice and sea conveyance, a distinct winter house architecture and an expansive trade network. In the centuries that followed, these trade networks became increasingly tied to the exchange of goods supplied from a growing fleet of European whalers and traders that appeared on the west coast of Greenland beginning in the 17th century CE. This European presence became permanent with the founding of the first Danish-Norwegian colony in 1721 by missionary and priest Hans Egede. The slow colonisation of Greenland in the 18th and 19th centuries led to many changes in the social and economic patterns and resource use of the Inuit society, some of which are still recognisable in Greenland today.

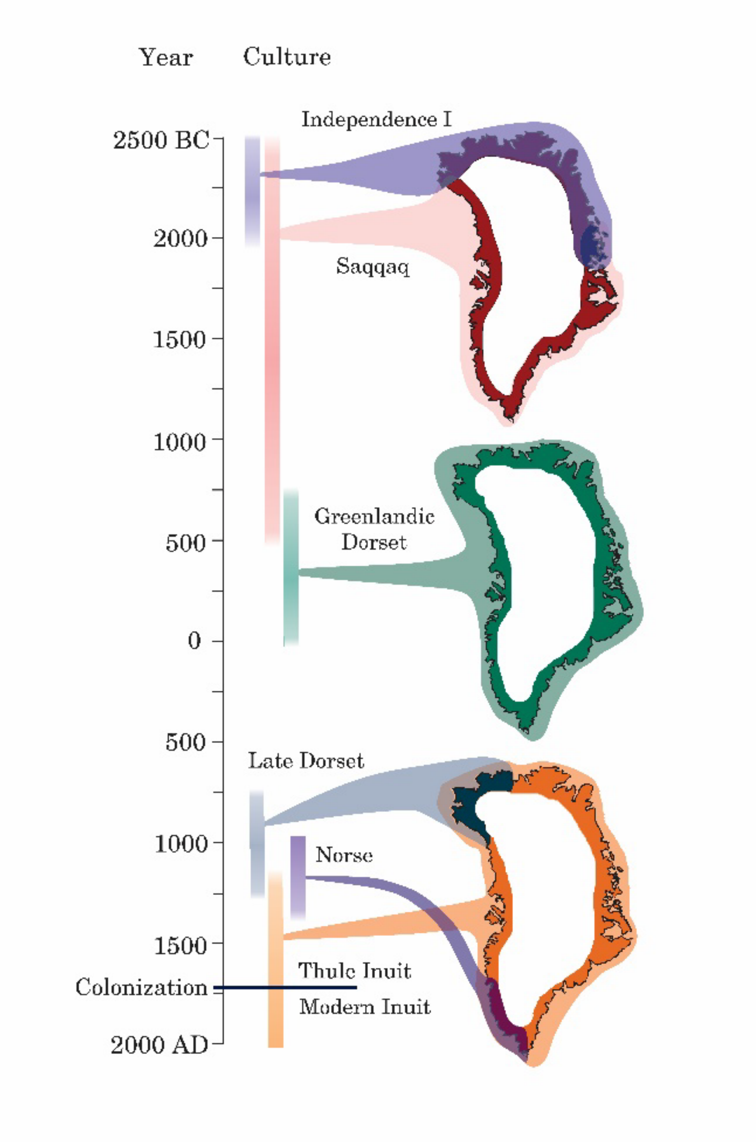

Figure 6.1. Timeline and geographical distribution of Greenland's major cultural phases.

6.1 National heritage authorities and sites in Greenland

Nunatta Katersugaasivia Allagaateqarfialu/Greenland National Museum & Archives (NKA) is a public institution operating under the authority of the Ministry of Education, Culture, Sports and Church. NKA is the central authority for overseeing and protecting all of Greenland's heritage sites and cultural resources. The Museum's mandate is specified through existing legal frameworks laid down by the Government of Greenland in a series of heritage acts and executive orders (see below). NKA also reviews and approves mineral exploration, extraction and other activities with potential impacts on heritage sites and protected cultural landscapes. Additional information on the mission and legal responsibilities of the NKA can be found at the museum's website: http://www.nka.gl.

The National Greenlandic Heritage Act (Anon. 2019a) defines heritage sites as: "ancient physical remains or traces of human activity in the past, and the context in which they are situated" (§ 2, stk. 2). It is a broad definition designed to protect ancient and historic remains—everything from isolated, single artifact finds to multi-component sites with well-preserved features and ruins. Heritage sites are found in every part of the country with 5,686 heritage sites currently registered in the Greenland National Museum and Archives' online heritage site inventory, Nunniffiit.

This digital registry of heritage sites has been built over the last 200 years, and site information and data quality vary greatly. A certain portion of heritage sites in the catalog (less than 20%) are described and mapped with precision, while others may be only registered with a place name. The accuracy of site positions varies greatly as most were recorded prior to the development of modern cartographic mapping techniques and GPS-technology. Only heritage sites marked with a GPS-symbol in Nunniffiit are considered geographically fixed. Additionally, different numbering conventions have also been employed in Greenland over the years. Today, all heritage sites are officially designated 'NKAH' (Nunatta Katersugaasivia Allagaateqarfialu Heritage) with a unique ID number.

Heritage sites registered in Nunniffiit only represent a small portion of ancient sites and features in Greenland as large portions of the country have only been archaeologically surveyed to a small extent, or in some cases not at all, leaving large blind spots for both the frequency and distribution of ancient settlements and ancient land use. The 5,686 heritage sites may constitute as little as 10% of the actual tangible heritage in the country. However, all heritage sites and features—whether registered or not and irrespective of their documentation level—are protected under Greenlandic law.

6.2 National Greenlandic heritage legislation summarised

A unique aspect of Greenlandic heritage sites is that they are frequently well preserved and readable as ancient remains on the surface of the ground. Additionally, cool and dry environmental conditions have ensured the preservation of rare organic artifacts such as, e.g., feather, fur, wood, hair, including mummified human and animal remains both above and below the surface. This high degree of preservation in Greenland is beneficial to science, archaeological research and tourism, but it also makes many Greenlandic heritage sites, and their surrounding vegetation, extremely sensitive to disturbance.

The National Greenlandic Heritage Act (Anon. 2019a) automatically protects all ancient human-built structures, their physical remains and the surrounding environment. In addition, the National Greenlandic Museum Act (Anon. 2019b) stipulates that cultural artifacts and ecofacts ('kulturlevn' in the National Museum Act) must not be disturbed or removed (§ 28, stk. 2) from their existing context. The discovery of any observed artifact or ecofact found in the open land should instead be reported to the NKA or nearest local museum. Natural heritage objects ('naturlevn' in the National Museum Act), such as fossil and subfossil botanical or zoological remains (including the layers in which they are found) and meteorites, are also protected under the National Museum Act (Inatsisartutlov nr. 4 af 12. juni 2019) and National Nature Act (Anon. 2003).

Special heritage legislation exists for several areas in Greenland. Generally, there are two types of heritage area protection: (1) *protected heritage areas* and (2) *other heritage protection* (denoted as 'fredning' and 'anden kulturarvsbeskyttelse' in the National Greenlandic Heritage Act). *Protected heritage areas* are the most regulated and, as a rule, no activities, other than providing access to within 2 metres of the heritage feature(s), are permitted. In areas defined under *other heritage protection*, certain activities are allowed if they comply with the heritage legislation (e.g., executive orders, Anon. 2016, Anon. 2018).

Specified regulations for the National Park in Northeast Greenland are written directly into the National Greenlandic Heritage Act, while heritage regulations for other protected areas are defined in a number of executive orders (Anon. 1937, Anon. 1950, Anon. 1954, Anon. 1971, Anon. 1989, Anon. 2005, Anon. 2007, Anon. 2008, Anon. 2010, Anon. 2016, Anon. 2018). Several areas in Greenland are protected to safeguard combined natural and cultural heritage values. Specific regulations for these areas are specified within individual executive orders.

The regulations laid down in the National Greenlandic Heritage Act are as follows:

All physical, ancient remains ('fortidsminder' in the National Greenlandic Heritage Act)—e.g., ruins, settlements, graves, cairns (inussuit), traps, cultural layers etc.— predating 1900 CE are automatically protected in Greenland and include all associated materials, components, artifacts and ecofacts. All graves, regardless of age, are automatically protected under Greenlandic law. In the National Park in Northeast Greenland, all cairns are protected, regardless of their age, and no man-made objects, regardless of age, can be picked up, disturbed or removed from the Northeast National Park without prior approval by the NKA. The same applies to man-made objects of Greenlandic origin predating 1945 for the rest of the country.

All individual ancient remains and heritage features in Greenland are protected by two types of buffer zones:

- Buffer 1 (2-metres): no disturbing or damaging activity can take place within 2 metres of an individual ancient remain or feature. This also prohibits access inside the ancient remain or feature.
- Buffer 2 (20/100-metres): Public access to or information about the site/feature may be established (signposts, paths, site/feature demarcation etc.) within a buffer area extending 2-20 metres from the feature. In the National Park in Northeast Greenland, this buffer zone is extended from 2-100 metres from the feature.

Any type of exploration and development activity —whether public or private— in the open land must be reviewed by the NKA through an established, formal hearing processes. Depending on the existing heritage values and the scale of impact from the proposed development plan, the NKA can require, or the developer can ask for, an archaeological survey ('arkæologisk besigtigelse' in the National Greenlandic Heritage Act § 11) to establish and define what heritage values and conservation concerns exist within a given area. Subsequently, the NKA can require, or the developer can ask for, an archaeological investigation ('arkæologisk undersøgelse' in the National Greenlandic Heritage Act § 12) of heritage sites/features in the area impacted by development, after which any restrictions on activities may be lifted or recommendations provided for mitigation.

All activities planned in areas with a pre-existing special heritage protection status must be reviewed by the NKA in accordance with Executive Order nr. 38 of 1 October 2020 (Anon. 2020). Depending on NKA's assessment of the potential impact of the proposed activity, the developer may be required to initiate a complete Heritage Impact Assessment or HIA ('kulturarvsvurdering' in Executive Order nr. 38 of 1 October 2020) of the area prior to the onset of their project. All expenses incurred by the NKA and Government of Greenland in connection with the HIA must be paid by a developer or contractor after a budget is agreed upon (National Greenlandic Heritage Act § 14).

Experience has shown that early and direct dialogue between the NKA and developers can significantly minimise the chance of running into any heritage issues that may impede the project's timeline and subsequently increase related economic expenses.

6.3 Heritage zones

This section provides an overview of heritage sites and values as defined for the Ummannaq region of West Greenland, north of the Nuussuaq Peninsula. The maps included below illustrate a desk-based approach for assessing heritage values and potential management concerns in and around license and activity areas. The character and uncertainties of the existing and available heritage site information and data (see above) present a great challenge in terms of geographically fixing and delineating areas with and without heritage values. Thus, the zoning and visualisation of heritage values adopted here are designed to be:

Robust: reflecting the actual site information currently registered in Nunniffiit.

Applicable: Boundaries and designations are presented in a way that corresponds to how the NKA is likely to delineate boundaries that are potentially impacted by development and exploration activities in the various heritage zones within the language of existing heritage legislation.

Reproducible: These methods can be seen as a uniform approach that can be applied and reproduced in any part of Greenland — regardless of data quality and without compromising heritage management concerns.

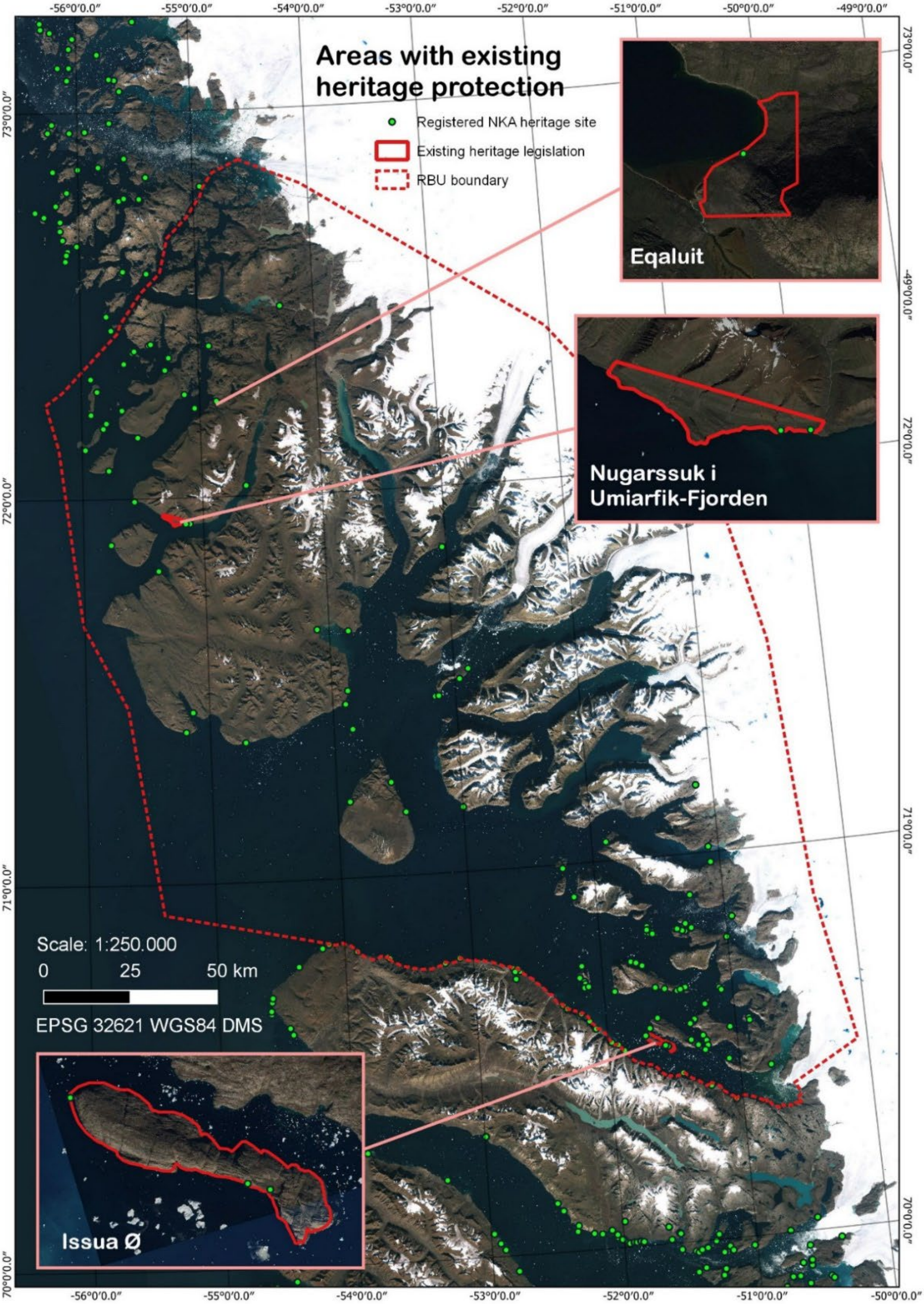

Figure 6.2. Map showing the most protected heritage areas in the AOI (Zone 1 protection). Satellite base map from Dataforsyningen, WMS service, 2022.

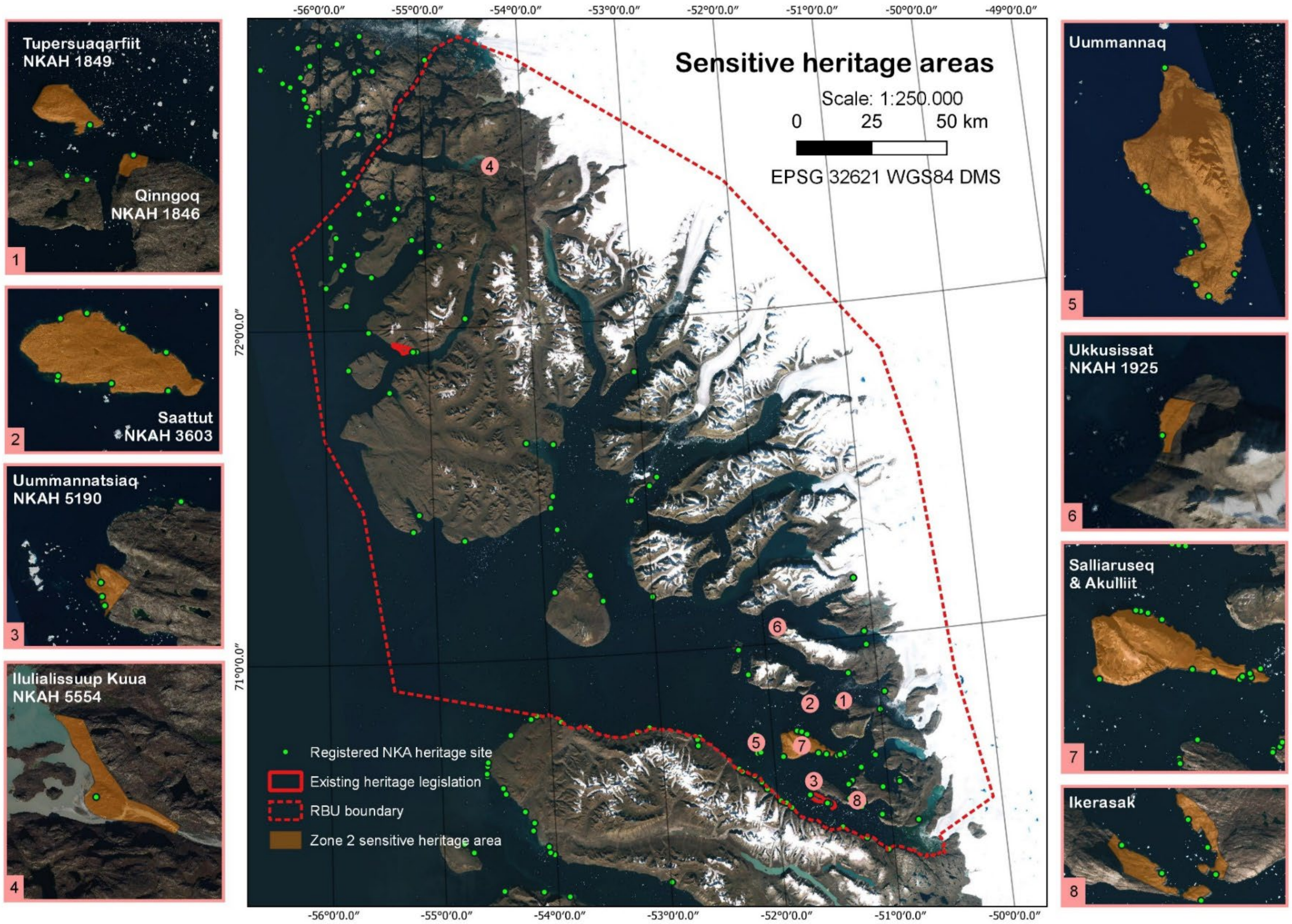

Figure 6.3. Map showing currently defined sensitive heritage areas in the AOI (Zone 2). Satellite base map data from https://dataforsyningen.dk/data/3769, WMS service, 2022

Zone 1: Protected Heritage Areas

Definition: Geographically defined heritage areas with pre-existing legal protections specified within existing national heritage acts or executive orders.

Expected heritage management action: No exploration, exploitation or development activity is allowed in these legally protected areas (Figure 6.2), and all planned activities must be evaluated through a rigorous hearing process pursuant to Executive Order no. 38 of 1 October 2020 (Anon. 2020) and approved by both the NKA and the National Heritage Committee ('Kulturarvsrådet' in the National Greenlandic Heritage Act).

Zone 2: Sensitive heritage areas

Definition: Heritage areas that include rare, sensitive and/or nationally important sites, including areas that are scheduled for future heritage protection.

Expected heritage management action: While exploration, exploitation or development activities are not automatically excluded inside sensitive heritage areas (Figure 6.3), the NKA will normally advise developers against disturbing such areas; especially in those areas scheduled for future heritage protection or already defined as 'no-go' zones that should be totally avoided or require further archaeological investigations prior to any exploration or development activity.

Zone 3: Heritage site buffer zones

Definition: A heritage site buffer zone extends from the geographic central point listed in Nunniffiit, extending 500 metres in diameter (250 metre radius from central point) inside of which >80% of the site's heritage features are observed.

Expected heritage management action: In the current version of Nunniffiit, all heritage sites are mapped as point data due to the varying degrees of data quality (see above). However, many sites consist of several separate heritage features ('fortidsminder' in the National Greenlandic Heritage Act). It is therefore not uncommon to see sometimes >10 individual features comprising the totality of a registered NKAH point. Each 'site' in Nunniffiit is protected by the 2 metre and 20 metre (100 metre in the Northeast Greenland National Park) buffer zone described above. Thus, heritage sites effectively consist of several overlapping protected zones, often with interlaying unprotected corridors. In these cases where these unprotected corridors exist, it is extremely difficult and risky to carry out exploration, extraction and development activities without directly or indirectly disturbing the legislated protective zones. The NKA therefore considers an ellipse of 500 metres in diameter (i.e., 250 metre radius extending from the point listed in Nunniffiit) a heritage site buffer zone (Zone 3). Within this buffer zone exploration, extraction and development activities are not advised or, at the very minimum, can only be carried out once all heritage elements and features in the given area have been mapped and documented.

6.4 Heritage site density maps

Figure 6.4 shows the density of all registered heritage sites within a 5 km hexagon grid in the Uummannaq area north of the Nuussuaq peninsula in

West Greenland, Avannaata Kommunia. The map illustrates both the concentration of archaeological survey and also, to some extent, actual past geographical settlement intensity. The density map therefore provides some indication of what heritage management action is required by the NKA prior to a mining company or developer carrying out activities in a given area:

- Areas with <4 heritage sites: These areas most likely have little previous investigations (or none at all) with the existing heritage site information based on older documentation, interviews and random reporting of sites. The NKA will likely require a full archaeological survey ('arkæologisk besigtigelse' in the National Greenlandic Heritage Act) prior to any exploration or development activity. Identified locations of ancient/historic sites and features may require a complete or partial archaeological investigation ('arkæologisk undersøgelse' in the National Greenlandic Heritage Act).
- Areas with ≥5 heritage sites: These areas are most likely moderately investigated, and the existing heritage inventory is based on a combination of both older and more recent systematic heritage site registrations or archaeological surveys. Depending on the exact situation and the information available, additional archaeological surveys in these areas may require more targeted or, in some instances, higher resolution digital mapping and inventories of the sites and features. In some cases, these sites may also require sub-surface archaeological testing or full excavation ('arkæologisk undersøgelse' in the National Greenlandic Heritage Act). In areas that already prove to be well investigated (where the existing heritage inventory is a fairly detailed combination of both older and recent, systematic heritage site registrations), the need for archaeological surveys required by the NKA will mainly be aimed at producing accurate, digital site inventories and maps, if they do not already exist. In some cases, these sites may also require subsequent complete or partial archaeological investigation ('arkæologisk undersøgelse' in the National Greenlandic Heritage Act).

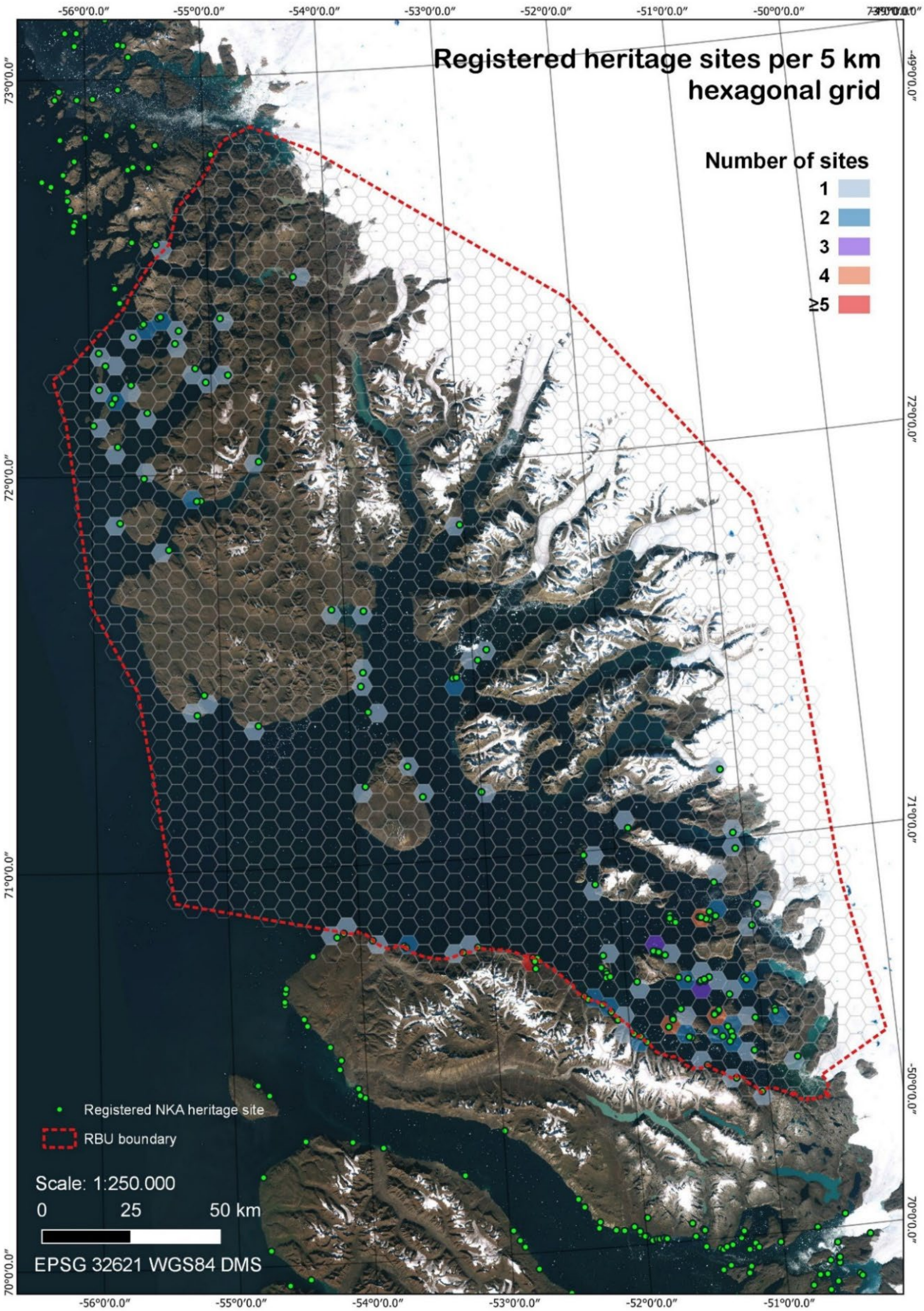

Figure 6.4. Map showing the density of currently recorded heritage sites within 5 km diameter hexagons. Satellite base map data from Dataforsyningen, WMS service, 2022.

6.5 Predictive landscape features

In Greenland, approximately 90% of all heritage sites are located on or adjacent to a fjord shoreline or open ocean, a clear result and evidence of the continued dependence of past populations dependence on marine resources and transportation by sea in Greenland in the past. While heritage sites may be found almost everywhere, certain types of landscape types, terrain and natural features are predictively more likely to be associated with unregistered sites – especially in the case of large seasonal camps or settlements. These landscape types and features normally receive heightened attention during archaeological surveys and therefore should also be identified during any mineral exploration and/or development activities due to the increased likelihood of producing new heritage sites/features (Table 6.1).

Table 6.1. List of landscape features that normally receive heightened attention during archaeological surveys. Note that the list of landscape features is not exhaustive or prioritised.

Landscape feature
Coasts and inland fjord shorelines near sheltered bays and inlets
Natural landscape bottlenecks (valleys, isthmuses, gorges etc.)
River mouths
River fords/crossings
South facing, grassy slopes
Promontories/headlands
Distinctive landmarks (hills, peaks, overlooks etc.)
Higher elevation, gravelly beach terraces
Expedient landscape routes
Mountain passes
Vantage points and wide viewsheds
Valley floors with freshwater access
Geological resource concentrations (steatite, calcedony, schist, sandstone etc.)
Natural resource concentrations (bird nesting cliffs, grazing areas, migratory bottlenecks, spawning rivers etc.)

6.6 References

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7 Integrated spatial analysis of overlapping interests

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7.1 Introduction

In Chapters 4-6, a number of maps have been presented, showing known distribution areas of important flora and fauna, human use of the region and cultural heritage areas. All these features – be it a seabird colony, a drinking water barrier zone or an archaeological site – may be regarded as landscape assets or interests that should be considered when planning mineral resource exploration or extraction activities.

In this chapter, we provide a summary analysis of how many of these landscape interests overlap in different parts of the area of interest (AOI). It is important to stress that the analysis involves no extrapolation or prediction of occurrences. It simply summarises what is presently known and presented in the maps of the report, though sometimes buffer zones are applied to the features (see below). This means that areas with few overlaps may be the result of lack of knowledge rather than lack of presence (see Chapter 9). It is also important to stress that the different landscape features included in the analysis may be affected very differently by, e.g., mining activities (see Chapter 8).

The summary analysis was performed as a so-called GIS overlay analysis using custom-made Python scripts in ArcGIS Pro 3.0.2. In principle, the different map layers presented in Chapters 4-6 were simply stacked on top of each other and for each 250x250 m cell in a grid system covering the entire AOI, the number of map layers with features present in the cell were counted. Thus, a resulting cell value of, e.g., 3 indicates that at the centre of the cell three different map layers have features present. In rare cases, an individual layer may have several features present at the cell centre, e.g., two cultural heritage zone 3 areas, but the layer will still only add a value of one to the overlay. Thus, it is the number of different layers with features present that is summarised, not the number of individual features.

In total, 28 map layers were included in the analysis (Table 7.1). As features need to cover an area to overlap and count in the overlay calculation, point and polyline features were buffered, effectively turning them into polygons with an area (see "Geometry" in Table 7.1). The buffer radii used were in some cases determined by legislative regulation, e.g., protection zones around cultural heritage sites, in other cases by the degree of spatial uncertainty associated with data or real-world sizes of features (see "Buffer radius (m)" in Table 7.1). Some features were also buffered in accordance with a perceived zone of influence: When conducting mineral activities within this distance, the feature needs to be considered (see Chapter 8). Thus, drinking water barrier zones were given a buffer zone of 5 km because of particular sensitivity to, e.g., dust pollution.

Especially when buffering features, it becomes relevant to make sure that they are constrained to their right element, e.g., that coasts with capelin do not count in adjacent cells at land, even though these cells fall within the 500 m buffer zone of the coastal stretch with capelin. Thus, each input layer was constrained to count only in cells of the type specified in the column "Habitat" in Table 7.1.

Table 7.1. Map layers included in the overlay analysis in Figure 7.1-2. The contents of the columns are explained in Section 7.1. Besides the analysis of all 28 layers listed, two sub-analyses were run: one including mainly biologically relevant layers (see column "Biology" and Figure 7.3a), and one including layers mainly reflecting human use/cultural heritage interest (see column "Human use" and Figure 7.3b). Layers were included in the analyses as visualised in the maps of Chapters 4-6. However, for some layers, additional processing or sub-selection of features was undertaken, which is detailed in the footnotes to the table.

Name	Geometry	Buffer radius (m)	Habitat	Sub-analysis	
				Biology	Human use
Arctic char freshwater catchments	Polygons	500	Ice free land	1	
Arctic char river mouths	Points	1000	Sea	1	1
Atlantic cod fishery[1]	Polygons	0	Sea	1	1
Biologically important areas	Polygons	0	Land and sea	1	
Coasts with capelin[2]	Polylines	500	Sea	1	1
Coasts with human resource use[3]	Polylines	500	Land and sea		1
Coasts with lumpsucker[2]	Polylines	500	Sea	1	1
Cultural heritage areas, zone 1	Polygons	0	Land		1
Cultural heritage areas, zone 2	Polygons	0	Land		1
Cultural heritage areas, zone 3	Points	250	Land		1
Drinking water barrier zones	Polygons	5000	Land		1
Fertile vegetation[4]	Polygons	0	Ice free land	1	
Goose moulting and breeding areas	Polygons	0	Ice free land	1	
Greenland halibut fishery[1]	Polygons	0	Sea	1	1
Homothermic springs 100 m zone	Polygons	400	Land	1	
Municipal planning zones	Polygons	0	Land		1
Muskox calving area	Polygons	0	Ice free land	1	
Muskox hunting hotspots[5]	Polygons	0	Ice free land	1	1
Muskox licence area	Polygons	0	Land		1
Oil spill sensitive shorelines[6]	Polylines	500	Land and sea	1	1
Red-listed plants, possible area	Polygons	0	Ice free land	1	
Salt or saline lakes 100 m zone	Polygons	400	Land	1	
Seabird colony protection zones	Polygons	0	Land and sea	1	
Seabird colony sites	Polygons	100	Land and sea	1	
Seaduck moulting areas	Polygons	0	Sea	1	
Snow mobile driving corridors	Polylines	177	Land and sea		1
Tsunami no-go area	Polygons	0	Land and sea		1
Walrus winter and spring areas	Polygons	0	Sea	1	

[1]All fishery squares with catch > 0 included.

[2]All shoreline segments with relative abundance score > 0 included.

[3]All coasts with relative importance > 1 included.

[4]All 250x250 cells with NDVI>=0.25 included.

[5]All 250x250 cells with kill density > 0.04 animals/km^2 included (based on kernel density model of point data with a 10 km radius).

[6]All shoreline segments ranked as high or extreme included.

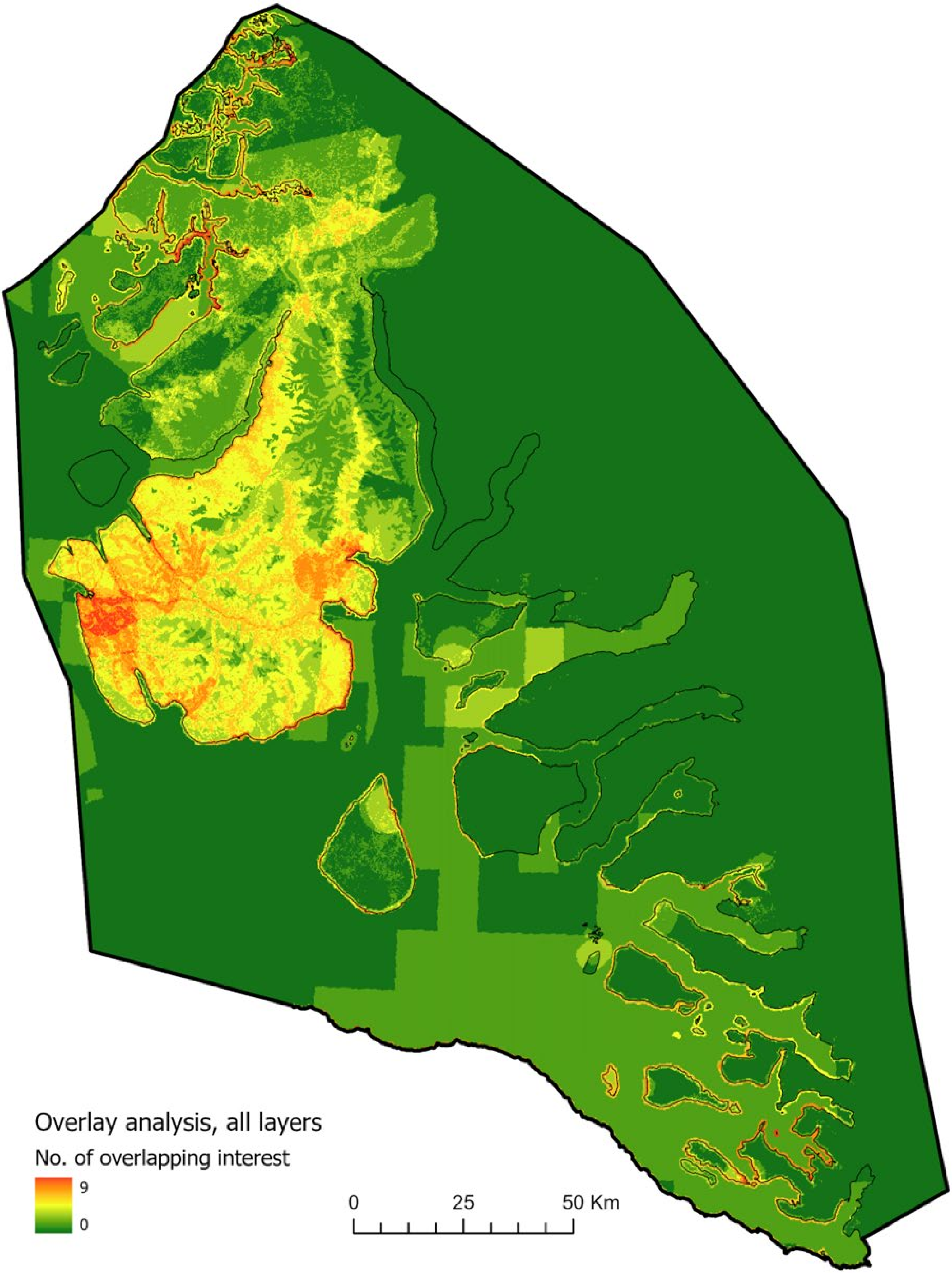
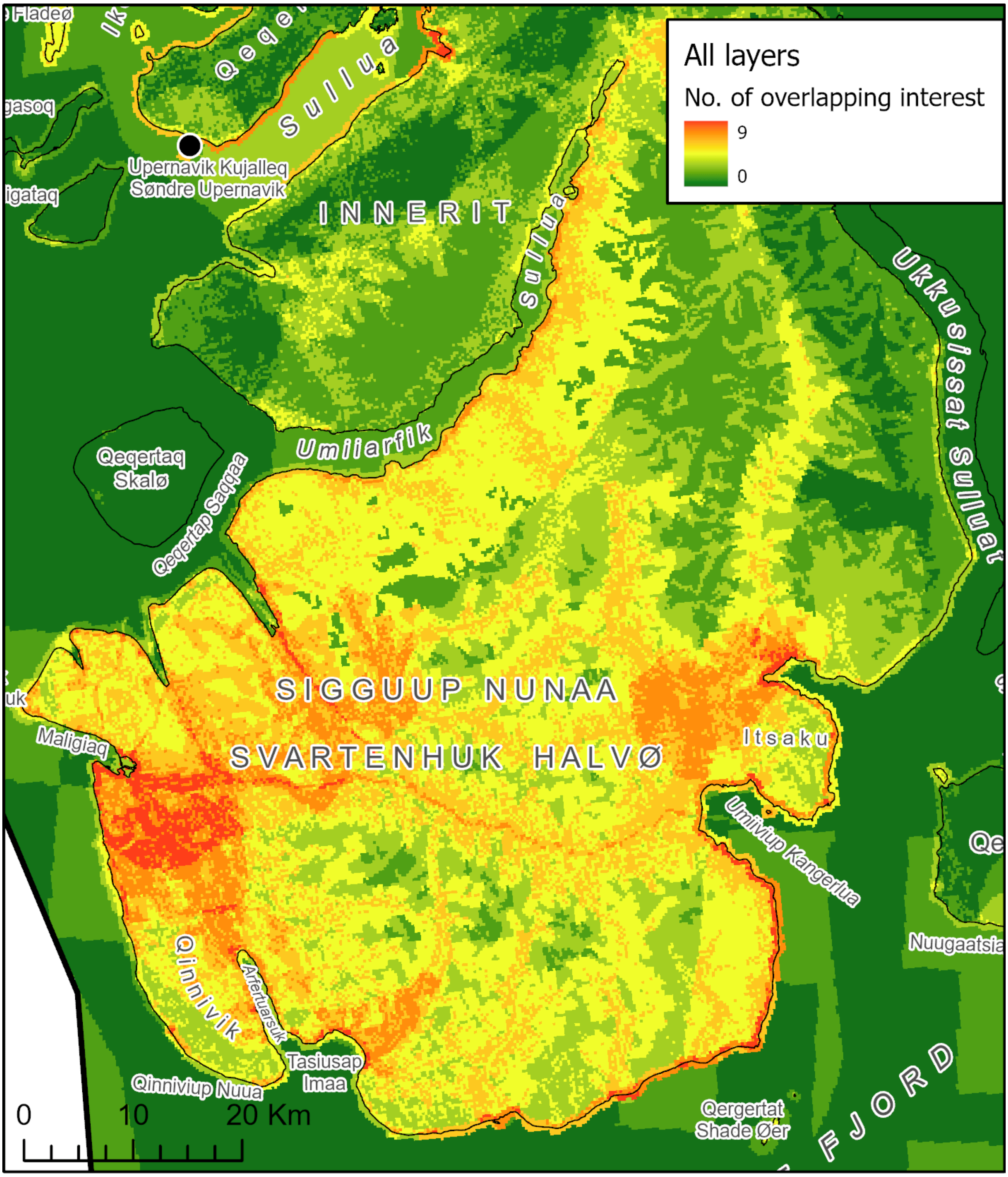


Figure 7.1. Result of overlay analysis of all 28 map layers listed in Table 7.1, spanning flora and fauna, human use and cultural heritage interests. The maximum cell values are nine, reflecting that in these cells features from nine different map layers overlap.

7.2 Results of the integrated spatial analyses

Three different analyses were conducted – one main analysis including all 28 map layers, reflecting both flora and fauna, human use and cultural heritage interests (Figure 7.1 and 7.2), one sub-analysis including 19 map layers with mainly biologically relevant information (Figure 7.3a), and one sub-analysis based on 16 map layers with information primarily reflecting human use and cultural heritage interests (Figure 7.3b). It is not possible to make a strict distinction between biological layers and human use layers, mainly because several of the biological distributions are only known through spatial patterns in hunting or fishery data. Thus, some of the layers are included in both sub-analyses, and this is important to keep in mind when assessing the results (see the column "Sub-analysis" in Table 7.1).



Figur 7.2. Same overlay analysis result as in Figure 7.1, only this time zoomed in on the area where most landscape interests overlap.

The main analysis based on all 28 map layers primarily highlights Sigguup Nunaa as an area with many overlapping interests. Here, many important biological features co-occur, e.g., vegetation, geese moulting/breeding areas, freshwater systems with Arctic char and muskoxen. There are also human use interests, including important muskox hunting areas and exploitation of coastal resources like capelin and lumpsucker. Within Sigguup Nunaa, it is particularly an area southeast of Maligiaq/Svartenhavn in the west, an area west of the Itsaku pensinsula in the east and to some degree an area northeast of the Tasiusap Imaa Bay in the south that are highlighted (Figure 7.2). These areas roughly correspond to three large wetlands that are designated as important geese moulting/breeding areas in the *Field rules for mineral resources activities* (Figure 4.1). Besides Sigguup Nunaa, the main analysis also emphasises coastal areas in the northern and the southern part of the AOI. These areas, located closer to towns and settlements, are mainly highlighted because of human use, especially of coastal resources, but there are also relatively many cultural heritage sites and seabird colonies.

As for the sub-analyses, the result of the analysis of the biologically relevant layers (Figure 7.3a) in many ways resembles the result of the main analysis. Thus, Sigguup Nunaa in general, and in particular the aforementioned areas at Maligiaq/Svartenhavn in the west and the Itsaku peninsular in the east, are highlighted as are coastal stretches in the northern and the southern part of the AOI. The human use analysis, on the other hand, gives a somewhat different picture (Figure 7.3b). Here, the relatively remote Sigguup Nunaa has few overlapping interests (mainly muskoxen hunting), and instead coastal areas (and to some degree also more open water areas) in the northern and southern parts of the AOI are emphasised. Thus, the human use interests cluster in coastal areas in proximity to towns and settlements where most of the hunting and fishery activities take place, and these are also the areas where most of the cultural heritage sites have been recorded.

As a closing remark to this chapter, it is important to stress that even though the overlay analyses classify a particular area as red or yellow, it does not necessarily mean that mineral resource activities will have a high environmental and/or negative social impact here. It does, however, emphasise that, based on our present knowledge, several different interests need to be addressed in case of mineral resources activities. It is important to be aware of data gaps (see Chapter 9) when interpreting the overlay analysis results, and new data will certainly add details to the picture. However, we do consider the overall results of the analyses, in particular the areas highlighted on Sigguup Nunaa, to be fairly robust. In the following chapter, the potential pollution and generic impacts on biodiversity from mineral exploration and exploitation are summarised.

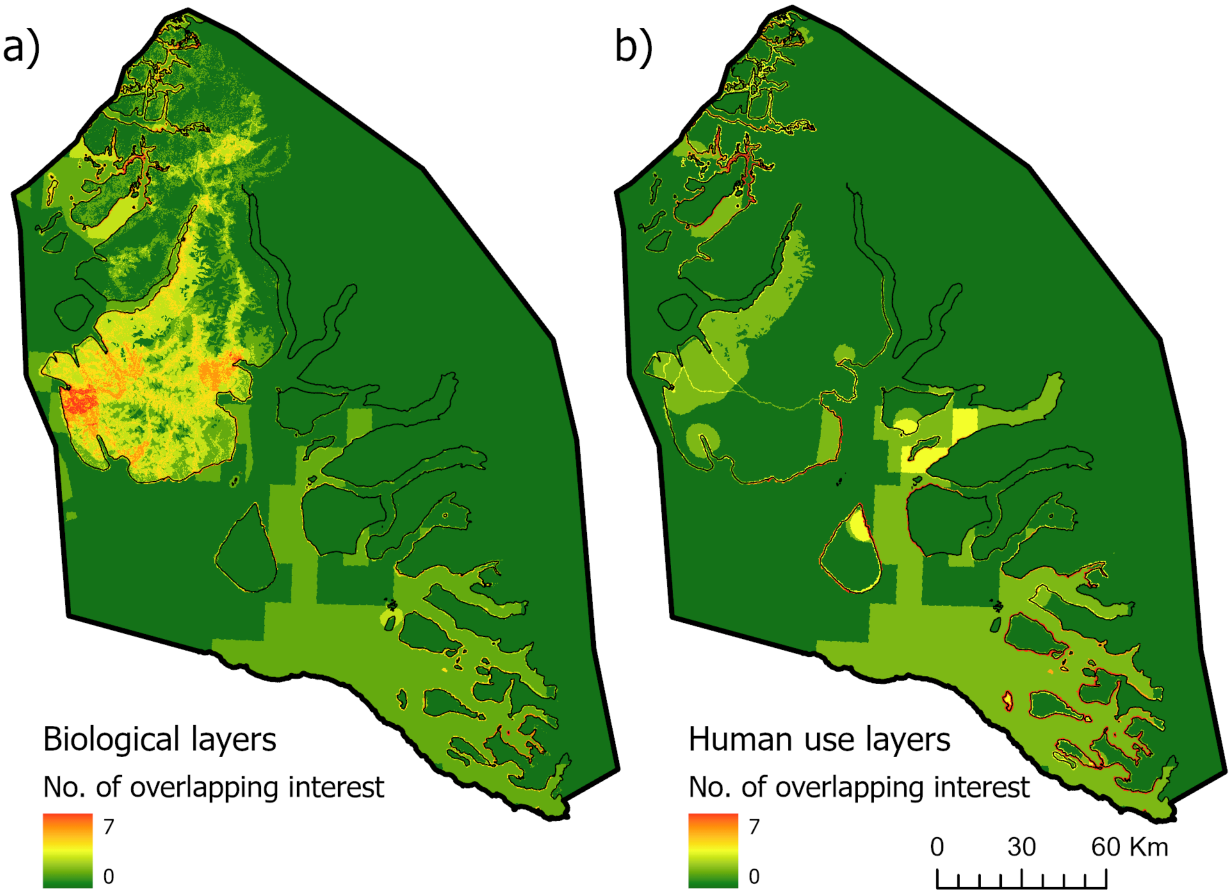


Figure 7.3. a) Result of sub-analysis of 19 map layers with mainly biologically relevant information. b) Result of sub-analysis of 16 map layers with information mainly relevant for human use and cultural heritage protection. See column "Sub-analysis" in Table 7.1 for information of included map layers.

8 Mining and environmental impacts

By Anders Mosbech[1], David Boertmann[1], Kim Gustavson[1], Christian Juncher Jørgensen[1] and Janne Fritt-Rasmussen[1]

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8.1 Environmental impacts from mining activities

In this chapter, we give an overview of the typical environmental impacts and effects that can be expected from modern mines operated according to high international environmental standards. It should, however, be kept in mind that mineral projects are diverse and so are the potential environmental impacts and effects.

The last section in this chapter describes potential environmental impacts from accidents.

Exploration is the first phase of the mining activities and includes search for exploitable minerals by various methods. Typically, small teams of geologists, transported by helicopters, boats, ATV's etc., search the terrain using different geophysical methods and take samples by hand or handheld equipment. These activities are regulated by the "field rules" (see Appendix 3 for more details). The main environmental impacts of such activities are often limited to local disturbances of wildlife with expected short-term effects and damage to the vegetation when using ATVs and other vehicles. There may also be risk of minor spills of fuel.

Later in the exploration phase, the activities focus on mapping of the ore and on assessing the concentrations of commercial minerals at a potential mine site. Since this part is important for the economy of the mining project, this phase of the work can extend over several years of work with mapping the quality and quantities of the exploitable ore. The activities may include many kilometres of drilling, many geological and geochemical analyses, temporary camps, helicopter traffic etc. Establishment of more permanent infrastructure, buildings, roads, airstrips etc. may follow when the ore is to be mined. The environmental focus should be on minimising the potential long-term impacts and effects of the above- mentioned activities. Environmental impacts and effects of the activities may include disturbance of wildlife, habitat loss because of infrastructure, emissions from and pollution of the surrounding environment, including generated dust and waste/wastewater from the camp facilities and the exploration activities (including drilling additives).

If a mine is established, the largest environmental challenge to handle in a safe manner is the deposition of mining waste and tailings, from which harmful substances otherwise may leach into the environment. If the mine is constructed as an open pit mine, land areas will be excavated with impacts on the physical environment (see Figure 8.1). Such impacts can be more restricted for underground mines, especially if backfilling of waste rock and tailings is possible. During active mining, the infrastructure will be enlarged, with facilities for ore processing and harbour facilities for overseas shipment of concentrate. To avoid pollution, the ore concentration processes should be carefully handled, especially if chemical processes are applied. The energy consumption will typically be large and based on diesel oil unless hydropower is established.

Finally, when the mine closes, the mine site will be remediated/rehabilitated, and the goal is normally that with time the area should resemble pre-mining conditions. However, it is likely that some changes in topography reflecting the mine pit and permanent storage of waste rock and tailings will remain.

In the following, the different potential impacts and environmental effects of mining activities are reviewed, and we provide examples of the geographical extent and duration of the effects that can be expected from a typical modern mining operation.

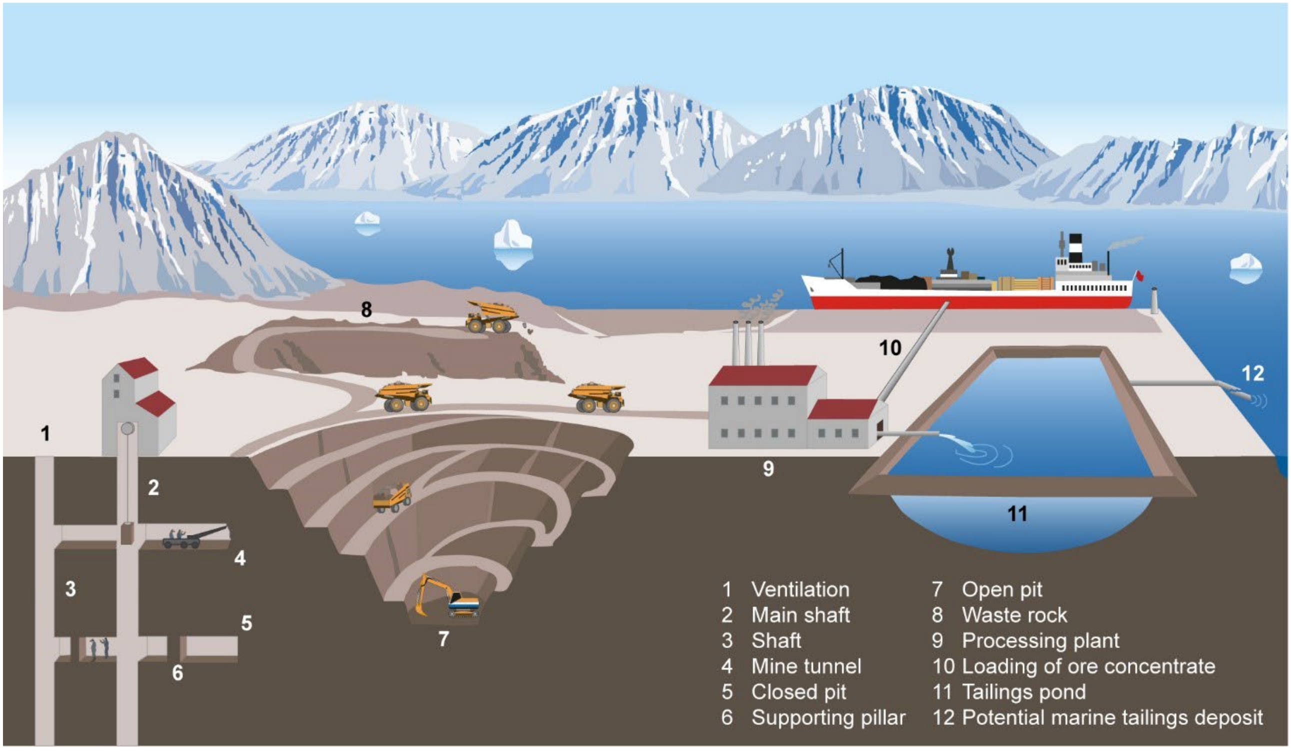

Figure 8.1. Overview of impacts from a mine site.

Definitions of terms used in the impact overview

The geographical extent of impacts can vary. Three overall levels are defined for the impact review:

- Local: Refers to the actual industrial project area and to the near surroundings up to a few kilometres.
- Regional: Refers to the region in which the mining-related activities take place, up to a few tenth of kilometres.
- Global: Refers to the entire world and is only relevant for the release of greenhouse gasses.

The duration of impacts and effects includes three levels:

- Short-term: Refers to a period of up to a few years.
- Long-term but temporary: Refers to a period longer than a few years and often decades, e.g., the lifetime of a mine, but effects are still potentially reversible.

- Permanent: Refers to a period where the effects are irreversible or expected to last for more than 100 years.

The effects on habitats caused by impacts from the activities are catagorised into three levels:

- No significant reduction of habitat quality or ecological damage: An insignificant number of individuals of a population of animals or plants are affected by reduced habitat quality or habitat loss. The level of pollutants is below the guideline values for good environmental quality but may be above background concentrations.
- Reduced habitat quality: The quality of a habitat is reduced by a given activity, e.g., dust, wastewater discharge or disturbance. The density of specific animals or plants can be reduced. The level of pollutants can be above guideline values for good environmental quality or background concentrations, and biological effects may occur.
- Habitat loss: This is the process by which a natural habitat becomes incapable of supporting its naturally occurring species so that the plants and animals previously inhabiting the site become displaced or die. This typically happens in the mining area itself due to excavation of mine pits and construction of waste facilities. The lost habitats can to some extent be rehabilitated when the mining activity ceases, but in the Arctic, this will typically take decades as biological processes like revegetation are slow.

8.2 Disturbance of wildlife – noisy activities and presence of people and infrastructure

Noisy activities at a mine site include, e.g., blasting, mechanical processing of ore and all the machinery used at the site besides the presence of people and infrastructure. All these activities have the potential to disturb the wildlife, i.e., birds and mammals, by displacement from their natural habitats, and they should therefore be regulated carefully to reduce the impact. Disturbance of wildlife is usually a local impact, but in case of pipelines, roads and helicopter flying etc. the disturbance can be more widespread. If short-term and/or if alternative habitats are available, the effects will be reversible or insignificant, but long-term impacts could cause loss of feeding possibilities, calving grounds, moulting grounds etc. Some animals such as caribou will also avoid infrastructure at a certain distance, contributing to reducing their available habitat. A few species such as polar foxes, polar bears and ravens may be attracted to a mine site because of easily available food in the form of garbage, and this may increase their predation pressure on prey species near a mine site.

Disturbance of wildlife is reduced by concentrating infrastructure near the mine facilities, by careful planning of the construction of roads to avoid habitats critical to specific populations and by directing helicopter flying to defined traffic lanes and sufficiently high altitudes in order to minimise the affected areas. Moreover, off-road activities, including people on foot, should be restricted and only allowed along predefined tracks. Some animals, e.g., geese, may habituate to disturbance if the disturbing activities are carried out in a predictable way.

Wildlife may percieve people as predators (hunters) and try to avoid them at long distances. Therefore, animals belonging to populations exposed to human hunting pressure are more shy and scared at longer distances than animals from populations that are not hunted. This effect may also apply to infrastructures that the animals relate to the presence of human beings.

Vessel traffic in relation to shipping of ore and supplies to the mine causes underwater noise which can disturb marine mammals, mask their communication and cause habitat loss. For most marine mammals, the disturbance from ship noise seems to be limited to less than a few km (Erbe et al. 2019). However, narwhals are among the species that are very sensitive to disturbance from underwater noise. Shipping traffic and associated ice breaking have caused an unprecedented displacement of narwhals from Eclipse Sound (NAMMCO 2022). Shipping traffic causes significant disturbances to narwhals (e.g., disruption in foraging) at distances from 0 to 20 km, while icebreaking can cause impacts at distances from 0 to 35 km. The NAMMCO (2022) Workshop recommends that these values are used to establish buffer zones around narwhal summer aggregations as well as traffic corridors to protect migration routes and winter foraging grounds.

In Table 8.1 the disturbance by noise is described for different noise types. More details about disturbances can be found in Frederiksen et al. (2017).

Table 8.1. Source and effect of disturbance by noise.

Type/stressor	Duration of impact	Geographical extent	Effect and effect level
Helicopters	Short-/long-term	Local/Few km along the route	Reduced habitat quality for wildlife if disturbance is frequent
Helicopters are an important means of transport during most of the phases of the development of a mine. Helicopters are very noisy and have the potential to scare wildlife such as moulting geese many km away, both locally and along the flight routes (regional). The effects can be mitigated, although not avoided, by establishing well-defined flight routes and flight altitudes.			
Fixed winged aircrafts	Short-/long-term	Local/Few km from airstrip	Reduced habitat quality for wildlife if disturbance is frequent
Fixed winged aircrafts will be used if airstrips are established at a mine site and occasionally also during exploration. They are noisy during take-off and landing, but their cruising altitude is usually too high to disturb wildlife. As fixed winged aircraft behaviour is relatively predictable, some animals living near the airstrip may habituate to the noise.			
Blasting	Short-/long-term	Local/Few km	Reduced habitat quality for wildlife if disturbance is frequent
Blasting generates noise and, if frequent, possible loss of habitats. However, a few blastings might only have short-term and local impacts.			
Other noisy processes	Short-/long-term	Local/Up to a few km	Reduced habitat quality for wildlife if disturbance is frequent
These activities take place at and near the mine site and will have local effects.			

8.3 Loss of habitats from constructions and buildings

Habitat losses occur when activities or infrastructure affect habitats physically so that the plants and animals living there can no longer use the habitat. The loss can be extremely localised, e.g., a building, or more extensive, e.g., the area where the mining pit is excavated. In addition, deposition sites for mining waste and tailings may occupy large areas, and, in the case of tailings, lakes may be included as deposits. A dam across a river can obstruct the passage of Arctic char, and the flooding behind a dam may impact large terrestrial areas.

The hydrology of an area may be impacted by road construction, causing water logging or the opposite – drainage of wetland areas. There is permafrost in many parts of Greenland, which may be impacted by the establishment of different infrastructures.

In general, habitat loss from mining activities is local. However, if, e.g., a rare, red-listed plant species has its only occurrence at a mine site, the effect of the habitat loss is of national concern. While the habitat loss following mine establishment typically is local, the effects are often of long-term duration. Rehabilitation after termination of the activities is therefore required to prevent permanent habitat loss. Full remediation of old mining areas to the pre-mining state is often difficult, but new habitats can be created.

The effects of mining constructions are best mitigated by including high quality background knowledge in the planning of all constructions and activities in the affected area to avoid the most valuable habitats. Such knowledge should be gained by background studies of the local ecology and natural history before initiating any activities.

Table 8.2 gives an overview of the most typical types of mining constructions related to mineral exploration and exploitation activities. Specific plans and regulations will be established as part of the prospecting licence and exploration licence and will include the terms under which the constructions can take place. These regulations will follow the principles of the Best Available Technology (BAT) and Best Environmental Practice (BEP) to avoid unnecessary environmental impact on the surroundings.

Table 8.2. The impact of key mining infrastructure.

Type/stressor	Duration of impact	Geographical extent	Effect and effect level
Roads	Long-term	Local/regional	Habitat loss
Helipads and airstrips	Long-term	Local	Habitat loss
Harbour	Long-term	Local	Habitat loss
These examples of habitat loss caused by the building of new infrastructure are local and generally restricted to the area of the infrastructure itself. The ecological effects will mainly be at individual level, but habitat loss may be significant for the biodiversity of rare plants and vegetation types. Where new infrastructure changes currents or water runoff, some habitat change in a larger area may occur. Careful planning based on in-depth background knowledge can mitigate the effects.			
Buildings and other facilities	Long-term	Local	Individual
Buildings and other stationary facilities differ in size and number, but overall the impacts are local. Effects on especially rare plant species can be mitigated by careful planning of the construction to avoid habitats critical for specific populations.			
Mine pit	Permanent	Local	Habitat loss
Waste rock and tailings storage facilities	Permanent	Local	Habitat loss
Dams across streams and rivers	Long-term	Local/regional	Habitat loss/Reduced habitat quality
A mine pit, waste rock and tailings deposits are permanent and will result in destruction of habitats in the area that they cover. After mine closure, the area may be rehabilitated; however, in general not to the state of the original habitat. A dam can be removed, but if the population of Arctic char is gone, immediate recovery is not likely. Restocking may be a possibility.			

8.4 Spread and distribution of marine invasive alien species

The Arctic marine ecosystem is still relatively unaffected by non-native invasive species compared with temperate, subtropical and tropical regions due to the generally low shipping activity at these northern latitudes. Shipping in connection with the extraction of minerals in the Arctic may poses the risk of bringing alien invasive species to Greenlandic waters through discharge of ballast water containing viable eggs and larval and plankton organisms or organisms attached to the hull of the vessels.

8.5 Pollution from mining activities

There are multiple potential sources of pollution from mining activities, which should be carefully analysed, regulated and mitigated to avoid unacceptable short- and long-term impacts and effects on the environment. Potential sources of pollution include deposition of mining waste and tailings, the processes used for concentration of the ore, dust generation, sewage from camps (grey and black wastewater) etc. The recipients are the atmosphere (airborne emissions), the waterbodies near the mining site (sewage, leaching from tailings and waste rock, discharges from mining processes) and the terrestrial environment (dust, waste rock, tailings). The pollution and its effects should be reduced to acceptable levels, enforced by regulations, and the levels should be carefully followed by monitoring.

Discharges to water bodies – water pollution

Discharges to waters bodies and coastal waters include, e.g., effluents from mining waste and tailings, tailings depositions, wastewater from processing activities and wastewater (sewage) from camp facilities etc.

Treatment of wastewater from mine sites is typically needed to achieve sufficiently low levels of contaminants before the wastewater can be discharged to the environment. Several techniques exist to treat the different kinds of wastewater from mining activities and may include biological filtration and/or chemical precipitation of pollutants.

Discharges of water from processing activities can also be a source of pollution, and the water should be properly treated to avoid release to the environment of heavy metals, other non-degradable contaminants and toxic substances as well as chemicals used in the concentration processes. Radionuclides may also be a concern if these occur in the ore.

Wastewater from the mining processes may also contain slurry and other fine particles that may accumulate on the seabed or the lake bottom near the discharge site and possibly lead to habitat loss where local benthic fauna can be covered by the accumulating sediments. There is also a risk of resuspension of fine particles and hence further spreading.

Sewage from camps may cause local eutrophication and be the source of different toxic as well as pharmaceutical contaminants. Sewage can be treated and discharged with acceptable concentrations of polluting substances.

In Table 8.3 and 8.4, examples of sources of water pollution are given.

Table 8.3. Discharges of particulate matter and sediment from mining activities to waterbodies.

<table>
<tr><th>Type/stressor</th><th>Duration of impact</th><th>Geographical extent</th><th>Effects and effect level</th></tr>
<tr><td>Discharge to lakes</td><td>Lifespan of mine</td><td>Local*, < 1 km according to guideline value restrictions</td><td>Reduced habitat quality</td></tr>
<tr><td>Discharge to rivers</td><td>Lifespan of mine</td><td>Regional downstream</td><td>Reduced habitat quality</td></tr>
<tr><td>Discharge to the sea</td><td>Lifespan of mine</td><td>Local*, < 1 km according to guideline value restrictions</td><td>Reduced habitat quality</td></tr>
<tr><td colspan="4">Discharges from a mine include, e.g., effluents from mining waste and tailings, tailings deposition etc. Long-term impacts exceeding the lifetime of a mine are found if the discharged sediments accumulate and contaminants in the sediments are not adequately removed, elements of concern constituting a particular risk, e.g., process chemicals, metals, radionuclides and nutrients. There is also a risk of resuspension and subsequent downstream spreading of particles. If discharge concentrations are below the guideline values, the effects are of short-term duration when the discharge stops. Guideline value restrictions on discharges ensure that there will be no significant effect outside a buffer/mixing zone of typically less than 1 km.
*) However, if runoff from lakes occurs, the extent might be regional downstream of the recipient. Further, the geographical extent depends on the particle size of the discharged particulate matter/sediment, wind, waves etc. Reduced habitat quality is expected in the form of increased turbidity, reduced algae growth and increased sedimentation, which can cause physical/chemical stress to pelagic and benthic organisms. Potentially, bioaccumulation and toxic effects of chemicals and metals on algae, crustaceans, fish, birds etc. may occur if discharges are not properly regulated and monitored. Note that special focus should be directed at the possible generation of acid mine drainage if the tailings or waste rock contain reactive sulphides. The acid will increase the solubility of metals and result in higher concentrations in the drainage water.</td></tr>
</table>

Table 8.4. Discharges of wastewater from mining activities to waterbodies.

<table>
<tr><th>Type/stressor</th><th>Duration of impact</th><th>Geographical extent</th><th>Effects and effect level</th></tr>
<tr><td>Discharge to lakes</td><td>Lifespan of mine</td><td>Local*, < 1 km according to guideline value restrictions</td><td>Reduced habitat quality</td></tr>
<tr><td>Discharge to rivers</td><td>Lifespan of mine</td><td>Local*, < 1 km according to guideline value restrictions</td><td>Reduced habitat quality</td></tr>
<tr><td>Discharge to the sea</td><td>Lifespan of mine</td><td>Local*, < 1 km according to guideline value restrictions</td><td>Reduced habitat quality</td></tr>
<tr><td colspan="4">Wastewater discharge from a mine includes, e.g., effluents from mining waste and tailings, wastewater from processing activities etc. Long-term impacts are seen if dilution is insufficient or the wastewater contains critical levels of elements of concern, e.g., process chemicals, metals, radionuclides and nutrients. If discharge concentrations are below the guideline values, effects are of short-term duration when the discharge stops. Guideline value restrictions ensure that there will be no significant effect outside a buffer/mixing zone of typically less than 1 km.
*) However, if runoff from lakes occurs, the effect might extend downstream of the recipient. Further, the geographical extent depends on the mixing/dilution capacity of the recipient. Reduced habitat quality is expected. This includes bioaccumulation and toxic effects of chemicals and metals on algae, crustaceans, fish, birds etc. if discharges are not properly regulated and monitored. Note that special focus should be directed at the possible generation of acid mine drainage if the material contains reactive sulphides.</td></tr>
<tr><td>Sewage (domestic wastewater) discharge to fresh and marine recipients</td><td>Lifespan of mine</td><td>Local, < 1 km according to guideline value restrictions</td><td>Reduced habitat quality</td></tr>
<tr><td colspan="4">Discharge of sewage from camps may have long-term local impacts, but cleaning is possible and should be applied already when exploration takes place to avoid negative effects. Long-term or short-term effects of nutrient and pathogens depend on the mixing capacity of the recipient as well as on the discharge composition. If the discharge is below the guideline values, only short-term effects are expected when the discharge stops. Discharge restrictions can ensure that there will be no significant effect outside a buffer/mixing zone of typically less than 1 km. The size of the geographical extent depends on the mixing capacity at the point of discharge and the recipient (water depth, wave height, wind strength, current etc.). Reduced habitat quality is expected, which may include eutrophication and spreading of pathogens.</td></tr>
</table>

Air pollution – combustion

Combustion of fuel oil for energy generation and for vehicles, ships, aircrafts and other machinery consumes significant amounts of fuel. The combustion activities may emit considerable amounts of greenhouse gasses, soot, PAHs, black carbon (BC) and, especially if heavy fuel oil is used, also SO_x and NO_X that contribute to formation of Arctic haze and acidification of soil and freshwater bodies. The processing of the ore may also release pollutants to the air.

The emissions from energy generation can be reduced by applying the most energy efficient processes by including smoke cleaning and avoiding heavy fuel oils and are best mitigated by establishing renewable energy plants in connection with the mine. This could, however, increase other impacts such as habitat loss and disturbance of wildlife. Other emissions to the atmosphere, including incineration of domestic waste, can be reduced by different cleaning processes and by applying BET and BAP.

In Table 8.5 examples of the sources to air pollution are provided.

Table 8.5. Air emissions – combustion.

Type/stressor	Duration of impact	Geographical extent	Effects and effect level
Fuel oil as energy supply	Short-term (air quality)/Long-term (climate change)	Global/Regional/Local	Local/Global NO_X, SO_x
Air emissions from a mine using fuel oil as energy supply release greenhouse gasses, NO_x, SO_x, particulate matter and black carbon (soot), which may impact the local air quality. Greenhouse gas emissions also contribute to the global climate change. Emissions can be reduced by applying the most energy efficient processes and smoke cleaning as well as by avoiding heavy fuel oil and, ultimately, by use of renewable energy.			
Waste incineration	Lifespan of mine	Local, < 1 km according to guideline value restrictions	Reduced habitat quality
Waste incineration takes place during the entire lifetime of a mine. If emissions are below guideline values, only short-term effects are expected when the emission stops. Emissions can be reduced by applying the most efficient processes and smoke cleaning, thereby ensuring that there will be no significant effects outside a buffer/mixing zone of typically less than 1 km. Air emission from waste incineration may include, e.g., acid gases, dioxins/furans, heavy metals and NO_x.			

Air pollution – dust

Many of the mechanical processes at a mine site such as blasting, crushing of ore, transport of ore, driving on dirt roads etc. will emit mineral dust. When dispersed and deposited in the environment, mineral dust may cause habitat loss through smothering of the surrounding vegetation and introduce contaminants from the ore, tailings and waste rock into the terrestrial ecosystems. Mineral dust on snow surfaces may decrease the albedo of the snow surface, leading to increased melt rates. Environmental impacts from mining-related emissions of mineral dust are mainly a local to regional phenomenon, but finer dust particles may potentially enter the global atmospheric circulation and affect cloud formation and the radiative balance. Presence of fine mineral dust in the work environment of mine sites is often also an occupational health issue.

There are many ways to mitigate and reduce dust emission from raw mineral extraction processes, but it cannot be eliminated completely. It is also important to reduce dust concentrations and emission from mines with radionuclide-containing ore due to occupational health issues.

In Table 8.6 examples of the sources of dust pollution are given.

Table 8.6. Air emission – dust.

Origin	Duration of impact	Geographical extent	Effect and impact
Mine activities (Excavating, blasting, sorting, processing)	Lifespan of mine	Local/regional,	Reduced habitat quality/worst case habitat loss
Transport	Lifespan of mine	Local, < 1 km according to guideline value restrictions	Reduced habitat quality/worst case habitat loss
Waste rock and tailings facilities	Lifespan of mine	Local, < 1 km according to guideline value restrictions	Reduced habitat quality/worst case habitat loss

Dust from the mechanical processes, traffic and transport at a mine site may cover and impact the surrounding vegetation and affect habitat quality and, in the worst case, cause habitat loss. The dust may contain contaminants from the ore and waste rock. Only short-term effects are expected when the activity stops if it is well regulated. However, long-term effects may occur if the dust contains critical levels of elements of concern, e.g., process chemicals, heavy metals and radionuclides. Dust-reducing measures should be implemented to limit the impact and dust management, and emission restrictions can ensure that there will be no significant effects outside a buffer zone of typically less than 1 km.

8.6 Accidents

Tailings facilities represent a risk, and polluted water and waste can spread to the environment following dam failure. The most catastrophic accidents related to mining are collapse of tailings deposits in old, badly constructed, poorly managed and uncontrolled sites. Accidents are prevented by careful planning and by applying BEP and BAT and by rigorous internal management as well as public monitoring and control systems in place.

Other accidents are related to storage and transport of fuel oil. On land, spilled oil can be contained, but if it is not contained and oil is released to rivers or the sea, large areas can be impacted. Especially, a large oil spill from a tanker supplying the mine with fuel may potentially affect the marine and coastal environments, with subsequent long-lasting, regional scale effects at ecosystem level.

Oil spills on land contaminate the soil, and in the Arctic, oil is extremely slowly degraded and still found in the soil many decades after the spill. However, oil spills on land are usually local with localised impacts.

In Table 8.7 examples of major accidents are given.

Table 8.7. Accidents

Type	Duration of impact	Geographical extent	Ecological level
Oil spills in rivers and sea	Potentially long-term	Potentially regional	Potentially ecosystem
Oil spills from fuel storage facilities or tankers/vessels. Long-term if not remediated in due time. The oil spill impact is likely local but could increase to a regional extent and result in reduced habitat quality and impacts on biota at the ecosystem level if the oil is heavy, the amount is large, and the oil spreads in the sea.			
Oil spills on land	Potentially long-term	Local	Individual
Oil spills from fuel storage facilities. Long-term if not remediated. The impact is most likely local but could spread and include nearby water bodies.			
Tailings deposit failure	Potentially long-term	Local/regional	Reduced habitat quality and habitat loss
Tailings dam failure may have long-term local and potentially regional impacts through waterways. If large amounts of toxic tailings and mining waste are released, reduced habitat quality and impacts on biota at ecosystem level might occur.			

8.7 References

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9 Future perspectives and data gaps

By Katrine Raundrup[1], Janne Fritt-Rasmussen[2], Kasper L. Johansen[2] and Anders Mosbech[2]

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9.1 Future perspectives – climate change

The climate is changing, and even the moderate IPCC climate models predict global temperature increases of ca. 2 °C by the end of the century (IPCC 2022). The temperatures are increasing 3-4 times faster in the Arctic compared to the rest of the world (Rantanen et al. 2022).

On a regional scale, DMI has developed climate models covering Greenland. The AOI for this report is part of the climate modelling for the former municipality Qaasuitsup Kommune (Christensen et al. 2016). For this region, the predicted climate-related changes include, e.g., annual temperature increases of ca. 3 °C (increases of ca. 2.1 °C during summer and 3.4 °C during winter compared to the reference period 1986-2005 and based on the IPCC RCP4.5 scenario) and an increased annual precipitation of 50-100 mm by the end of this century (increases of 17% during summer and 16% during winter compared to the reference period 1986-2005 and based on the IPCC RCP4.5 scenario).

The amount of sea ice in the Arctic is expected to decrease, and the IPCC RCP8.5 scenario indicates that no sea ice will be present during summer by the end of the century. According to the models, the winter distribution of sea ice is not expected to decrease rapidly until around 2050 (Christensen et al. 2016).

Further, the number of days with extreme weather conditions is expected to increase. This includes, e.g., days with extreme precipitation (corresponding to days with more than 25 mm precipitation), which are expected to increase by 3-5 days. Currently, the assessment area has 2-5 days with this type of extreme weather (Christensen et al. 2016).

The climate changes expected to occur during this century will have tremendous effect on the growing season of the vegetation. The beginning of the growing season (period of consecutive days with temperatures above 2°C) is expected to advance by 10-30 days. The length of the growing season is also expected to increase by up to 30 days – at least in part of the AOI, as large local variation is expected (Christensen et al. 2016).

Most of the AOI has continuous permafrost. Due to climate warming permafrost is expected to only occur sporadically by the end of the century. Within the AOI, it is further expected that permafrost will only be stable at high altitudes (Christensen et al. 2016).

The temperature increase will result in glacial retreat, making new areas available for mineral exploitation. Further, the combined effects of increased temperature, increased precipitation, longer growing season etc. will change the living conditions for vegetation, animals, and the local communities within the assessment area. The changes will likely favour some species, while others may decline, and new species may establish populations. These significant changes in the ecosystem may occur and the communities will have to adapt to the new conditions in a warmer and wetter future.

In a rapidly changing Arctic, the present biodiversity is challenged. The areas that today are biologically important may lose their importance, and new areas of significance may be identified based on changes in species distribution and abundance. Changes in the human use of biodiversity will trail ecological changes. The rapid changes also present a challenge for environmental management of mineral extraction as exploration and exploitation operations are multi-decadal, and waste storage facilities for tailings should last for thousands of years. Careful planning, monitoring at several levels, and adaptive management are recommended to avoid and manage unforeseen impacts of the operations.

9.2 Data gaps in the baseline data

In this baseline assessment, a number of data gaps regarding the biological environment described in the report have been identified that are relevant to highlight.

No data on insects, fungi, and lichens are presented, primarily due to lack of studies of their distribution, abundance, and coverage in the area. Data on salt or saline lakes as well as homeothermic springs are old, and precise locations of their distribution are lacking – not only within the AOI but in Greenland in general.

There are also geographical areas within AOI with no or limited baseline data. In the overlay analysis presented in Chapter 7, lack of data will result in areas with zero or only very few overlapping layers. Areas with low values are thus not necessarily areas with few relevant features but may represent areas that are "under-studied". However, we assess that this bias does not significantly affect the identification of the areas with most relevant features, but it may affect the relative values of areas where the maps show few overlapping features.

Some results included in this report are based on relatively old data. This holds particularly true for the distribution of plant species (Table 4.2, Figure 4.9), and several of the bird colonies have not been surveyed in recent years. New information on Arctic char rivers is also lacking (interview survey from 2002). The same goes for the muskox distribution and abundance, as the most recent survey is from 2002. It is thus recommended that a survey is conducted in the near future to assess the current status and development of the muskox population.

Environmental geo-chemical background samples are only available for limited parts of the AOI, and these are mostly related to monitoring in the area of the former Maamorilik lead and zinc mine operated from 1973 to 1990. A range of environmental background samples were collected at three locations at Sigguup Nunaa during the field campaign in 2022. Beside these samples, the number of available baseline environmental chemical samples from the AOI is very sparse. This highlights the importance of the sampling and analysis of a sufficient amount of relevant environmental background samples prior to mining activities.

9.3 Future perspectives - proposals for future monitoring and candidate areas for special attention

Due to the rapid climate change, there is a general need for more intense monitoring of biodiversity and ecological systems, to enable rapid adaptation of the planning and management of human activities. Ideally, the monitoring of mining operations should be integrated with a regional monitoring programme on climate, biodiversity, ecosystems, and other human activities to inform adaptive management.

While the development of such a regional ecological monitoring programme could improve the future management and regulation of mineral operations, the present study has summarised and integrated the current knowledge available for planning. DCE/GINR hope that this type of analysis is relevant for the mining industry as it provides a higher level of predictability regarding the environmental issues and coinciding interests. The information could facilitate a planning process potentially minimising future conflicts between mineral projects, biodiversity, and other human use. In this report we do not recommend specific protection actions. However, as a starting point for discussion we here suggest four candidate areas where DCE/GINR would have special attention in relation to environmental impacts from large mineral projects.

1. **The large wetlands at Sigguup Nunaa**

Based on the field work in 2022 and the available data, we have identified three areas at Sigguup Nunaa (Figure 9.1 and Table 9.1). All three areas are large wetlands used as moulting and breeding areas by geese, and a number of other species use the areas as well (see Figure 9.2). All three areas are flat wetlands with meandering river(s) and smaller lakes crisscrossed with elevated higher grounds. The areas provide excellent protection for the breeding and moulting geese as the lakes and intersecting rivers give amble opportunities for the birds to escape, e.g., from predators. The overlay analysis (Chapter 7) also highlighted the three areas as “hotspots”, primarily for biodiversity but also human use.

This type of wetland is rare in West Greenland and, combined, the three wetlands constitute the largest occurrence of this nature type outside Naterneq/Lersletten.

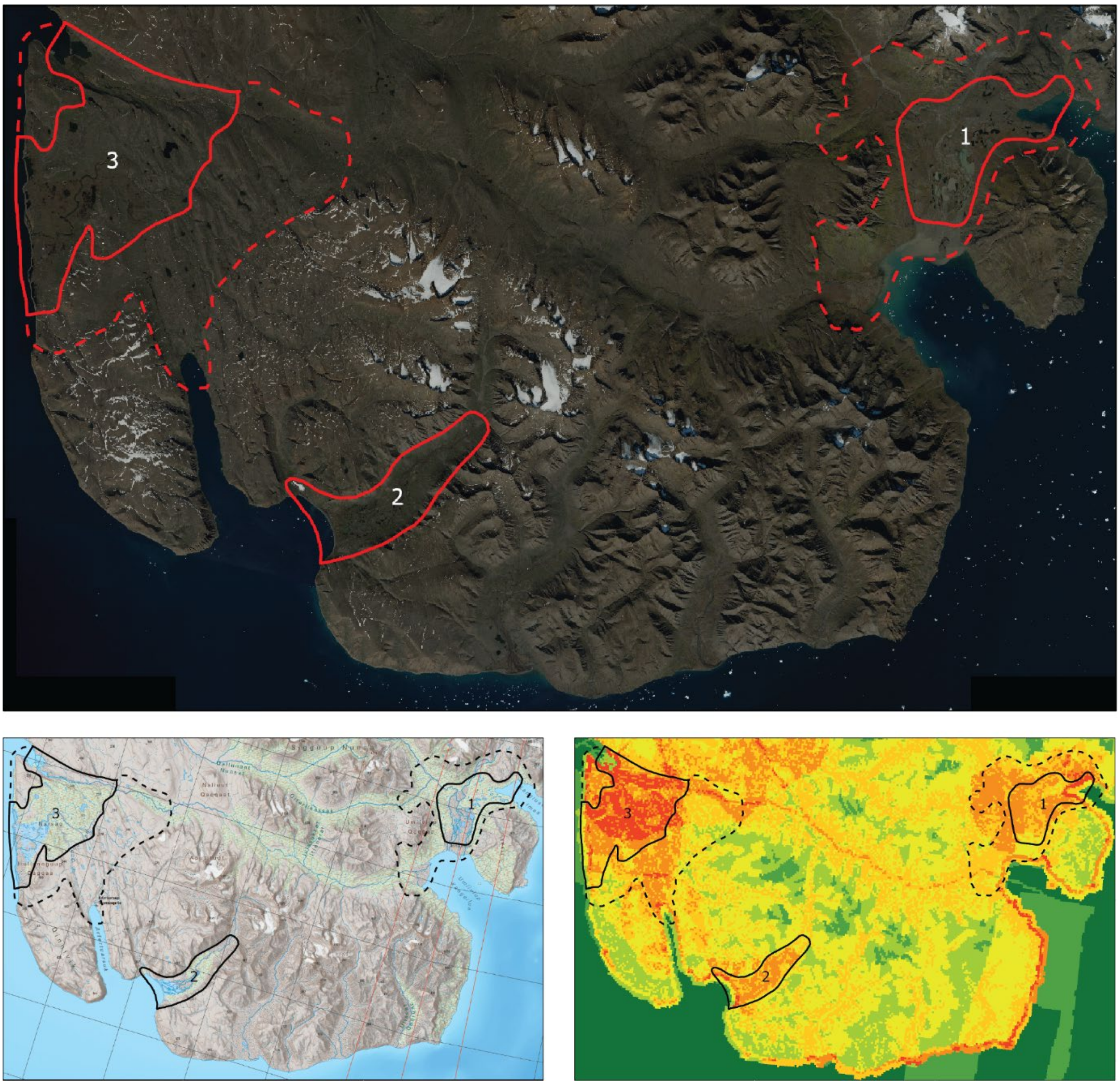

Figure 9.1. Areas on Sigguup Nunaa where DCE/GINR would have special attention in relation to environmental impacts from large mineral projects. The areas are shown on different background maps, reflecting the primary sources used for their delineation. The overlay analysis of all map layers (bottom right; Chapter 7) guided the overall identification of the areas, whereas high-resolution satellite images from SPOT6/7 (top; https://dataforsyningen.dk/data/4783) and the new 1:50,000 scale topographic map of Greenland (bottom left; https://dataforsyningen.dk/data/4771) were used for the detailed delineation. Core areas are indicated with thick continuous lines and more peripheral areas with dashed lines. Table 9.1 lists the map layers with features present in the different areas.

Table 9.1. Table of the map layers with features present within the three areas on Sigguup Nunaa where DCE/GINR would have special attention in relation to environmental impacts from large mineral projects. Area numbers refer to Figure 9.1, where core areas are delimited with thick continuous lines and peripheral areas with dashed lines. For a complete list of map layers tested for presence within the three areas, see Table 7.1.

Map layer	Area				
	1 Core	1 Periphery	2 Core	3 Core	3 Periphery
Arctic char freshwater catchments	1	1	1	1	1
Arctic char river mouths	1	1	1	1	1
Biologically important areas	1	1	1	1	1
Coasts with capelin	1	1	1		1
Coasts with human resource use	1	1	1		1
Cultural heritage areas, zone 3		1			
Fertile vegetation	1	1	1	1	1
Goose moulting and breeding areas	1	1	1	1	1
Greenland halibut fishery				1	1
Muskox calving area	1	1	1	1	1
Muskox hunting hotspots	1	1		1	1
Muskox licence area	1	1	1	1	1
Oil spill sensitive shorelines	1	1		1	1
Seabird colony protection zones					1
Seabird colony sites					1
Snow mobile driving corridors		1		1	1

Figure 9.2. Wetlands at Site 1 (top left and right) and at Site 2 (bottom) at Sigguup Nunaa. Photos: Janne Fritt-Rasmussen (top left), David Boertmann (top right), Katrine Raundrup (bottom).

2. The Salleq bird colony

The surprising thick-billed murre recolonisation of the Salleq bird colony (Boertmann 2023), the only thick-billed murre colony between Innaq/Ritenbenk and Southern Upernavik, calls for special attention in relation to future industrial activities. It could be considered that shipping lanes are placed, e.g., more than 5 km from the colony.

3. **Important whale foraging areas and shipping lanes**

Shipping from a large mine in the open water season can be intensive, and underwater shipping noise may impact a large area and cause changes in the distribution and abundance of whales (NAMMCO 2022). Especially the narwhal and white whales using the AOI during winter and migration seasons may be susceptible to disturbance from year-round shipping or shipping in the shoulder season from October to December. Special attention should be given to potential restrictions in area, season as well as type of vessel to mitigate the impact of shipping from large mining projects. The present knowledge indicates the importance of the AOI for a large number of narwhals from the Sommerset Island stock during October – December (see Chapter 4), and the new summer observation of bowhead whales in the northern part of AOI could indicate a potential shift in the distribution of this species (Boertmann et al. 2023). However, more information is needed to make informed decisions on mitigative measures.

4. **The fjords with moulting seaducks in the northernmost part of the AOI**

Seaducks lose their flight feathers for a few weeks after breeding and, in this period, they are very sensitive to disturbance. Remote fjords in the northernmost part of the AOI (Figure 4.2) are important moulting areas for king eiders, common eiders and other seaducks. Mining projects entailing long-lasting shipping disturbance in the fjords in the moulting period may cause the seaducks to abandon the moulting area. However, more updated information is needed to make informed decisions on protection zones.

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Appendix 1: Fieldwork at Sigguup Nunaa (Svartenhuk) 2022

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In the summer of 2022, a team of biologists from Greenland Institute of Natural Resources and Aarhus University carried out field work at Sigguup Nunaa to supplement the current knowledge base on birds, vegetation and contaminants in the area.

Itinerary

Three sites on the peninsula were visited in the period 19 to 31 July 2022 (Figure 1).

Figure 1. Overview of Sigguup Nunaa with the three study sites shown.

Site 1 in the head of the fjord Kangiusap Imaa on the eastern coast (19-24 July). Site 2 at Eqi in the bay Tasiusap Imaa (24-27 July) and site 3 in the head of the fjord Afertuarsuk (27-31 July). Site 3 was planned to be on the west coast of the peninsula (in order to reach the Narsaq wetland), but due to difficult landing conditions (exposed to open sea, with risk of strong swell and waves) it was decided to move it to Svartenhavn. However, this site proved similarly difficult to access, and camp conditions were also bad (no freshwater).

The transport from and to Uummannaq and between sites were by means of boat (Finnmaster P8, sailed by Paaluk Kreutzmann, Uummannaq Seasafaris aps). Weather was generally good, and mostly calm and clear, why field activities were possible all days except on 22 July when rain poured down until 12:30.

The overall purpose of the fieldwork was to gather new and updated knowledge about birds (abundance, species), to collect baseline environmental samples for background chemical analysis and lastly to complete vegetation analyses as ground truthing for remote vegetation mapping.

Previous bird studies

Information on land birds in the Sigguup Nunaa-area is either scarce or in case of the geese old. In 1989, Henning Thing and Henning Ettrup by foot surveyed the area with the purpose to evaluate the areas suitability for caribou and muskoxen and reported their bird observations without precise location (Thing 1989). The geese have been surveyed from aircraft several times: 1992, 1994, 1995 and 2007 (Glahder 1999, Fox & Glahder 2010), and in 2010 C. Egevang surveyed the large wetland west of Itsako (Egevang & Boertmann 2012). Breeding seabirds along the coasts were surveyed in 1994 (Boertmann et al. 1996) and in 1993, 1995 and 1998 moulting king-eiders were surveyed from aircraft in the fjord Umiiarfik (Mosbech & Boertmann 1999, Boertmann & Mosbech 2001). Finally, Berthelsen (1921) gives some information on seabird breeding colonies from the beginning of the 1900s.

Bird surveys 2022

The 2022 spring was delayed with snow cover as late as end of June. This may have delayed the breeding season for many birds or even forced some to abandon breeding. This could be the explanation of the very few sightings of geese with goslings and of the missing observations of long-tailed ducks and mallards with chicks. The lack of observations of purple sandpiber *Calidris maritima* is also remarkable. Lapland buntings had newly fledged young on 20 July and a nest with half grown chicks was seen on 24 July (which is very late). The moulting geese were extremely shy, assembled on the lakes shore when we were up to 1500 m from them, and by our approach, they ran into surrounding land areas.

Observations - Site 1

The many lakes and ponds in the surroundings of the camp were surveyed and the large wetland between Itsaku peninsula and the peak Umiviip Qaqqaa (hereafter Itsaku wetland) was surveyed from vantage points on the east side. On 20 July the light conditions (headlight) were rather bad at the Itsaku wetland, but on 21 July light conditions were optimal for counting the geese in the entire area.

Great northern diver *Gavia immer*. No breeding records, but seen daily on the fjord off the camp, and some at the lakes and in the Itsaku wetland. The species certainly breeds in the area.

Red-throated diver *Gavia stellata*. No breeding records, but seen and heard daily commuting between the fjord and the lakes and up to three birds seen on lakes and in the Itsaku wetland. The species certainly breeds in the area.

Northern fulmar *Fulmarus glacialis*. A few rounded the fjord during our stay.

Canada goose *Branta canadensis*. Numerous moulting birds in the area. At the lakes west and southwest of the camp on 20 July five flocks (300, 150, 90, 70, 4), at the lakes northwest of the camp on 23 July four flocks (95, 10, 60, 28) and at the Itsaku wetland in total 1835 on 21 July. However, this figure may include some of the birds from the lakes west of the camp, as these apparently fled to the large wetland – cf. the snow goose, which was seen in the lake area and the following day in the Itsaku wetland. Only one pair with chicks observed at a lake (Figure 1).

Goose unidentified *Branta/Anser sp*. 250 were counted on 21. July in the Itsaku wetland.

Snow goose *Anser caerulescens*. A white phase bird (in moult) was seen on 20 July in the lakes and the following day in the Itsaku wetland, and a blue phase goose was present in the Itsaku wetland on 21 July.

White-fronted goose *Anser albifrons*. Only 3 + 2 +1 observed at the lakes, but in the Itsaku wetland 305 were counted on July 21 (Figure 2). No observation of pairs with chicks.

Mallard *Anas platyrhynchos*. No breeding records, but in total 105 moulting birds (up to 22 in flock) at the lakes (Figure 3). Some lone females may have had nests. The species certainly breeds in the area.

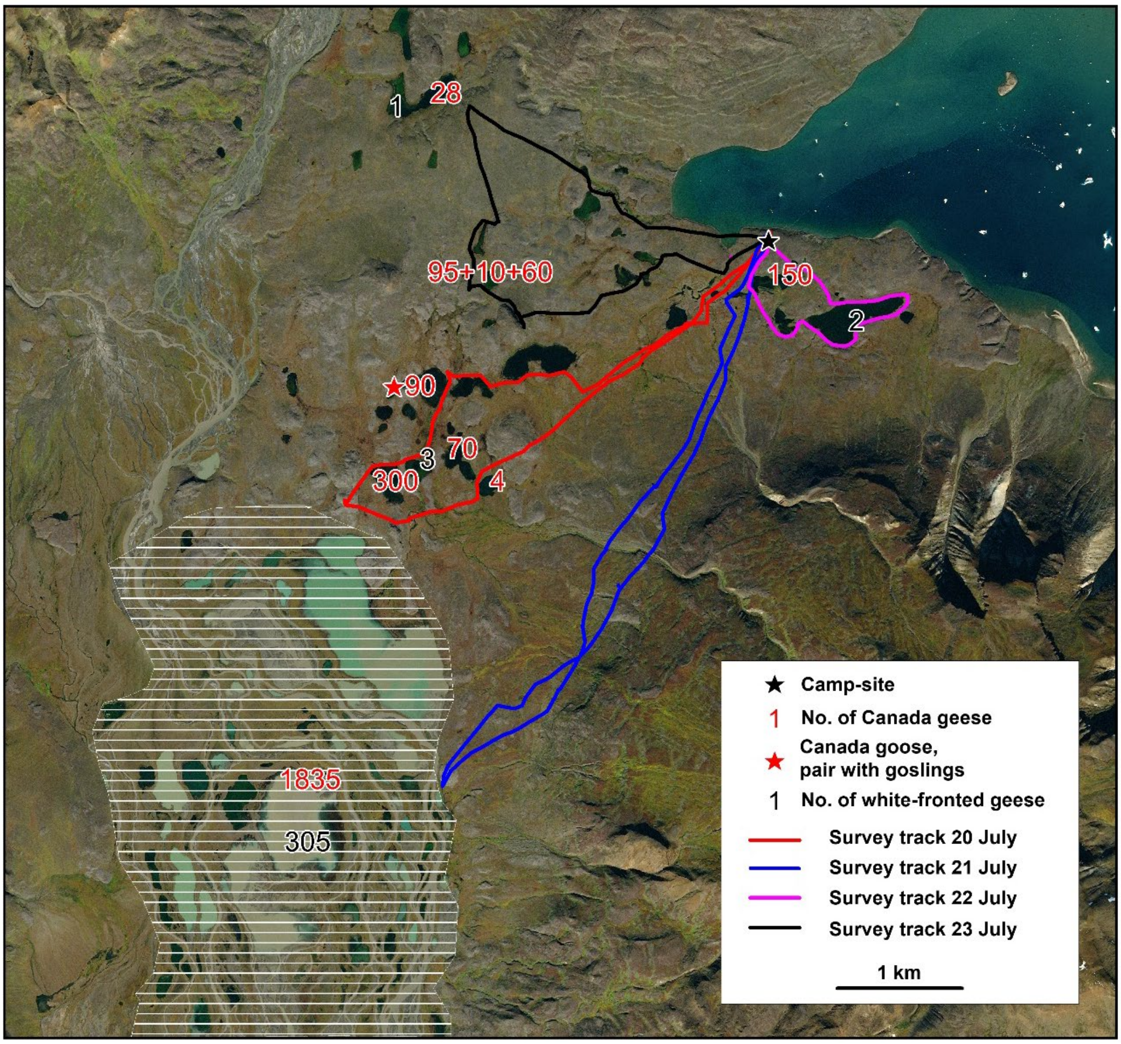

Figure 2. Distribution of Canada and white-fronted geese at Site 1. The geese of the Itsaku wetland were found within the area with pale shading and total number of geese here shown. The other figures refer to separate flocks. Note that the Itsaku wetland extends further south to the estuary and the sea.

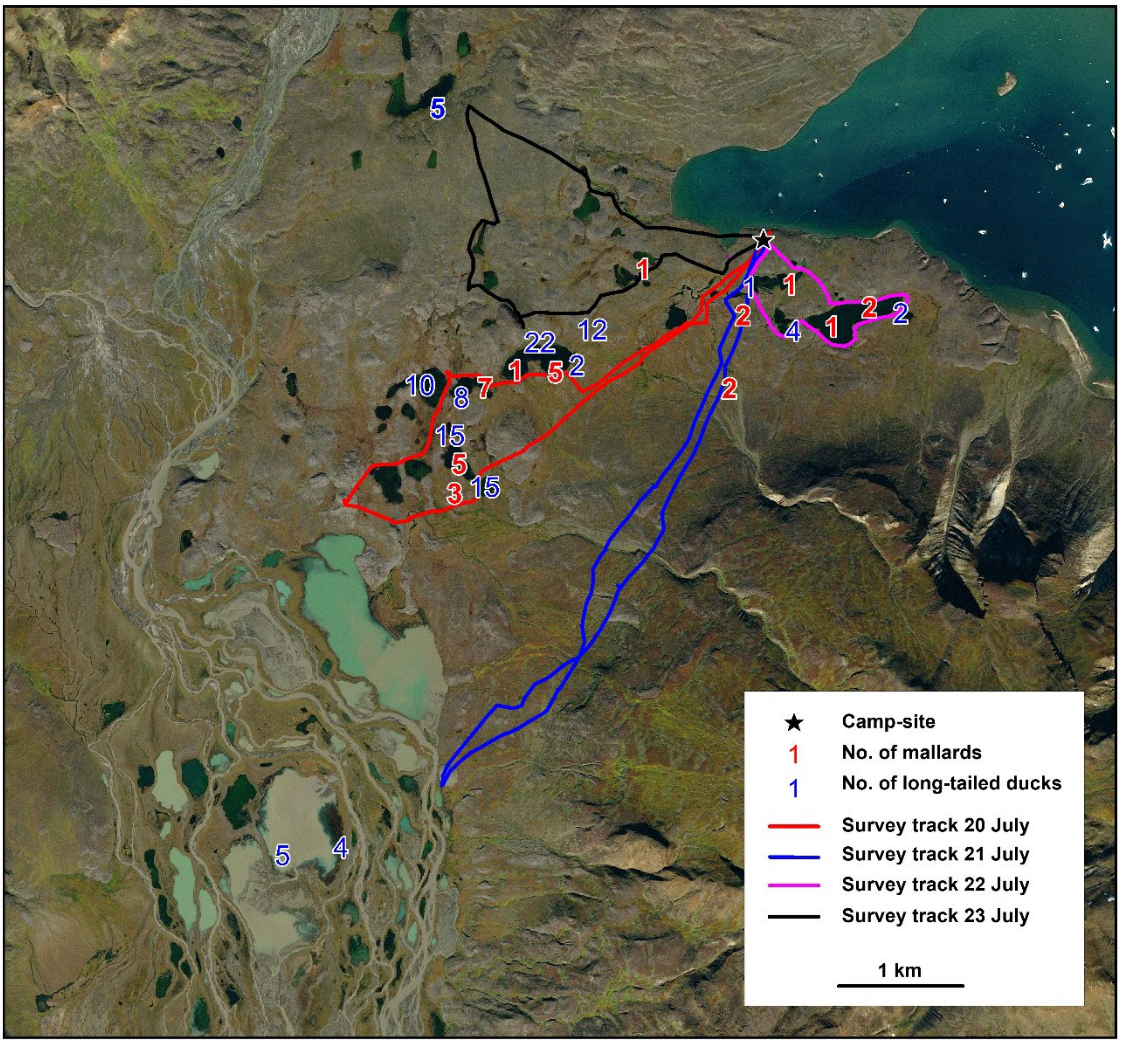

Figure 3. Distribution of mallards and long-tailed ducks at Site 1.

Pintail *Anas acuta*. Six moulting birds at one of the lakes and a single male in the Itsaku wetland.

Long-tailed duck *Clangula hyemalis*. In total, 30 observed of which most were females at the lakes and in the Itsaku wetland (Figure 3). Also some males. The females may represent failed breeders or birds which temporarily have left a nest. The species certainly breeds in the area.

Red-breasted merganser *Mergus serrator*. Overflying birds in pairs or smalls flocks (up to 6) seen daily, but no indication of breeding. However, the species most likely breeds in the area.

Ptarmigan *Lagopus mutus*. A pair was seen on 21 July. No other observations of this species, which most likely breeds in the area.

Ringed plover *Charadrius hiaticulus*. Only a single bird observed without any signs of breeding.

Red-necked phalarope *Phalaropus lobatus*. Birds showing signs of breeding (alarm calling, distraction behaviour) was observed at six sites (Figure 4), and there were also many post-breeding females in small flocks. The species certainly breeds in the area.

Pomarine skua *Stercorarius pomarimus*. An immature (2K) took a round in the fjord on 21 July. This species does not breed in the area.

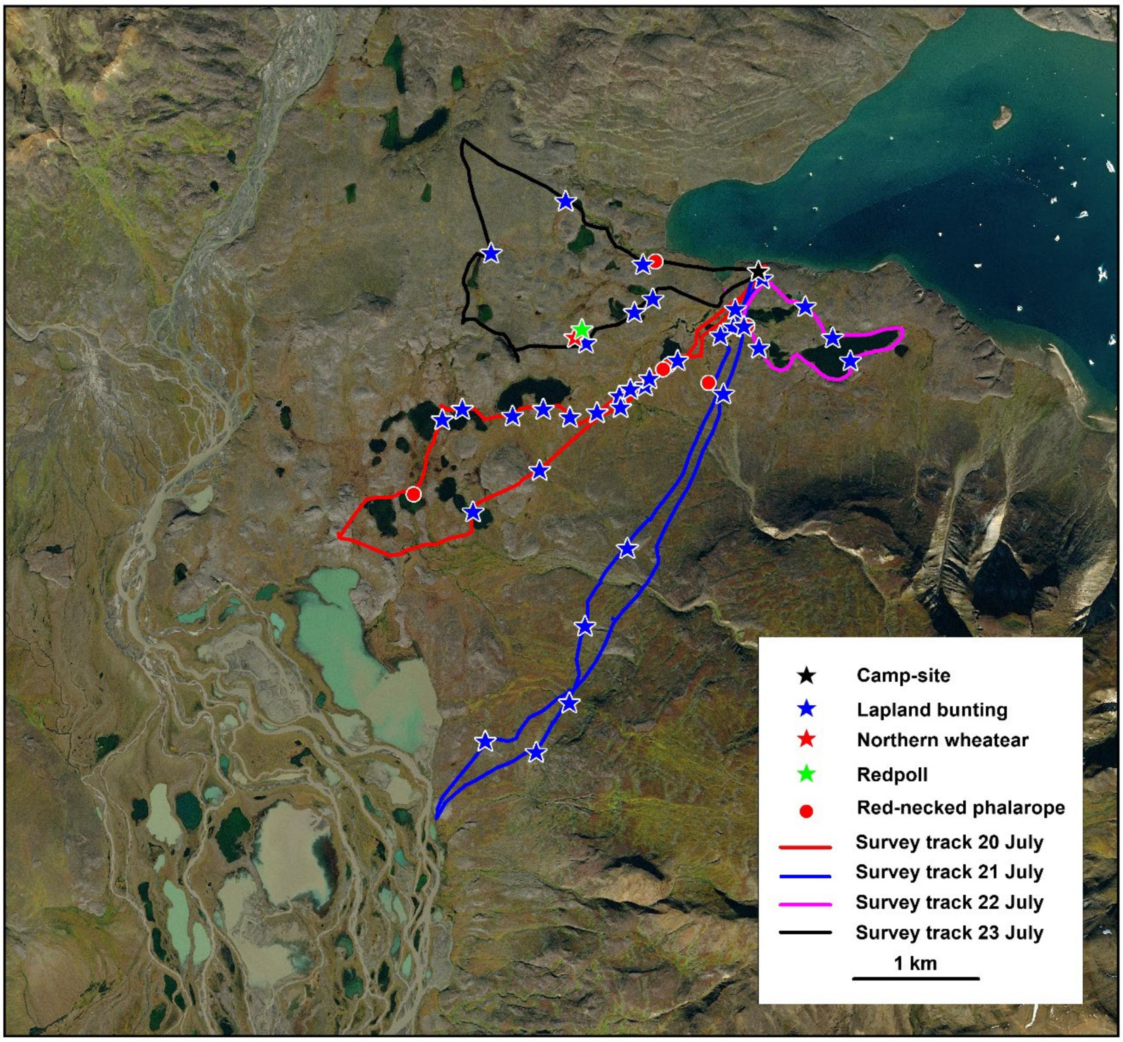

Figure 4. Distribution of presumed breeding territories of passerines (asterisks) and red-necked phalaropes (dots) at Site 1.

Arctic skua *Stercorarius parasiticus*. One in the Itsaku wetland on 21 July, and two immature birds passed the camp-site on 22 July. Likely breed in the area.

Long-tailed skua *Stercorarius longicaudus*. An adult passed the camp-site on 22. July in company with two Arctic skuas. Do not breed in the area.

Iceland gull *Larus glaucoides*. Several 100s foraged on the exposed tidal flats of the fjord opposite the camp-site during low tide.

Glaucous gull *Larus hyperboreus*. Few among the Iceland gulls.

Lesser black-backed gull *Larus fuscus*. An immature (3K) seen among the Iceland gulls.

Black guillemot *Cepphus grylle*. A few observed in the fjord off the camp-site.

Raven *Corvus corax*. Seen daily in pairs or family flocks.

Northern wheatear *Oenanthe oenanthe*. Two newly fledged juveniles seen at a basalt rock east of the camp (Figure 4). They could very well have been hatched there.

Redpoll *Acanthis flammea*. Two newly fledged juveniles seen at a basalt rock east of the camp (Figure 4). They could very well have been hatched in the surroundings.

Lapland bunting *Calcarius lapponicus*. Common breeder in the area, and several nests/recently fledged youngs were seen, totalling 30-35 occupied territories (Figure 4).

Snow bunting *Plectrophenax nivalis*. Only a single pair seen in the valley opposite the camp-site on the north side of the fjord. None seen in the wetlands and in the lowlands, probably due to lack of suitable breeding habitat (rocky outcrops, boulder fields etc.).

Observations - Site 2

This valley with many ponds, lakes and watercourses was surveyed from a vantage point on the east side on 25 July under optimal light conditions. Survey from the coast did not add supplementary information on birds in the wetland.

Red-throated diver *Gavia stellata*. Two brooding birds on nests in lakes.

Canada goose *Branta canadensis*. On 25 July, 1,870 were counted in the valley. No observations of breeding birds (Figure 5).

Snow goose *Anser caerulescens*. On 25 July, 12 were counted in the valley, of these 4 were white and 8 blue. No observations of breeding birds.

White-fronted goose *Anser albifrons*. On 25 July, 70 were counted in the valley (Figure 5). No observations of breeding birds.

Mallard *Anas platyrhynchos*. Five moulting birds observed on 25 July (Figure 5).

Common eider *Somateria mollissima*. Two females at river outlet at the coast on 26 July.

King eider *Somateria spectabilis*. Five males and one female at river outlet at the coast on 26 July

Long-trailed duck *Clangula hyemalis*. In the wetland, 12 birds were observed, mostly females and a pair in the river mouth on 26 July (Figure 5). No indication of breeding.

Ringed plover *Charadrius hiaticulus*. An adult and two small chicks on the beach west of the wetland on 26 July.

Red-necked phalarope *Phalaropus lobatus*. Only three post-breeding birds seen. No indication of breeding, but the species most likely breed in the wetland.

Arctic skua *Stercorarius parasiticus*. At least four adults in the wetland. Probably breeding birds.

Greater black-backed gull *Larus marinus*. Two immatures on an iceberg together with "white gulls" on 27 July.

Ptarmigan *Lagopus mutus*. One heard above the campsite on 25 July. No indication of breeding, but the species most likely breed in the area.

Sandhill crane *Antigone canadensis*. One adult stayed in the wetland on all three days that we were at the site. This is a rare visitor from the Canadian Arctic.

Raven *Corvus corax*. Seen daily and most likely breeds in or near the area.

Lapland bunting *Calcarius lapponicus*. Only three presumed breeding territories recorded. This was unexpectedly few, possibly due to the late spring.

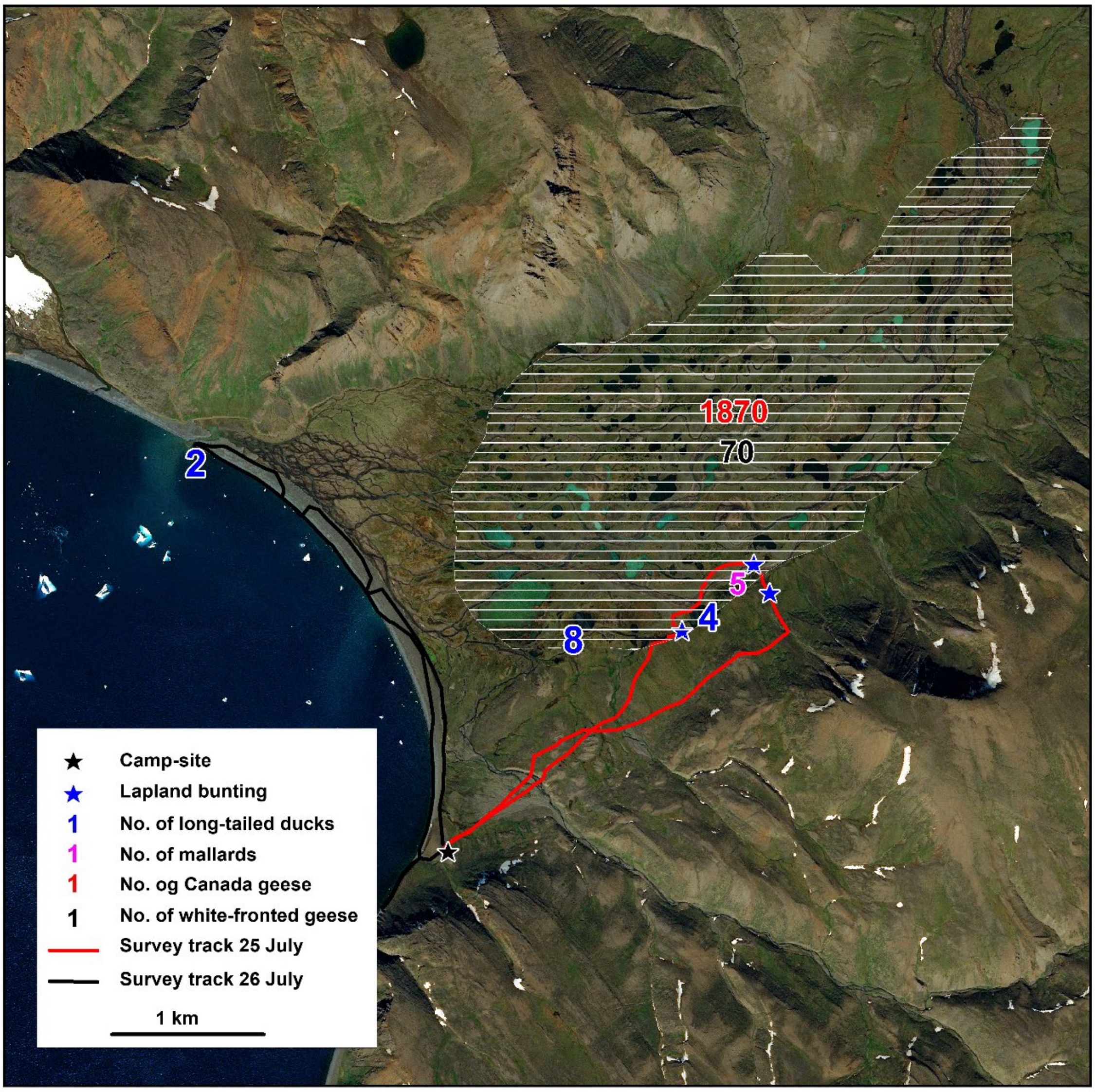

Figure 5. Distribution of Canada and white-fronted geese at Site 2. The geese were found within the area with pale shading and the total number of geese is shown. The other figures refer to separate flocks of long-tailed ducks and mallards and blue asterisks to presumed breeding territories of Lapland bunting.

Observations - Site 3

This site was chosen as an alternative to the originally planned Site 3. It is located in the head of the narrow fjord Afertuarsuk. The camp was established just above the coast at the western river. From the camp, the valley with some lakes was surveyed for birds, and from a top the Narsaq wetlands could be seen on far distance.

Red-throated diver *Gavia stellata*. Two on the fjord on 31 July. No indication of breeding in the area.

Canada goose *Branta canadensis*. Two flocks of moulting birds at the lakes in the valley (90, 230). Seven moulting birds at the large lake to the east of the valley (Figure 6). No breeding birds observed.

White-fronted goose *Anser albifrons*. At the lakes in the valley, 14 adults, and at the large lake to the east of the valley, four adults (Figure 6). On 31 July, eight adults flew over the camp-site. No breeding birds observed.

Common eider *Somateria mollissima*. Up to 450 staged on the fjord off the camp-site.

King eider *Somateria spectabilis*. Up to 100 staged on the fjord off the camp-site. Each evening, flocks circled several times over the head of the fjord.

Harlequin duck *Histrionicus histrionicus*. A female was seen twice – on 27 and 31 July in the river mouth. This is a known breeding site for the species (Bennike 1990), and the observed bird could be a brooding female that temporarily had left the nest.

Long-tailed duck *Clangula hyemalis*. Three females together and a single female at the lakes in the valley (Figure 6). The latter may be a female that temporarily have left the nest.

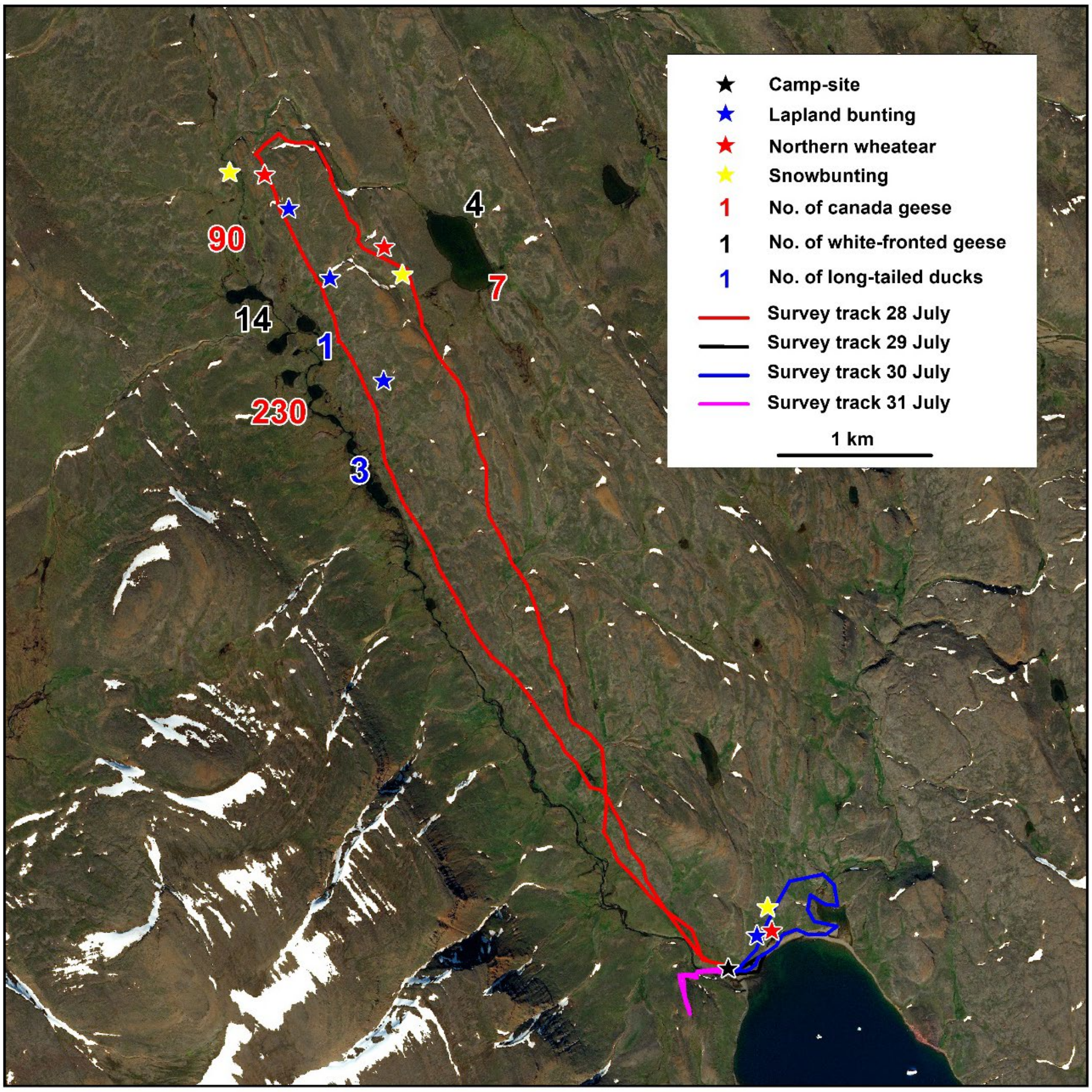

Figure 6. Distribution of Canada and white-fronted geese at Site 3. The figures refer to separate flocks of geese and long-tailed ducks and the asterisks to presumed breeding territories of passerines.

Red-breasted merganser *Mergus serrator*. Two passing by on 27 July and one in the lakes in the valley on 28 July. The species may breed here.

Lesser back-backed gull *Larus fuscus*. An immature (3K) together with "white gulls" at the fjord on 31 July.

Northern wheatear *Oenanthe oenanthe*. A recently fledged juvenile seen in the cliffs above the valley to the east and another at the larger lake east of the valley on 28 July (Figure 6). Probably from local breeding pairs.

Lapland bunting *Calcarius lapponicus*. In the valley, only three territorial birds seen on 28 July and an alarm calling bird just east of the camp-sites on 30 July (Figure 6). Again, this is unexpectedly few, and perhaps a result of the late spring.

Snow bunting *Plectrophenax nivalis*. A male and two juveniles in the cliffs above the valley to the east and a single male near the large lake to the east of the valley on 28 July. On 30 July, a male and two juveniles just east of the camp-site (Figure 6).

Bird observations elsewhere

At Svartenhavn, which was briefly visited on 27 July, 150 moulting Canada geese were observed.

Mammals

Site 1

Caribou *Rangifer tarandus*. Two old antlers were found in the valley opposite the camp-site.

Muskox *Ovibos moschatus*. Three single males seen: two west of the Itsaku wetland and one northeast of the wetland.

Site 2

Bowhead whale *Baleana mysticeti.* Approaching the camp-site at Eqi on 24 July, a bowhead whale was seen near the coast. Two days later, a bowhead was seen close to the river outlet, and later in the evening on the same day four bowheads stayed in the bay off the camp. On 27 July, four bowheads were again seen from the camp-site, and a fifth whale was sighted near Cape Cranstown on the other side of the bay when we sailed towards Camp 3. Our skipper Paaluk Kreutzmann saw additionally two when returning from Site 3 on 27 July.

Muskox *Ovibos moschatus*. A flock of six adults and three calves (1 year) stayed in the eastern part of the large wetland. Two bulls were also seen in that area.

Arctic fox *Vulpes lagopus*. A blue phase fox passed the camp on 26 July.

Site 3

Muskox *Ovibos moschatus*. Three lone bulls were observed in the valley above the camp-site and a flock of nine individuals (1 cow with a calf, 1 adult bull, 1 younger bull, two second-year calves and 3 unidentified individuals) to the northeast of the camp. This site is a popular hunting ground for muskoxen, and on 31 July six boats arrived with muskox hunters as the hunting season opened on 1 August.

Fish

The only fish observed was three-spined sticklebacks (*Gasterosteus aculeatus*) in some of the lakes at Site 1. The fjord Kangiusap Imaa at Camp-site 1 is a popular water for fishing Arctic char (*Salvelinus alpinus*), and during our stay there two boat parties arrived and camped at the small island northeast of our camp.

Invertebrates

Northern clouded yellow *Colias hecla*. Recorded at all three study sites.
Arctic fritillary *Boloria chariclea*. Seen in numbers at all three study sites.
Arctic woolly bear moth *Gynaephora groenlandica* larvae and pupae were seen at all three study sites.
Pond snails *Ladislavella catascopium**. Numerous in lakes and slow streams at Site 1. **Vinarski et al. 2017.*
Fairy shrimp *Brachinecta paludosa*. Numerous in a shallow pond near Site 2.

Other observations

Misc. biology

Nostoc pruniforme in many of the lakes at Sites 1 and 2.

Vegetation studies

The results are reported in the main report, Chapter 4 and Appendix 4.

Environmental samples

Lichens, soil, blue mussels, seaweed and freshwater were sampled for chemical analyses. The results are reported in the main report, Chapter 3.

Beach litter

At Site 1, there was much coarse litter in the form of fragments of buildings and large fish boxes, apparently flotsam from the tsunami disaster in Nuugaatsiaq in 2017. Smaller items were diverse fishing gear, empty bottles etc.
At Site 2 where the coast is very exposed, there was not much beach litter – mainly some empty bottles, wood and ropes.
At Site 3, there were enormous quantities of litter –plastics, wood, garbage of local origin, apparently from a dump in the neighbourhood (Illorsuit?), and in the case of the garbage also from camps on the beach.

Conclusions

The two large wetlands (Sites 1 and 2) visited during the fieldwork in 2022 are unique in a Greenland context due to their extensive size and their abundance of ponds and lakes among many winding rivers. Only the Naternaq (Lersletten) area east of Aasiaat and Sullorsuaq (Kvandalen) on Disko are comparable. These areas of Sigguup Nunaa both hold numerous waterbirds – mainly geese and ducks, and both are important sites for the threatened Greenland white-fronted goose. Unfortunately, we did not succeed in reaching the third large wetland of Sigguup Nunaa – the Narsaq plains. This has previously proven to be an important site for geese, and particularly the Greenland white-fronted goose and should be surveyed in the near future.

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Appendix 2 Baseline environmental chemistry data

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Table A2.1. Summary statistics on AMDA samples from outside the potentially polluted area around the former Maarmorilik mine. Concentration levels are given for approx. 60 different elements across nine different sample types for unpolluted samples from the area of interest.

Sample_category	Element	Unit	min	q25	median	q75	max	n_meas	n_samp
Blue mussel	Ag	mg/kg	0.004	0.005	0.012	0.060	0.113	15	11
Blue mussel	Al	mg/kg	135.850	310.357	730.936	912.868	2038.732	12	10
Blue mussel	As	mg/kg	12.511	13.872	14.788	15.548	17.200	17	13
Blue mussel	Au	mg/kg	0.005	0.005	0.007	0.008	0.020	12	10
Blue mussel	Ba	mg/kg	1.275	1.392	1.828	3.027	12.645	9	8
Blue mussel	Be	mg/kg	0.004	0.008	0.009	0.010	0.025	9	8
Blue mussel	Bi	mg/kg	0.002	0.002	0.003	0.035	0.052	9	8
Blue mussel	Ca	mg/kg	2165.204	2858.431	3233.743	3941.919	5664.130	12	10
Blue mussel	Cd	mg/kg	2.040	2.572	2.852	3.117	4.580	32	26
Blue mussel	Ce	mg/kg	0.913	0.924	1.115	1.409	4.451	9	8
Blue mussel	Co	mg/kg	0.995	1.567	1.761	1.961	2.502	12	9
Blue mussel	Cr	mg/kg	1.092	1.309	1.648	2.057	6.435	15	11
Blue mussel	Cs	mg/kg	0.034	0.037	0.038	0.097	0.388	9	8
Blue mussel	Cu	mg/kg	7.369	8.737	10.285	12.465	14.953	15	11
Blue mussel	d.m.%	%	13.000	15.300	16.320	17.930	22.100	50	44
Blue mussel	Dy	mg/kg	0.055	0.107	0.119	0.139	0.178	9	8
Blue mussel	Er	mg/kg	0.027	0.059	0.064	0.075	0.087	9	8
Blue mussel	Eu	mg/kg	0.018	0.031	0.036	0.040	0.056	9	8
Blue mussel	Fe	mg/kg	207.600	275.250	572.451	1424.514	2395.762	15	11
Blue mussel	Ga	mg/kg	0.150	0.273	0.312	0.357	0.837	9	8
Blue mussel	Gd	mg/kg	0.091	0.135	0.145	0.169	0.275	9	8
Blue mussel	Hf	mg/kg	0.005	0.030	0.031	0.034	0.039	9	8
Blue mussel	Hg	mg/kg	0.064	0.080	0.086	0.109	0.129	32	26
Blue mussel	Ho	mg/kg	0.010	0.021	0.023	0.027	0.032	9	8
Blue mussel	K	mg/kg	11642.149	14420.230	16101.373	16987.319	17397.323	9	8
Blue mussel	La	mg/kg	0.656	0.680	0.788	1.186	2.486	9	8
Blue mussel	Li	mg/kg	0.181	0.207	0.216	0.266	1.434	9	8
Blue mussel	Lu	mg/kg	0.003	0.007	0.007	0.008	0.010	9	8
Blue mussel	Mg	mg/kg	2022.534	3299.762	3725.117	4349.106	5743.000	12	10
Blue mussel	Mn	mg/kg	11.383	28.320	32.375	38.096	42.238	9	8
Blue mussel	Mo	mg/kg	0.490	0.585	0.631	0.700	0.751	9	8
Blue mussel	Na	mg/kg	8355.127	10974.970	19500.646	19911.694	25721.065	9	8
Blue mussel	Nb	mg/kg	0.068	0.147	0.157	0.162	0.369	9	8
Blue mussel	Nd	mg/kg	0.566	0.584	0.663	0.700	1.839	9	8
Blue mussel	Ni	mg/kg	1.847	3.270	3.544	3.918	6.749	15	11

Blue mussel	P	mg/kg	14978.621	15332.061	15953.079	16058.974	16448.447	9	8
Blue mussel	Pb	mg/kg	0.118	0.308	0.628	0.905	3.306	47	40
Blue mussel	Pd	mg/kg	0.003	0.004	0.004	0.004	0.005	9	8
Blue mussel	Pr	mg/kg	0.131	0.135	0.154	0.179	0.488	9	8
Blue mussel	Pt	mg/kg	<DL	<DL	<DL	<DL	<DL	9	8
Blue mussel	Rb	mg/kg	6.907	8.152	8.973	9.187	12.058	9	8
Blue mussel	Re	mg/kg	0.000	0.000	0.000	0.000	0.000	9	8
Blue mussel	Ru	mg/kg	<DL	<DL	<DL	<DL	<DL	9	8
Blue mussel	Sb	mg/kg	0.008	0.009	0.010	0.010	0.011	9	8
Blue mussel	Sc	mg/kg	0.234	0.473	0.515	0.593	1.020	9	8
Blue mussel	Se	mg/kg	4.547	5.783	6.163	6.803	10.449	32	26
Blue mussel	Sm	mg/kg	0.100	0.125	0.132	0.155	0.334	9	8
Blue mussel	Sr	mg/kg	20.872	29.679	32.195	36.114	46.003	9	8
Blue mussel	Ta	mg/kg	0.001	0.001	0.001	0.002	0.002	9	8
Blue mussel	Tb	mg/kg	0.010	0.019	0.020	0.024	0.034	9	8
Blue mussel	Te	mg/kg	<DL	0.004	0.005	0.009	0.012	9	8
Blue mussel	Th	mg/kg	0.036	0.038	0.044	0.125	0.573	9	8
Blue mussel	Ti	mg/kg	32.086	131.312	142.749	180.107	204.040	9	8
Blue mussel	Tl	mg/kg	<DL	<DL	<DL	<DL	0.030	9	8
Blue mussel	Tm	mg/kg	0.003	0.008	0.008	0.010	0.011	9	8
Blue mussel	U	mg/kg	0.171	0.181	0.221	0.247	0.272	9	8
Blue mussel	V	mg/kg	1.523	4.475	4.960	6.324	7.319	9	8
Blue mussel	W	mg/kg	0.011	0.011	0.013	0.027	0.062	9	8
Blue mussel	Y	mg/kg	0.386	0.738	0.828	0.962	1.147	9	8
Blue mussel	Yb	mg/kg	0.021	0.045	0.051	0.057	0.069	9	8
Blue mussel	Zn	mg/kg	17.500	22.572	112.261	129.218	205.750	30	25
Blue mussel	Zr	mg/kg	0.310	1.589	1.648	1.833	2.165	9	8
Crinkled snow lichen	Ag	mg/kg	0.001	0.002	0.003	0.005	0.015	22	20
Crinkled snow lichen	Al	mg/kg	97.436	178.664	280.369	379.515	479.389	22	20
Crinkled snow lichen	As	mg/kg	0.025	0.081	0.100	0.297	0.436	22	20
Crinkled snow lichen	Au	mg/kg	<DL	<DL	<DL	<DL	0.036	22	20
Crinkled snow lichen	Ba	mg/kg	1.109	1.990	2.898	11.583	17.065	19	17
Crinkled snow lichen	Be	mg/kg	0.001	0.002	0.005	0.009	0.011	19	17
Crinkled snow lichen	Bi	mg/kg	0.002	0.004	0.007	0.013	0.026	19	17
Crinkled snow lichen	Ca	mg/kg	2668.200	3761.335	5359.838	9722.512	21822.741	22	20
Crinkled snow lichen	Cd	mg/kg	0.040	0.057	0.088	0.143	0.682	22	20
Crinkled snow lichen	Ce	mg/kg	0.996	1.521	1.909	2.817	5.804	19	17
Crinkled snow lichen	Co	mg/kg	0.132	0.215	0.365	0.565	0.819	19	17
Crinkled snow lichen	Cr	mg/kg	0.351	0.513	0.786	1.498	1.978	22	20
Crinkled snow lichen	Cs	mg/kg	0.030	0.049	0.055	0.198	0.303	19	17
Crinkled snow lichen	Cu	mg/kg	0.561	0.713	0.996	1.366	1.774	22	20
Crinkled snow lichen	d.m.%	%	100.000	100.000	100.000	100.000	100.000	3	3
Crinkled snow lichen	Dy	mg/kg	0.062	0.107	0.137	0.171	0.228	19	17
Crinkled snow lichen	Er	mg/kg	0.034	0.052	0.071	0.087	0.113	19	17
Crinkled snow lichen	Eu	mg/kg	0.018	0.036	0.043	0.054	0.079	19	17
Crinkled snow lichen	Fe	mg/kg	98.010	182.030	233.789	376.527	542.662	22	20
Crinkled snow lichen	Ga	mg/kg	0.077	0.100	0.134	0.219	0.329	19	17
Crinkled snow lichen	Gd	mg/kg	0.078	0.149	0.172	0.224	0.350	19	17

Crinkled snow lichen	Hf	mg/kg	0.003	0.004	0.007	0.011	0.019	19	17
Crinkled snow lichen	Hg	mg/kg	0.021	0.032	0.040	0.046	0.050	22	20
Crinkled snow lichen	Ho	mg/kg	0.012	0.019	0.027	0.032	0.041	19	17
Crinkled snow lichen	K	mg/kg	1393.780	1693.120	1787.451	1874.894	2188.620	19	17
Crinkled snow lichen	La	mg/kg	0.480	0.744	0.905	1.408	2.743	19	17
Crinkled snow lichen	Li	mg/kg	0.015	0.021	0.030	0.145	0.192	19	17
Crinkled snow lichen	Lu	mg/kg	0.003	0.005	0.008	0.009	0.013	19	17
Crinkled snow lichen	Mg	mg/kg	885.316	1019.667	1172.229	1534.030	2019.822	22	20
Crinkled snow lichen	Mn	mg/kg	13.420	24.145	31.559	52.487	134.160	19	17
Crinkled snow lichen	Mo	mg/kg	0.022	0.030	0.034	0.058	0.072	19	17
Crinkled snow lichen	Na	mg/kg	264.907	346.539	369.136	469.605	651.763	19	17
Crinkled snow lichen	Nb	mg/kg	0.016	0.031	0.048	0.068	0.089	19	17
Crinkled snow lichen	Nd	mg/kg	0.449	0.765	0.968	1.226	2.337	19	17
Crinkled snow lichen	Ni	mg/kg	<DL	0.846	1.400	1.915	2.565	22	20
Crinkled snow lichen	P	mg/kg	447.277	498.990	644.646	651.997	719.163	19	17
Crinkled snow lichen	Pb	mg/kg	0.195	0.311	0.470	0.665	2.258	30	28
Crinkled snow lichen	Pd	mg/kg	0.001	0.001	0.001	0.002	0.002	19	17
Crinkled snow lichen	Pr	mg/kg	0.114	0.188	0.231	0.319	0.615	19	17
Crinkled snow lichen	Pt	mg/kg	<DL	<DL	<DL	<DL	<DL	19	17
Crinkled snow lichen	Rb	mg/kg	0.859	1.610	2.149	4.153	6.371	19	17
Crinkled snow lichen	Re	mg/kg	<DL	<DL	<DL	<DL	0.000	19	17
Crinkled snow lichen	Ru	mg/kg	<DL	<DL	<DL	<DL	<DL	19	17
Crinkled snow lichen	Sb	mg/kg	<DL	<DL	<DL	<DL	<DL	19	17
Crinkled snow lichen	Sc	mg/kg	0.090	0.122	0.180	0.201	0.292	19	17
Crinkled snow lichen	Se	mg/kg	<DL	0.083	0.109	0.129	0.172	22	20
Crinkled snow lichen	Sm	mg/kg	0.086	0.155	0.191	0.240	0.421	19	17
Crinkled snow lichen	Sr	mg/kg	9.043	11.667	15.497	21.080	37.174	19	17
Crinkled snow lichen	Ta	mg/kg	<DL	0.000	0.000	0.001	0.001	19	17
Crinkled snow lichen	Tb	mg/kg	0.011	0.020	0.024	0.031	0.045	19	17
Crinkled snow lichen	Te	mg/kg	<DL	<DL	<DL	<DL	<DL	19	17
Crinkled snow lichen	Th	mg/kg	0.027	0.040	0.052	0.144	0.220	19	17
Crinkled snow lichen	Ti	mg/kg	12.657	21.291	31.066	38.556	50.746	19	17
Crinkled snow lichen	Tl	mg/kg	<DL	<DL	<DL	<DL	0.015	19	17
Crinkled snow lichen	Tm	mg/kg	0.004	0.007	0.009	0.011	0.015	19	17
Crinkled snow lichen	U	mg/kg	0.010	0.012	0.014	0.063	0.092	19	17
Crinkled snow lichen	V	mg/kg	0.318	0.519	0.604	1.097	1.362	19	17
Crinkled snow lichen	W	mg/kg	0.003	0.004	0.005	0.013	0.046	19	17
Crinkled snow lichen	Y	mg/kg	0.382	0.627	0.846	1.023	1.340	19	17
Crinkled snow lichen	Yb	mg/kg	0.027	0.040	0.054	0.067	0.094	19	17
Crinkled snow lichen	Zn	mg/kg	9.079	12.444	14.218	16.122	27.397	30	28
Crinkled snow lichen	Zr	mg/kg	0.172	0.221	0.336	0.522	0.818	19	17
Filtered water	Ag	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Filtered water	Al	ug/l	3.042	7.192	11.342	11.763	12.183	3	3
Filtered water	As	ug/l	<DL	<DL	<DL	0.091	0.183	3	3
Filtered water	Au	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Filtered water	Ba	ug/l	0.017	0.080	0.142	2.076	4.009	3	3
Filtered water	Be	ug/l	<DL	<DL	<DL	0.001	0.002	3	3
Filtered water	Bi	ug/l	<DL	<DL	<DL	<DL	<DL	3	3

Filtered water	Ca	ug/l	5952.700	6273.135	6593.569	10930.476	15267.383	3	3
Filtered water	Cd	ug/l	<DL	<DL	<DL	0.002	0.004	3	3
Filtered water	Ce	ug/l	0.007	0.009	0.012	0.040	0.069	3	3
Filtered water	Co	ug/l	0.015	0.016	0.018	0.064	0.110	3	3
Filtered water	Cr	ug/l	0.132	0.158	0.185	0.219	0.253	3	3
Filtered water	Cs	ug/l	<DL	0.000	0.001	0.002	0.004	3	3
Filtered water	Cu	ug/l	0.644	1.062	1.481	1.573	1.665	3	3
Filtered water	Dy	ug/l	0.002	0.004	0.007	0.010	0.013	3	3
Filtered water	Er	ug/l	0.001	0.003	0.006	0.006	0.006	3	3
Filtered water	Eu	ug/l	0.001	0.001	0.002	0.002	0.003	3	3
Filtered water	Fe	ug/l	11.644	12.942	14.240	55.031	95.822	3	3
Filtered water	Ga	ug/l	<DL	0.001	0.003	0.008	0.014	3	3
Filtered water	Gd	ug/l	0.002	0.005	0.007	0.010	0.013	3	3
Filtered water	Hf	ug/l	0.001	0.001	0.001	0.001	0.002	3	3
Filtered water	Hg	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Filtered water	Ho	ug/l	0.000	0.001	0.002	0.002	0.002	3	3
Filtered water	K	ug/l	106.705	169.315	231.926	878.743	1525.560	3	3
Filtered water	La	ug/l	0.004	0.007	0.011	0.030	0.049	3	3
Filtered water	Li	ug/l	0.011	0.031	0.051	0.452	0.854	3	3
Filtered water	Lu	ug/l	0.000	0.001	0.001	0.001	0.001	3	3
Filtered water	Mg	ug/l	2368.821	2510.546	2652.272	4122.283	5592.293	3	3
Filtered water	Mn	ug/l	0.604	0.946	1.289	8.904	16.520	3	3
Filtered water	Mo	ug/l	0.054	0.061	0.068	0.124	0.179	3	3
Filtered water	Na	ug/l	6551.687	6787.703	7023.719	8358.411	9693.102	3	3
Filtered water	Nb	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Filtered water	Nd	ug/l	0.007	0.013	0.019	0.040	0.062	3	3
Filtered water	Ni	ug/l	0.257	0.288	0.319	1.093	1.866	3	3
Filtered water	P	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Filtered water	Pb	ug/l	<DL	0.005	0.010	0.015	0.020	3	3
Filtered water	Pd	ug/l	0.001	0.001	0.001	0.002	0.002	3	3
Filtered water	Pr	ug/l	0.001	0.003	0.004	0.009	0.013	3	3
Filtered water	Pt	ug/l	<DL	0.002	0.003	0.003	0.003	3	3
Filtered water	Rb	ug/l	0.043	0.103	0.163	0.554	0.945	3	3
Filtered water	Re	ug/l	<DL	0.000	0.000	0.000	0.001	3	3
Filtered water	Ru	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Filtered water	Sb	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Filtered water	Sc	ug/l	0.017	0.017	0.017	0.021	0.025	3	3
Filtered water	Se	ug/l	0.027	0.042	0.058	0.081	0.104	3	3
Filtered water	Sm	ug/l	0.002	0.003	0.005	0.009	0.013	3	3
Filtered water	Sr	ug/l	3.246	5.473	7.699	30.817	53.934	3	3
Filtered water	Ta	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Filtered water	Tb	ug/l	0.000	0.001	0.001	0.002	0.002	3	3
Filtered water	Te	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Filtered water	Th	ug/l	0.000	0.000	0.000	0.004	0.007	3	3
Filtered water	Ti	ug/l	0.140	0.188	0.237	0.349	0.460	3	3
Filtered water	Tl	ug/l	<DL	0.001	0.002	0.005	0.007	3	3
Filtered water	Tm	ug/l	0.000	0.000	0.001	0.001	0.001	3	3
Filtered water	U	ug/l	0.003	0.005	0.007	0.045	0.082	3	3

Filtered water	V	ug/l	0.203	0.609	1.016	2.143	3.270	3	3
Filtered water	W	ug/l	<DL	0.003	0.005	0.006	0.007	3	3
Filtered water	Y	ug/l	0.010	0.035	0.059	0.066	0.073	3	3
Filtered water	Yb	ug/l	0.001	0.003	0.005	0.006	0.006	3	3
Filtered water	Zn	ug/l	<DL	<DL	<DL	0.232	0.464	3	3
Filtered water	Zr	ug/l	0.029	0.035	0.041	0.052	0.062	3	3
Rough periwinkle	Ag	mg/kg	1.825	1.825	1.825	1.825	1.825	1	1
Rough periwinkle	As	mg/kg	13.385	13.385	13.385	13.385	13.385	1	1
Rough periwinkle	Cd	mg/kg	2.251	2.251	2.251	2.251	2.251	1	1
Rough periwinkle	Co	mg/kg	0.577	0.577	0.577	0.577	0.577	1	1
Rough periwinkle	Cr	mg/kg	0.533	0.533	0.533	0.533	0.533	1	1
Rough periwinkle	Cu	mg/kg	34.097	34.097	34.097	34.097	34.097	1	1
Rough periwinkle	Fe	mg/kg	351.400	351.400	351.400	351.400	351.400	1	1
Rough periwinkle	Hg	mg/kg	0.062	0.062	0.062	0.062	0.062	1	1
Rough periwinkle	Ni	mg/kg	3.284	3.284	3.284	3.284	3.284	1	1
Rough periwinkle	Pb	mg/kg	1.576	1.576	1.576	1.576	1.576	1	1
Rough periwinkle	Se	mg/kg	1.036	1.036	1.036	1.036	1.036	1	1
Rough periwinkle	Zn	mg/kg	53.175	53.175	53.175	53.175	53.175	1	1
Seaweed	Ag	mg/kg	0.038	0.038	0.039	0.070	0.102	3	2
Seaweed	Al	mg/kg	249.898	255.105	260.312	1025.257	1790.203	3	2
Seaweed	As	mg/kg	36.140	40.823	44.415	51.790	54.640	6	4
Seaweed	Au	mg/kg	0.007	0.008	0.008	0.010	0.012	3	2
Seaweed	Ba	mg/kg	9.582	9.587	9.592	19.450	29.309	3	2
Seaweed	Be	mg/kg	0.003	0.003	0.003	0.013	0.022	3	2
Seaweed	Bi	mg/kg	0.002	0.002	0.002	0.013	0.024	3	2
Seaweed	Ca	mg/kg	11882.138	11896.427	11910.715	12424.714	12938.712	3	2
Seaweed	Cd	mg/kg	0.301	0.413	0.524	0.539	0.554	3	2
Seaweed	Ce	mg/kg	0.317	0.320	0.323	2.532	4.742	3	2
Seaweed	Co	mg/kg	1.278	1.281	1.284	1.347	1.410	3	2
Seaweed	Cr	mg/kg	0.572	0.629	0.686	2.971	5.255	3	2
Seaweed	Cs	mg/kg	0.037	0.037	0.038	0.202	0.366	3	2
Seaweed	Cu	mg/kg	7.621	7.643	7.664	8.372	9.080	3	2
Seaweed	d.m.%	%	100.000	100.000	100.000	100.000	100.000	2	2
Seaweed	Dy	mg/kg	0.059	0.059	0.059	0.129	0.200	3	2
Seaweed	Er	mg/kg	0.032	0.032	0.032	0.064	0.096	3	2
Seaweed	Eu	mg/kg	0.019	0.019	0.019	0.038	0.056	3	2
Seaweed	Fe	mg/kg	439.112	443.196	447.281	1217.913	1988.545	3	2
Seaweed	Ga	mg/kg	0.103	0.105	0.108	0.431	0.753	3	2
Seaweed	Gd	mg/kg	0.070	0.071	0.072	0.187	0.301	3	2
Seaweed	Hf	mg/kg	0.013	0.013	0.014	0.028	0.042	3	2
Seaweed	Hg	mg/kg	0.005	0.007	0.008	0.008	0.008	3	2
Seaweed	Ho	mg/kg	0.012	0.012	0.012	0.024	0.036	3	2
Seaweed	K	mg/kg	25953.693	26088.728	26223.762	32105.918	37988.074	3	2
Seaweed	La	mg/kg	0.234	0.235	0.237	1.330	2.424	3	2
Seaweed	Li	mg/kg	0.158	0.159	0.159	0.746	1.333	3	2
Seaweed	Lu	mg/kg	0.004	0.004	0.004	0.007	0.011	3	2
Seaweed	Mg	mg/kg	8416.395	8509.236	8602.077	9432.412	10262.746	3	2
Seaweed	Mn	mg/kg	55.528	55.822	56.116	56.710	57.304	3	2

Seaweed	Mo	mg/kg	0.170	0.176	0.182	0.190	0.198	3	2
Seaweed	Na	mg/kg	15302.445	15433.595	15564.746	16843.498	18122.249	3	2
Seaweed	Nb	mg/kg	0.058	0.061	0.063	0.195	0.327	3	2
Seaweed	Nd	mg/kg	0.274	0.274	0.274	1.165	2.056	3	2
Seaweed	Ni	mg/kg	1.856	1.862	1.867	3.037	4.207	3	2
Seaweed	P	mg/kg	1990.071	2297.161	2604.251	2622.559	2640.866	3	2
Seaweed	Pb	mg/kg	0.046	0.157	0.191	0.245	0.582	16	13
Seaweed	Pd	mg/kg	0.024	0.024	0.024	0.025	0.027	3	2
Seaweed	Pr	mg/kg	0.059	0.060	0.061	0.298	0.536	3	2
Seaweed	Pt	mg/kg	<DL	<DL	<DL	<DL	<DL	3	2
Seaweed	Rb	mg/kg	13.705	13.707	13.708	16.129	18.549	3	2
Seaweed	Re	mg/kg	0.042	0.044	0.047	0.047	0.048	3	2
Seaweed	Ru	mg/kg	<DL	<DL	<DL	0.000	0.000	3	2
Seaweed	Sb	mg/kg	0.012	0.013	0.014	0.014	0.014	3	2
Seaweed	Sc	mg/kg	0.173	0.177	0.181	0.467	0.752	3	2
Seaweed	Se	mg/kg	0.044	0.044	0.044	0.058	0.071	3	2
Seaweed	Sm	mg/kg	0.066	0.066	0.067	0.221	0.375	3	2
Seaweed	Sr	mg/kg	672.571	677.750	682.930	683.283	683.636	3	2
Seaweed	Ta	mg/kg	0.001	0.001	0.001	0.001	0.001	3	2
Seaweed	Tb	mg/kg	0.010	0.010	0.010	0.024	0.038	3	2
Seaweed	Te	mg/kg	<DL	<DL	<DL	0.003	0.005	3	2
Seaweed	Th	mg/kg	0.012	0.012	0.012	0.280	0.548	3	2
Seaweed	Ti	mg/kg	43.788	45.537	47.287	125.822	204.357	3	2
Seaweed	Tl	mg/kg	<DL	<DL	<DL	0.015	0.030	3	2
Seaweed	Tm	mg/kg	0.004	0.004	0.004	0.008	0.012	3	2
Seaweed	U	mg/kg	0.830	0.839	0.848	0.862	0.875	3	2
Seaweed	V	mg/kg	1.824	1.839	1.854	4.163	6.471	3	2
Seaweed	W	mg/kg	0.005	0.005	0.006	0.018	0.031	3	2
Seaweed	Y	mg/kg	0.398	0.401	0.404	0.826	1.248	3	2
Seaweed	Yb	mg/kg	0.026	0.026	0.026	0.052	0.077	3	2
Seaweed	Zn	mg/kg	7.609	9.341	11.280	13.294	19.258	16	13
Seaweed	Zr	mg/kg	0.868	0.883	0.898	1.567	2.236	3	2
Sediment	Ag	mg/kg	<DL	<DL	<DL	<DL	<DL	2	1
Sediment	Al	mg/kg	65594.000	65779.750	65965.500	66151.250	66337.000	2	1
Sediment	As	mg/kg	<DL	2.235	2.960	4.580	11.230	11	6
Sediment	Ca	mg/kg	15273.000	15447.000	15621.000	15795.000	15969.000	2	1
Sediment	Cd	mg/kg	<DL	<DL	<DL	<DL	<DL	2	1
Sediment	Cr	mg/kg	35.600	35.675	35.750	35.825	35.900	2	1
Sediment	Cu	mg/kg	1.020	7.595	14.170	20.745	27.320	2	1
Sediment	Fe	mg/kg	8428.000	8479.000	8530.000	8581.000	8632.000	2	1
Sediment	Hg	mg/kg	<DL	0.006	0.008	0.018	0.048	53	6
Sediment	Mg	mg/kg	4127.000	4193.750	4260.500	4327.250	4394.000	2	1
Sediment	Ni	mg/kg	12.150	12.375	12.600	12.825	13.050	2	1
Sediment	Pb	mg/kg	15.900	15.925	15.950	15.975	16.000	2	1
Sediment	Se	mg/kg	<DL	<DL	<DL	<DL	<DL	2	1
Sediment	Zn	mg/kg	13.800	14.100	14.400	14.700	15.000	2	1
Shorthorn sculpin	Ag	mg/kg	0.006	0.041	0.113	0.174	0.392	7	7
Shorthorn sculpin	As	mg/kg	7.375	10.575	13.243	19.340	21.699	7	7

Shorthorn sculpin	Cd	mg/kg	0.485	0.692	1.032	1.492	2.560	7	7
Shorthorn sculpin	Co	mg/kg	0.028	0.033	0.080	0.137	0.239	7	7
Shorthorn sculpin	Cr	mg/kg	0.001	0.002	0.004	0.019	0.061	7	7
Shorthorn sculpin	Cu	mg/kg	0.634	1.475	2.288	4.306	5.504	7	7
Shorthorn sculpin	d.m.%	%	16.594	19.000	24.590	27.480	36.600	37	32
Shorthorn sculpin	Fe	mg/kg	23.100	68.850	130.100	160.000	347.000	7	7
Shorthorn sculpin	Hg	mg/kg	0.014	0.041	0.047	0.054	0.097	7	7
Shorthorn sculpin	Ni	mg/kg	0.015	0.025	0.045	0.109	0.907	7	7
Shorthorn sculpin	Pb	mg/kg	<DL	0.011	0.016	0.040	0.353	39	34
Shorthorn sculpin	Se	mg/kg	0.798	0.862	1.092	1.364	1.937	7	7
Shorthorn sculpin	Zn	mg/kg	25.785	41.911	62.072	63.142	65.023	7	7
Soil	Ag	mg/kg	0.005	0.009	0.013	0.015	0.358	20	17
Soil	Al	mg/kg	18499.213	32310.205	45653.654	49778.783	70356.612	20	17
Soil	As	mg/kg	<DL	0.273	0.725	5.394	16.629	20	17
Soil	Au	mg/kg	<DL	<DL	<DL	<DL	0.004	20	17
Soil	Ba	mg/kg	28.031	50.574	84.361	174.571	331.901	20	17
Soil	Be	mg/kg	0.185	0.390	0.474	0.703	2.291	20	17
Soil	Bi	mg/kg	0.018	0.037	0.053	0.201	0.483	20	17
Soil	Ca	mg/kg	3665.426	6445.558	10412.358	17221.172	28808.614	20	17
Soil	Cd	mg/kg	0.080	0.093	0.123	0.210	1.104	20	17
Soil	Ce	mg/kg	13.094	24.147	32.272	45.048	94.962	20	17
Soil	Co	mg/kg	9.508	18.003	35.116	42.881	48.828	20	17
Soil	Cr	mg/kg	13.658	99.369	189.507	251.690	510.860	20	17
Soil	Cs	mg/kg	0.151	0.379	0.460	2.644	6.048	20	17
Soil	Cu	mg/kg	18.779	49.180	127.543	190.314	365.365	20	17
Soil	Dy	mg/kg	0.976	2.115	2.781	3.594	8.126	20	17
Soil	Er	mg/kg	0.531	1.154	1.543	2.030	4.544	20	17
Soil	Eu	mg/kg	0.353	0.539	0.782	1.021	2.217	20	17
Soil	Fe	mg/kg	17079.829	33648.066	55826.049	68296.423	100948.193	20	17
Soil	Ga	mg/kg	6.019	11.867	14.018	16.017	26.531	20	17
Soil	Gd	mg/kg	1.428	2.522	3.047	4.313	8.908	20	17
Soil	Hf	mg/kg	0.444	0.601	0.746	0.919	2.317	20	17
Soil	Hg	mg/kg	<DL	<DL	0.028	0.055	0.201	20	17
Soil	Ho	mg/kg	0.187	0.412	0.546	0.719	1.578	20	17
Soil	K	mg/kg	566.019	1201.686	1844.976	5935.711	9205.982	20	17
Soil	La	mg/kg	6.441	9.517	13.237	20.247	43.974	20	17
Soil	Li	mg/kg	3.991	5.557	7.136	22.720	32.653	20	17
Soil	Lu	mg/kg	0.065	0.142	0.187	0.242	0.558	20	17
Soil	Mg	mg/kg	4712.930	11258.968	14292.348	21064.539	43009.391	20	17
Soil	Mn	mg/kg	328.124	488.410	759.294	1054.272	1577.644	20	17
Soil	Mo	mg/kg	<DL	<DL	<DL	<DL	1.257	20	17
Soil	Na	mg/kg	454.428	744.319	1510.948	2024.001	4565.746	20	17
Soil	Nb	mg/kg	<DL	<DL	<DL	0.041	0.065	20	17
Soil	Nd	mg/kg	6.897	11.259	14.496	18.871	42.910	20	17
Soil	Ni	mg/kg	27.061	56.485	101.689	158.201	354.784	20	17
Soil	P	mg/kg	395.753	575.679	800.056	908.234	1177.313	20	17
Soil	Pb	mg/kg	1.072	2.122	2.853	6.712	17.329	20	17
Soil	Pd	mg/kg	0.005	0.011	0.019	0.025	0.038	20	17

Soil	Pr	mg/kg	1.707	2.787	3.461	4.747	10.979	20	17
Soil	Pt	mg/kg	<DL	<DL	0.007	0.010	0.014	20	17
Soil	Rb	mg/kg	2.900	6.478	9.369	41.186	82.466	20	17
Soil	Re	mg/kg	<DL	<DL	<DL	<DL	0.007	20	17
Soil	Ru	mg/kg	<DL	<DL	<DL	<DL	0.003	20	17
Soil	Sb	mg/kg	<DL	<DL	<DL	<DL	0.050	20	17
Soil	Sc	mg/kg	4.427	7.195	10.656	12.444	24.603	20	17
Soil	Se	mg/kg	<DL	0.087	0.183	0.238	0.771	20	17
Soil	Sm	mg/kg	1.537	2.523	3.148	4.085	9.091	20	17
Soil	Sr	mg/kg	26.718	40.649	66.969	136.041	247.470	20	17
Soil	Ta	mg/kg	<DL	<DL	<DL	0.001	0.003	20	17
Soil	Tb	mg/kg	0.179	0.370	0.467	0.609	1.370	20	17
Soil	Te	mg/kg	<DL	<DL	0.014	0.018	0.056	20	17
Soil	Th	mg/kg	0.623	1.268	1.870	5.125	9.153	20	17
Soil	Ti	mg/kg	243.927	347.238	401.088	439.491	529.019	20	17
Soil	Tl	mg/kg	<DL	<DL	<DL	0.241	0.512	20	17
Soil	Tm	mg/kg	0.073	0.157	0.203	0.276	0.613	20	17
Soil	U	mg/kg	0.169	0.410	0.552	1.411	3.213	20	17
Soil	V	mg/kg	44.747	79.190	114.866	157.302	199.141	20	17
Soil	W	mg/kg	<DL	<DL	<DL	<DL	<DL	20	17
Soil	Y	mg/kg	4.633	9.946	12.866	16.795	34.839	20	17
Soil	Yb	mg/kg	0.441	0.977	1.292	1.738	3.852	20	17
Soil	Zn	mg/kg	63.294	80.076	97.311	107.948	157.593	20	17
Soil	Zr	mg/kg	11.574	25.062	31.775	38.757	108.389	20	17
Unfiltered water	Ag	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Unfiltered water	Al	ug/l	6.893	29.876	52.858	717.993	1383.128	3	3
Unfiltered water	As	ug/l	<DL	<DL	<DL	0.141	0.282	3	3
Unfiltered water	Au	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Unfiltered water	Ba	ug/l	0.761	0.831	0.900	2.725	4.550	3	3
Unfiltered water	Be	ug/l	<DL	0.002	0.003	0.007	0.010	3	3
Unfiltered water	Bi	ug/l	<DL	<DL	<DL	0.001	0.001	3	3
Unfiltered water	Ca	ug/l	6162.431	6920.636	7678.841	11431.303	15183.766	3	3
Unfiltered water	Cd	ug/l	0.001	0.002	0.004	0.005	0.006	3	3
Unfiltered water	Ce	ug/l	0.019	0.133	0.247	0.362	0.478	3	3
Unfiltered water	Co	ug/l	0.019	0.103	0.187	0.833	1.479	3	3
Unfiltered water	Cr	ug/l	0.109	0.153	0.198	0.969	1.741	3	3
Unfiltered water	Cs	ug/l	0.001	0.002	0.003	0.007	0.011	3	3
Unfiltered water	Cu	ug/l	1.504	1.719	1.934	2.864	3.795	3	3
Unfiltered water	Dy	ug/l	0.009	0.017	0.024	0.049	0.074	3	3
Unfiltered water	Er	ug/l	0.007	0.010	0.013	0.027	0.042	3	3
Unfiltered water	Eu	ug/l	0.003	0.005	0.007	0.016	0.026	3	3
Unfiltered water	Fe	ug/l	22.540	134.793	247.047	742.092	1237.137	3	3
Unfiltered water	Ga	ug/l	0.005	0.012	0.019	0.178	0.337	3	3
Unfiltered water	Gd	ug/l	0.010	0.019	0.029	0.055	0.081	3	3
Unfiltered water	Hf	ug/l	0.001	0.002	0.003	0.003	0.004	3	3
Unfiltered water	Hg	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Unfiltered water	Ho	ug/l	0.002	0.003	0.005	0.010	0.015	3	3
Unfiltered water	K	ug/l	141.953	190.909	239.866	885.486	1531.107	3	3

Unfiltered water	La	ug/l	0.015	0.073	0.132	0.157	0.182	3	3
Unfiltered water	Li	ug/l	0.052	0.074	0.096	0.495	0.893	3	3
Unfiltered water	Lu	ug/l	0.001	0.001	0.002	0.003	0.004	3	3
Unfiltered water	Mg	ug/l	2747.379	3421.265	4095.150	4800.902	5506.654	3	3
Unfiltered water	Mn	ug/l	0.715	10.737	20.759	24.454	28.149	3	3
Unfiltered water	Mo	ug/l	0.029	0.035	0.041	0.095	0.148	3	3
Unfiltered water	Na	ug/l	6690.204	7056.943	7423.682	8442.623	9461.564	3	3
Unfiltered water	Nb	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Unfiltered water	Nd	ug/l	0.025	0.088	0.152	0.234	0.317	3	3
Unfiltered water	Ni	ug/l	0.261	1.123	1.985	7.006	12.027	3	3
Unfiltered water	P	ug/l	<DL	1.985	3.970	14.239	24.509	3	3
Unfiltered water	Pb	ug/l	<DL	0.011	0.023	0.033	0.044	3	3
Unfiltered water	Pd	ug/l	0.001	0.001	0.001	0.001	0.002	3	3
Unfiltered water	Pr	ug/l	0.005	0.019	0.033	0.050	0.066	3	3
Unfiltered water	Pt	ug/l	<DL	<DL	<DL	0.002	0.003	3	3
Unfiltered water	Rb	ug/l	0.125	0.140	0.156	0.602	1.047	3	3
Unfiltered water	Re	ug/l	0.000	0.000	0.000	0.000	0.001	3	3
Unfiltered water	Ru	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Unfiltered water	Sb	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Unfiltered water	Sc	ug/l	0.013	0.026	0.039	0.060	0.080	3	3
Unfiltered water	Se	ug/l	0.028	0.038	0.047	0.059	0.070	3	3
Unfiltered water	Sm	ug/l	0.010	0.022	0.034	0.057	0.079	3	3
Unfiltered water	Sr	ug/l	7.192	7.587	7.982	30.675	53.369	3	3
Unfiltered water	Ta	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Unfiltered water	Tb	ug/l	0.001	0.003	0.004	0.008	0.012	3	3
Unfiltered water	Te	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Unfiltered water	Th	ug/l	0.000	0.001	0.002	0.008	0.014	3	3
Unfiltered water	Ti	ug/l	0.261	1.628	2.996	8.399	13.803	3	3
Unfiltered water	Tl	ug/l	<DL	0.001	0.003	0.005	0.007	3	3
Unfiltered water	Tm	ug/l	0.001	0.001	0.002	0.003	0.005	3	3
Unfiltered water	U	ug/l	0.004	0.009	0.015	0.053	0.090	3	3
Unfiltered water	V	ug/l	0.425	0.734	1.044	2.862	4.681	3	3
Unfiltered water	W	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
Unfiltered water	Y	ug/l	0.074	0.108	0.141	0.278	0.415	3	3
Unfiltered water	Yb	ug/l	0.007	0.008	0.010	0.022	0.034	3	3
Unfiltered water	Zn	ug/l	<DL	0.377	0.753	1.627	2.501	3	3
Unfiltered water	Zr	ug/l	0.043	0.066	0.089	0.130	0.171	3	3

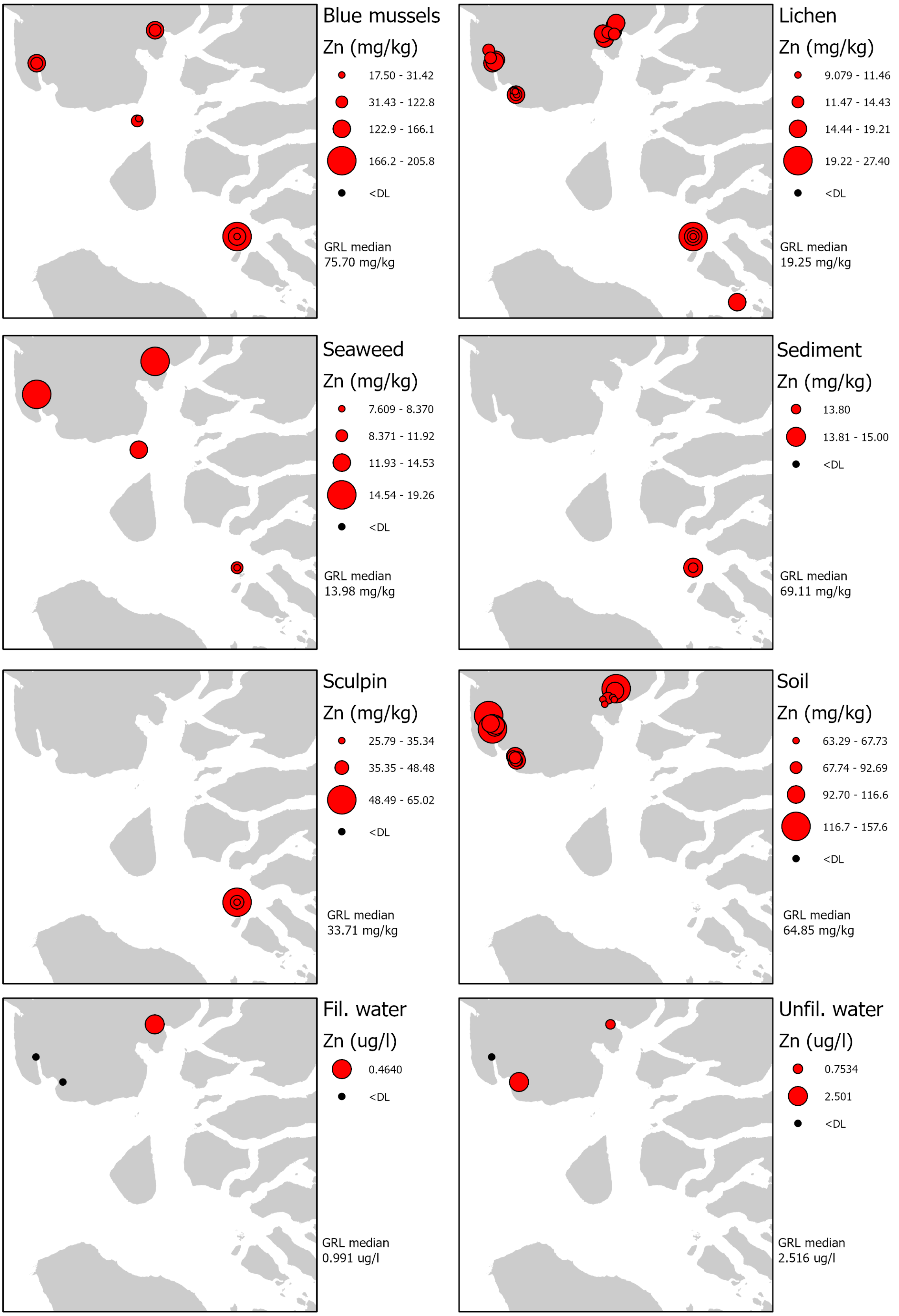

Figure A2.1. Concentrations of Zn in unpolluted samples. The Greenland median concentration level in unpolluted AMDA samples (Fritt-Rasmussen et al. 2023) is given as reference.

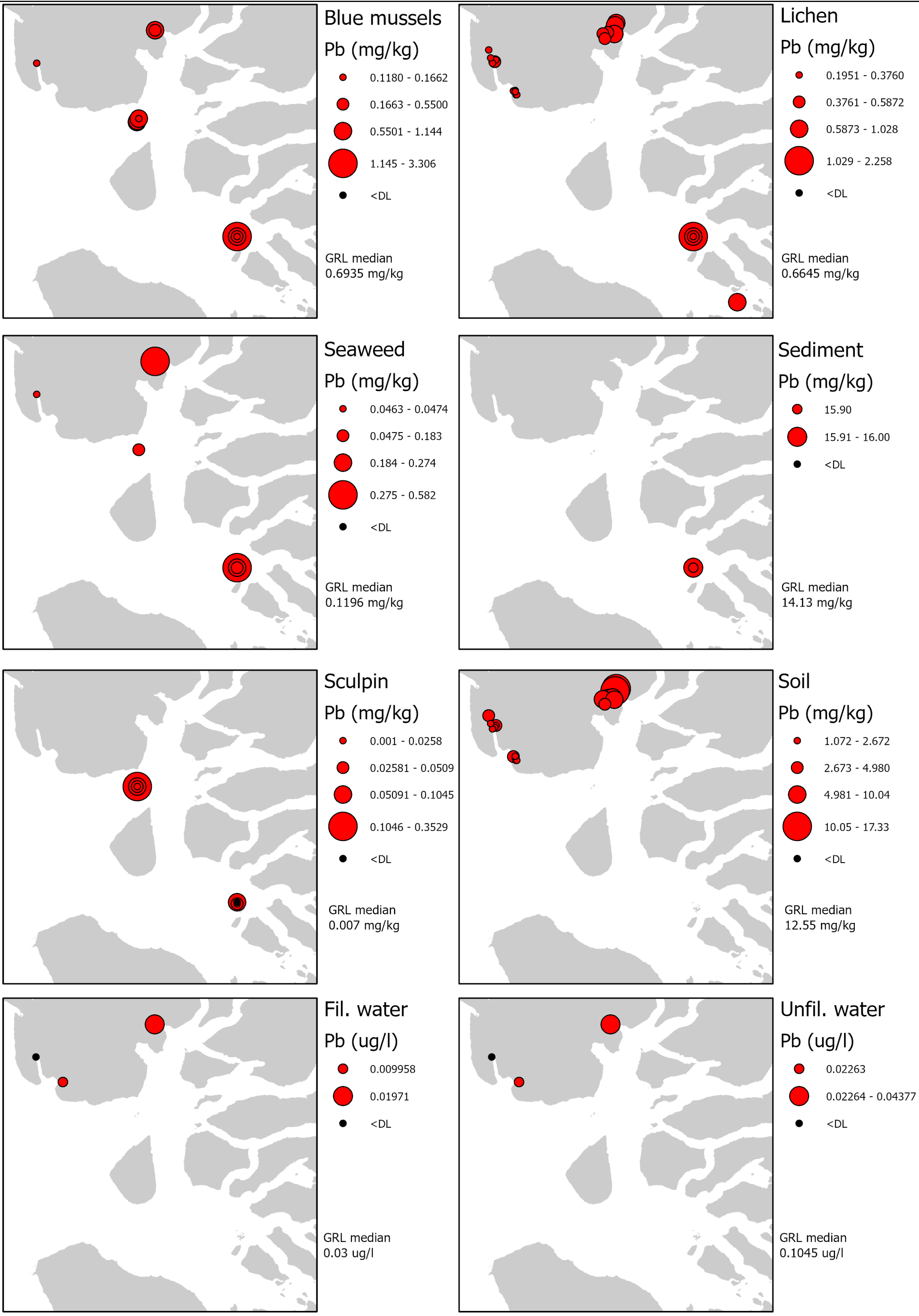

Figure A2.2. Concentrations of Pb in unpolluted samples. The Greenland median concentration level in unpolluted AMDA samples (Fritt-Rasmussen et al. 2023) is given as reference.

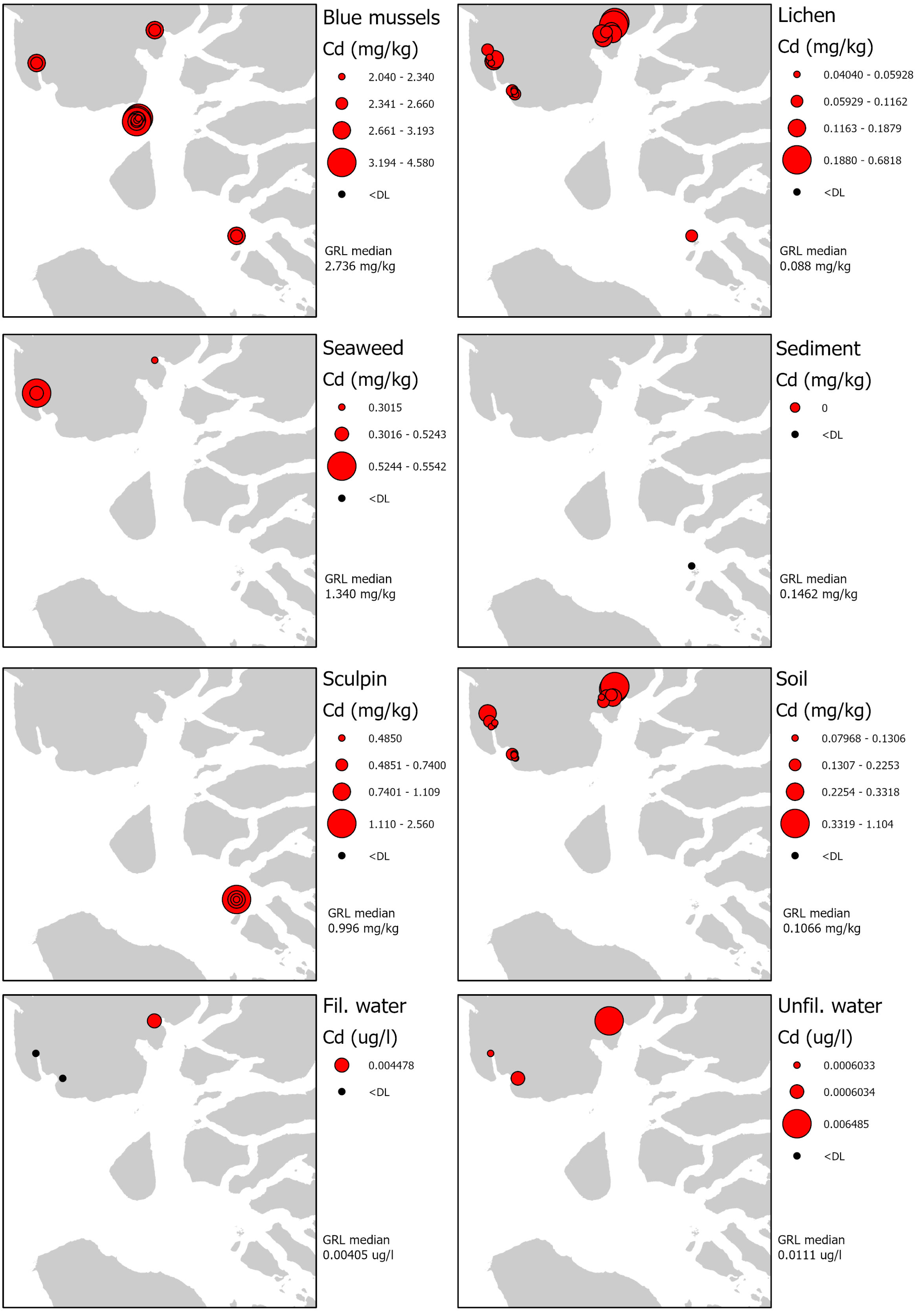

Figure A2.3. Concentrations of Cd in unpolluted samples. The Greenland median concentration level in unpolluted AMDA samples (Fritt-Rasmussen et al. 2023) is given as reference.

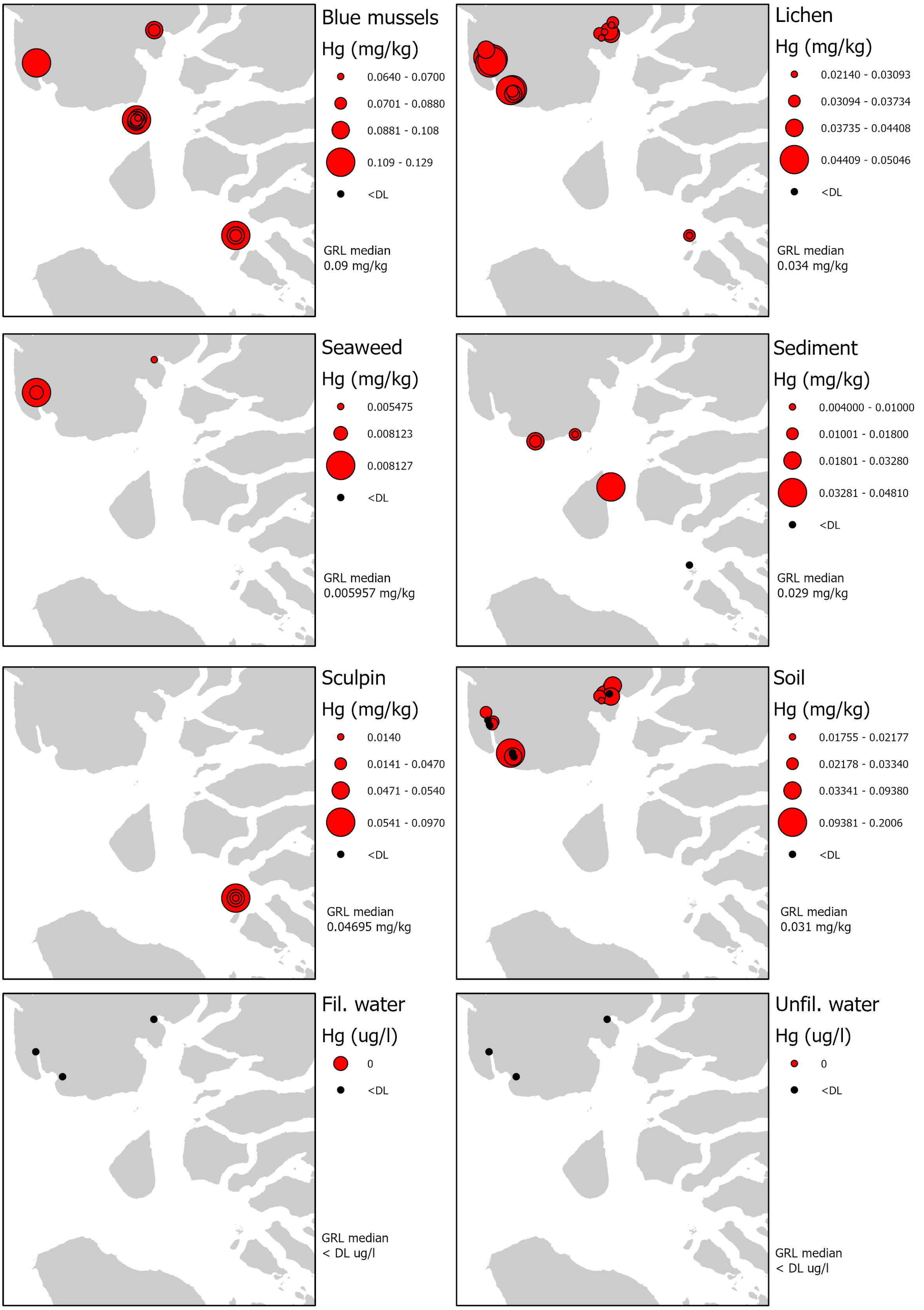

Figure A2.4. Concentrations of Hg in unpolluted samples. The Greenland median concentration level in unpolluted AMDA samples (Fritt-Rasmussen et al. 2023) is given as reference.

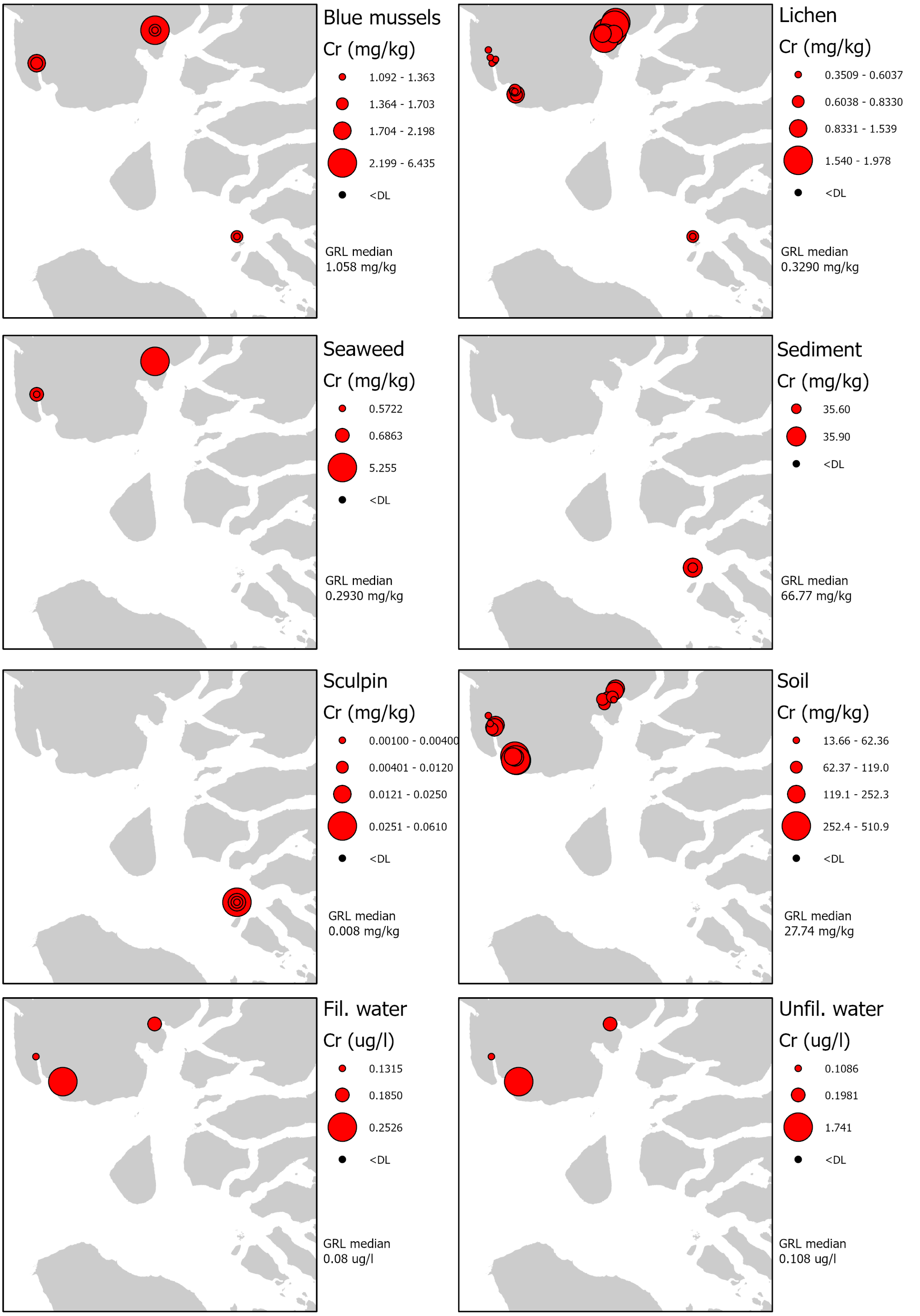

Figure A2.5. Concentrations of Cr in unpolluted samples. The Greenland median concentration level in unpolluted AMDA samples (Fritt-Rasmussen et al. 2023) is given as reference.

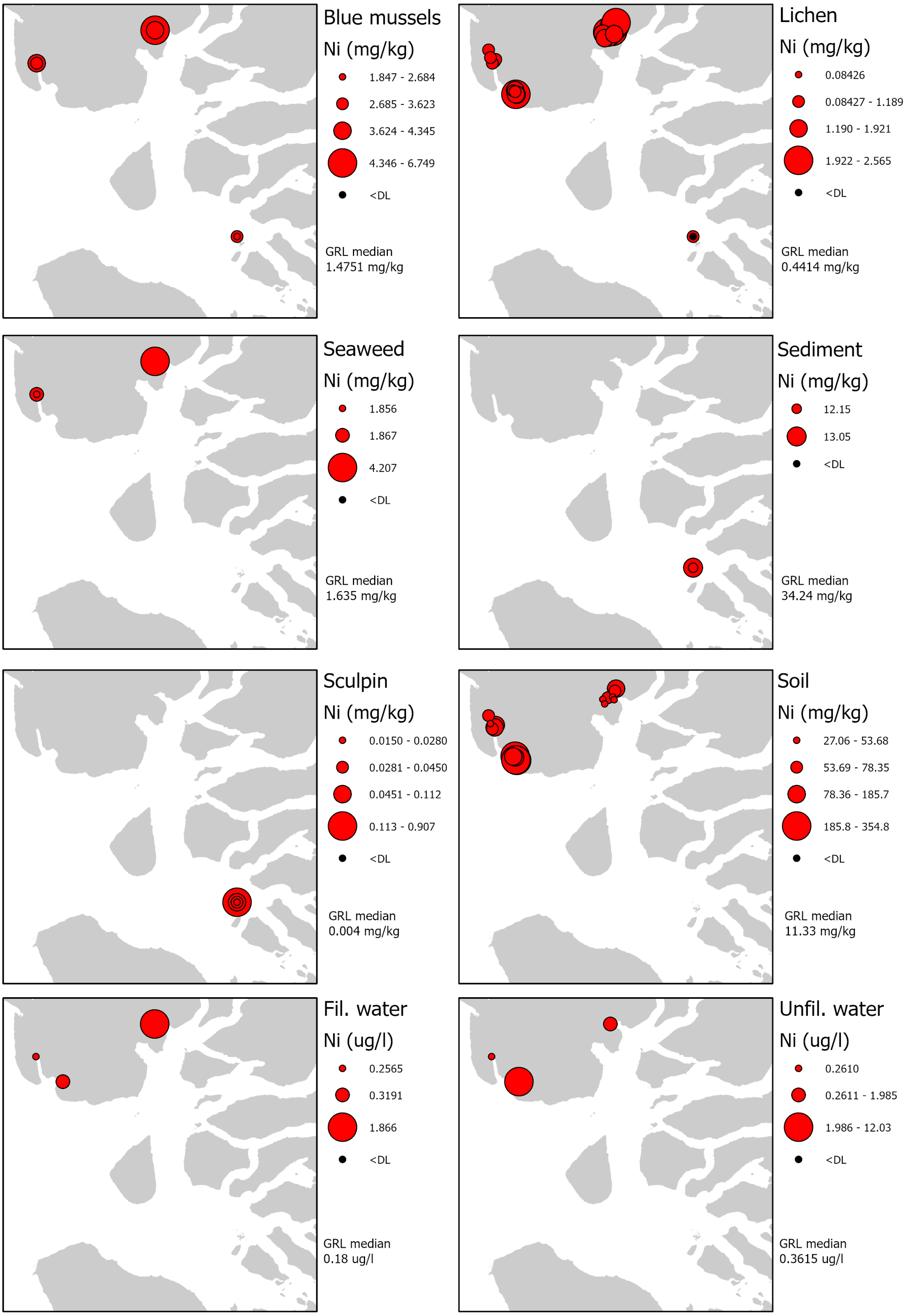

Figure A2.6. Concentrations of Ni in unpolluted samples. The Greenland median concentration level in unpolluted AMDA samples (Fritt-Rasmussen et al. 2023) is given as reference.

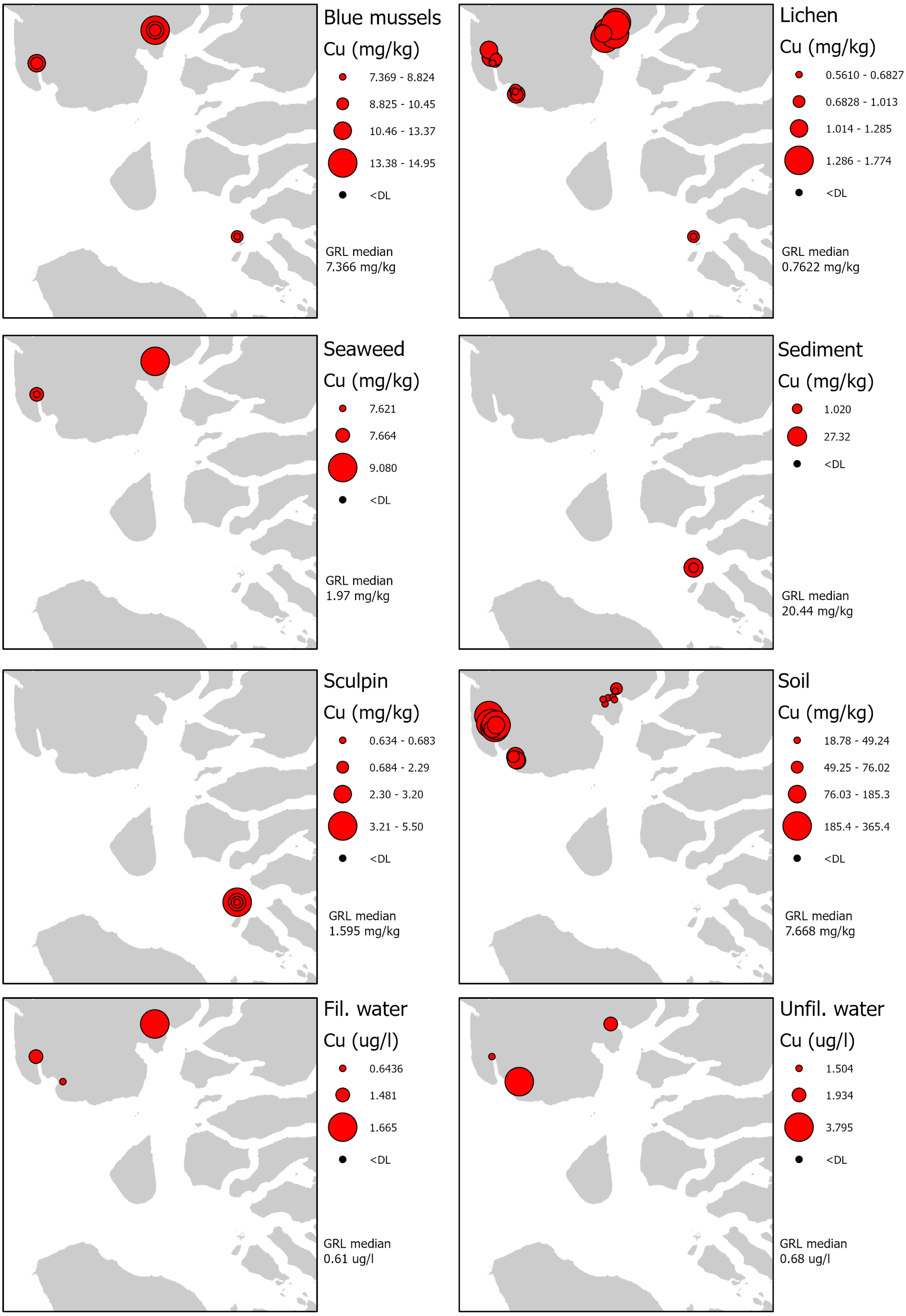

Figure A2.7. Concentrations of Cu in unpolluted samples. The Greenland median concentration level in unpolluted AMDA samples (Fritt-Rasmussen et al. 2023) is given as reference.

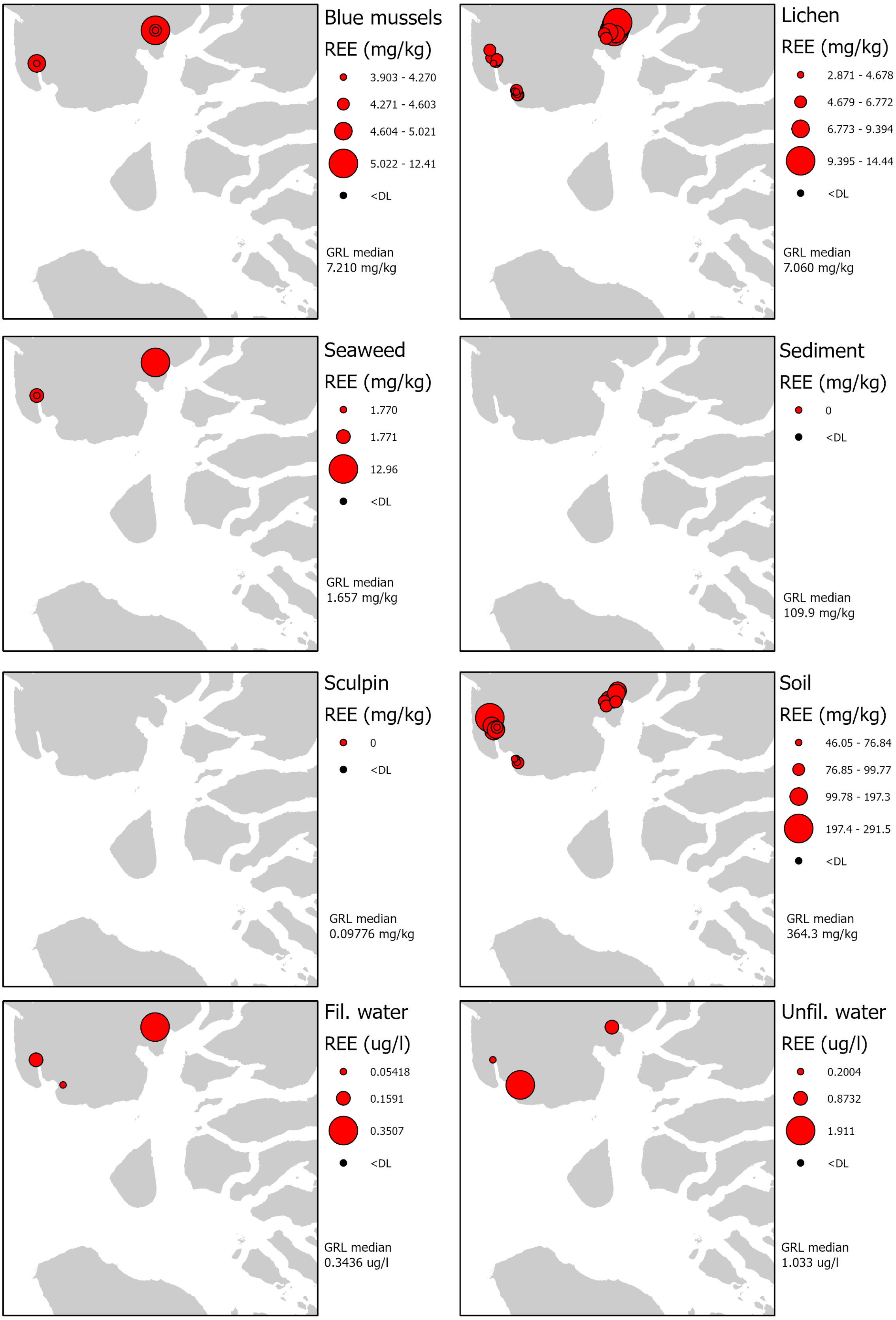

Figure A.8. Concentrations of REE in unpolluted samples. The Greenland median concentration level in unpolluted AMDA samples (Fritt-Rasmussen et al. 2023) is given as reference.

Table A2.2. Summary statistics on samples collected during the field work conducted at Siggu Nunaa in 2022 as part of the present RBA project. Concentration levels for approx. 60 different elements across the collected sample types of lichens, soil, blue mussels, seaweed and freshwater (filtered and unfiltered) are given.

Project	Sample_category	Element	Unit	min	q25	median	q75	max	n_meas	n_samp
RBA	Blue mussel	Ag	mg/kg	0.004	0.004	0.006	0.011	0.014	9	8
RBA	Blue mussel	Al	mg/kg	321.242	711.764	870.209	990.685	2038.732	9	8
RBA	Blue mussel	As	mg/kg	13.703	13.872	14.693	15.459	17.200	9	8
RBA	Blue mussel	Au	mg/kg	0.005	0.005	0.006	0.007	0.007	9	8
RBA	Blue mussel	Ba	mg/kg	1.275	1.392	1.828	3.027	12.645	9	8
RBA	Blue mussel	Be	mg/kg	0.004	0.008	0.009	0.010	0.025	9	8
RBA	Blue mussel	Bi	mg/kg	0.002	0.002	0.003	0.035	0.052	9	8
RBA	Blue mussel	Ca	mg/kg	2165.204	2812.973	2999.097	3755.774	5664.130	9	8
RBA	Blue mussel	Cd	mg/kg	2.471	2.561	2.655	2.908	3.193	9	8
RBA	Blue mussel	Ce	mg/kg	0.913	0.924	1.115	1.409	4.451	9	8
RBA	Blue mussel	Co	mg/kg	1.722	1.746	1.941	1.964	2.502	9	8
RBA	Blue mussel	Cr	mg/kg	1.363	1.684	1.988	2.198	6.435	9	8
RBA	Blue mussel	Cs	mg/kg	0.034	0.037	0.038	0.097	0.388	9	8
RBA	Blue mussel	Cu	mg/kg	10.091	10.446	12.373	13.368	14.953	9	8
RBA	Blue mussel	Dy	mg/kg	0.055	0.107	0.119	0.139	0.178	9	8
RBA	Blue mussel	Er	mg/kg	0.027	0.059	0.064	0.075	0.087	9	8
RBA	Blue mussel	Eu	mg/kg	0.018	0.031	0.036	0.040	0.056	9	8
RBA	Blue mussel	Fe	mg/kg	495.376	1211.566	1325.967	1644.988	2395.762	9	8
RBA	Blue mussel	Ga	mg/kg	0.150	0.273	0.312	0.357	0.837	9	8
RBA	Blue mussel	Gd	mg/kg	0.091	0.135	0.145	0.169	0.275	9	8
RBA	Blue mussel	Hf	mg/kg	0.005	0.030	0.031	0.034	0.039	9	8
RBA	Blue mussel	Hg	mg/kg	0.082	0.093	0.115	0.119	0.129	9	8
RBA	Blue mussel	Ho	mg/kg	0.010	0.021	0.023	0.027	0.032	9	8
RBA	Blue mussel	K	mg/kg	11642.149	14420.230	16101.373	16987.319	17397.323	9	8
RBA	Blue mussel	La	mg/kg	0.656	0.680	0.788	1.186	2.486	9	8
RBA	Blue mussel	Li	mg/kg	0.181	0.207	0.216	0.266	1.434	9	8
RBA	Blue mussel	Lu	mg/kg	0.003	0.007	0.007	0.008	0.010	9	8
RBA	Blue mussel	Mg	mg/kg	2022.534	2913.444	3494.026	3771.836	4264.141	9	8
RBA	Blue mussel	Mn	mg/kg	11.383	28.320	32.375	38.096	42.238	9	8
RBA	Blue mussel	Mo	mg/kg	0.490	0.585	0.631	0.700	0.751	9	8
RBA	Blue mussel	Na	mg/kg	8355.127	10974.970	19500.646	19911.694	25721.065	9	8
RBA	Blue mussel	Nb	mg/kg	0.068	0.147	0.157	0.162	0.369	9	8
RBA	Blue mussel	Nd	mg/kg	0.566	0.584	0.663	0.700	1.839	9	8

RBA	Blue mussel	Ni	mg/kg	3.222	3.623	3.885	4.345	6.749	9	8
RBA	Blue mussel	P	mg/kg	14978.621	15332.061	15953.079	16058.974	16448.447	9	8
RBA	Blue mussel	Pb	mg/kg	0.118	0.123	0.137	0.621	1.004	9	8
RBA	Blue mussel	Pd	mg/kg	0.003	0.004	0.004	0.004	0.005	9	8
RBA	Blue mussel	Pr	mg/kg	0.131	0.135	0.154	0.179	0.488	9	8
RBA	Blue mussel	Pt	mg/kg	<DL	<DL	<DL	<DL	<DL	9	8
RBA	Blue mussel	Rb	mg/kg	6.907	8.152	8.973	9.187	12.058	9	8
RBA	Blue mussel	Re	mg/kg	0.000	0.000	0.000	0.000	0.000	9	8
RBA	Blue mussel	Ru	mg/kg	<DL	<DL	<DL	<DL	<DL	9	8
RBA	Blue mussel	Sb	mg/kg	0.008	0.009	0.010	0.010	0.011	9	8
RBA	Blue mussel	Sc	mg/kg	0.234	0.473	0.515	0.593	1.020	9	8
RBA	Blue mussel	Se	mg/kg	5.760	5.998	6.243	9.031	10.449	9	8
RBA	Blue mussel	Sm	mg/kg	0.100	0.125	0.132	0.155	0.334	9	8
RBA	Blue mussel	Sr	mg/kg	20.872	29.679	32.195	36.114	46.003	9	8
RBA	Blue mussel	Ta	mg/kg	0.001	0.001	0.001	0.002	0.002	9	8
RBA	Blue mussel	Tb	mg/kg	0.010	0.019	0.020	0.024	0.034	9	8
RBA	Blue mussel	Te	mg/kg	<DL	0.004	0.005	0.009	0.012	9	8
RBA	Blue mussel	Th	mg/kg	0.036	0.038	0.044	0.125	0.573	9	8
RBA	Blue mussel	Ti	mg/kg	32.086	131.312	142.749	180.107	204.040	9	8
RBA	Blue mussel	Tl	mg/kg	<DL	<DL	<DL	<DL	0.030	9	8
RBA	Blue mussel	Tm	mg/kg	0.003	0.008	0.008	0.010	0.011	9	8
RBA	Blue mussel	U	mg/kg	0.171	0.181	0.221	0.247	0.272	9	8
RBA	Blue mussel	V	mg/kg	1.523	4.475	4.960	6.324	7.319	9	8
RBA	Blue mussel	W	mg/kg	0.011	0.011	0.013	0.027	0.062	9	8
RBA	Blue mussel	Y	mg/kg	0.386	0.738	0.828	0.962	1.147	9	8
RBA	Blue mussel	Yb	mg/kg	0.021	0.045	0.051	0.057	0.069	9	8
RBA	Blue mussel	Zn	mg/kg	108.973	112.833	113.573	120.260	131.189	9	8
RBA	Blue mussel	Zr	mg/kg	0.310	1.589	1.648	1.833	2.165	9	8
RBA	Crinkled snow lichen	Ag	mg/kg	0.001	0.002	0.003	0.006	0.015	19	17
RBA	Crinkled snow lichen	Al	mg/kg	97.436	163.780	210.924	370.824	479.389	19	17
RBA	Crinkled snow lichen	As	mg/kg	0.049	0.089	0.104	0.307	0.436	19	17
RBA	Crinkled snow lichen	Au	mg/kg	<DL	<DL	<DL	<DL	<DL	19	17
RBA	Crinkled snow lichen	Ba	mg/kg	1.109	1.990	2.898	11.583	17.065	19	17
RBA	Crinkled snow lichen	Be	mg/kg	0.001	0.002	0.005	0.009	0.011	19	17
RBA	Crinkled snow lichen	Bi	mg/kg	0.002	0.004	0.007	0.013	0.026	19	17
RBA	Crinkled snow lichen	Ca	mg/kg	3006.751	4200.736	5567.343	10023.798	21822.741	19	17

RBA	Crinkled snow lichen	Cd	mg/kg	0.040	0.056	0.091	0.144	0.682	19	17
RBA	Crinkled snow lichen	Ce	mg/kg	0.996	1.521	1.909	2.817	5.804	19	17
RBA	Crinkled snow lichen	Co	mg/kg	0.132	0.215	0.365	0.565	0.819	19	17
RBA	Crinkled snow lichen	Cr	mg/kg	0.351	0.484	0.781	1.603	1.978	19	17
RBA	Crinkled snow lichen	Cs	mg/kg	0.030	0.049	0.055	0.198	0.303	19	17
RBA	Crinkled snow lichen	Cu	mg/kg	0.561	0.828	1.126	1.396	1.774	19	17
RBA	Crinkled snow lichen	Dy	mg/kg	0.062	0.107	0.137	0.171	0.228	19	17
RBA	Crinkled snow lichen	Er	mg/kg	0.034	0.052	0.071	0.087	0.113	19	17
RBA	Crinkled snow lichen	Eu	mg/kg	0.018	0.036	0.043	0.054	0.079	19	17
RBA	Crinkled snow lichen	Fe	mg/kg	98.010	166.685	215.478	406.416	542.662	19	17
RBA	Crinkled snow lichen	Ga	mg/kg	0.077	0.100	0.134	0.219	0.329	19	17
RBA	Crinkled snow lichen	Gd	mg/kg	0.078	0.149	0.172	0.224	0.350	19	17
RBA	Crinkled snow lichen	Hf	mg/kg	0.003	0.004	0.007	0.011	0.019	19	17
RBA	Crinkled snow lichen	Hg	mg/kg	0.030	0.035	0.043	0.046	0.050	19	17
RBA	Crinkled snow lichen	Ho	mg/kg	0.012	0.019	0.027	0.032	0.041	19	17
RBA	Crinkled snow lichen	K	mg/kg	1393.780	1693.120	1787.451	1874.894	2188.620	19	17
RBA	Crinkled snow lichen	La	mg/kg	0.480	0.744	0.905	1.408	2.743	19	17
RBA	Crinkled snow lichen	Li	mg/kg	0.015	0.021	0.030	0.145	0.192	19	17
RBA	Crinkled snow lichen	Lu	mg/kg	0.003	0.005	0.008	0.009	0.013	19	17
RBA	Crinkled snow lichen	Mg	mg/kg	885.316	1021.964	1223.299	1603.981	2019.822	19	17
RBA	Crinkled snow lichen	Mn	mg/kg	13.420	24.145	31.559	52.487	134.160	19	17
RBA	Crinkled snow lichen	Mo	mg/kg	0.022	0.030	0.034	0.058	0.072	19	17
RBA	Crinkled snow lichen	Na	mg/kg	264.907	346.539	369.136	469.605	651.763	19	17
RBA	Crinkled snow lichen	Nb	mg/kg	0.016	0.031	0.048	0.068	0.089	19	17
RBA	Crinkled snow lichen	Nd	mg/kg	0.449	0.765	0.968	1.226	2.337	19	17
RBA	Crinkled snow lichen	Ni	mg/kg	0.682	0.914	1.672	2.044	2.565	19	17
RBA	Crinkled snow lichen	P	mg/kg	447.277	498.990	644.646	651.997	719.163	19	17
RBA	Crinkled snow lichen	Pb	mg/kg	0.195	0.257	0.331	0.554	1.028	19	17
RBA	Crinkled snow lichen	Pd	mg/kg	0.001	0.001	0.001	0.002	0.002	19	17
RBA	Crinkled snow lichen	Pr	mg/kg	0.114	0.188	0.231	0.319	0.615	19	17
RBA	Crinkled snow lichen	Pt	mg/kg	<DL	<DL	<DL	<DL	<DL	19	17
RBA	Crinkled snow lichen	Rb	mg/kg	0.859	1.610	2.149	4.153	6.371	19	17
RBA	Crinkled snow lichen	Re	mg/kg	<DL	<DL	<DL	<DL	0.000	19	17
RBA	Crinkled snow lichen	Ru	mg/kg	<DL	<DL	<DL	<DL	<DL	19	17
RBA	Crinkled snow lichen	Sb	mg/kg	<DL	<DL	<DL	<DL	<DL	19	17
RBA	Crinkled snow lichen	Sc	mg/kg	0.090	0.122	0.180	0.201	0.292	19	17

RBA	Crinkled snow lichen	Se	mg/kg	0.069	0.097	0.111	0.130	0.172	19	17
RBA	Crinkled snow lichen	Sm	mg/kg	0.086	0.155	0.191	0.240	0.421	19	17
RBA	Crinkled snow lichen	Sr	mg/kg	9.043	11.667	15.497	21.080	37.174	19	17
RBA	Crinkled snow lichen	Ta	mg/kg	<DL	0.000	0.000	0.001	0.001	19	17
RBA	Crinkled snow lichen	Tb	mg/kg	0.011	0.020	0.024	0.031	0.045	19	17
RBA	Crinkled snow lichen	Te	mg/kg	<DL	<DL	<DL	<DL	<DL	19	17
RBA	Crinkled snow lichen	Th	mg/kg	0.027	0.040	0.052	0.144	0.220	19	17
RBA	Crinkled snow lichen	Ti	mg/kg	12.657	21.291	31.066	38.556	50.746	19	17
RBA	Crinkled snow lichen	Tl	mg/kg	<DL	<DL	<DL	<DL	0.015	19	17
RBA	Crinkled snow lichen	Tm	mg/kg	0.004	0.007	0.009	0.011	0.015	19	17
RBA	Crinkled snow lichen	U	mg/kg	0.010	0.012	0.014	0.063	0.092	19	17
RBA	Crinkled snow lichen	V	mg/kg	0.318	0.519	0.604	1.097	1.362	19	17
RBA	Crinkled snow lichen	W	mg/kg	0.003	0.004	0.005	0.013	0.046	19	17
RBA	Crinkled snow lichen	Y	mg/kg	0.382	0.627	0.846	1.023	1.340	19	17
RBA	Crinkled snow lichen	Yb	mg/kg	0.027	0.040	0.054	0.067	0.094	19	17
RBA	Crinkled snow lichen	Zn	mg/kg	9.079	12.461	14.873	16.181	19.206	19	17
RBA	Crinkled snow lichen	Zr	mg/kg	0.172	0.221	0.336	0.522	0.818	19	17
RBA	Filtered water	Ag	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Filtered water	Al	ug/l	3.042	7.192	11.342	11.763	12.183	3	3
RBA	Filtered water	As	ug/l	<DL	<DL	<DL	0.091	0.183	3	3
RBA	Filtered water	Au	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Filtered water	Ba	ug/l	0.017	0.080	0.142	2.076	4.009	3	3
RBA	Filtered water	Be	ug/l	<DL	<DL	<DL	0.001	0.002	3	3
RBA	Filtered water	Bi	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Filtered water	Ca	ug/l	5952.700	6273.135	6593.569	10930.476	15267.383	3	3
RBA	Filtered water	Cd	ug/l	<DL	<DL	<DL	0.002	0.004	3	3
RBA	Filtered water	Ce	ug/l	0.007	0.009	0.012	0.040	0.069	3	3
RBA	Filtered water	Co	ug/l	0.015	0.016	0.018	0.064	0.110	3	3
RBA	Filtered water	Cr	ug/l	0.132	0.158	0.185	0.219	0.253	3	3
RBA	Filtered water	Cs	ug/l	<DL	0.000	0.001	0.002	0.004	3	3
RBA	Filtered water	Cu	ug/l	0.644	1.062	1.481	1.573	1.665	3	3
RBA	Filtered water	Dy	ug/l	0.002	0.004	0.007	0.010	0.013	3	3
RBA	Filtered water	Er	ug/l	0.001	0.003	0.006	0.006	0.006	3	3
RBA	Filtered water	Eu	ug/l	0.001	0.001	0.002	0.002	0.003	3	3
RBA	Filtered water	Fe	ug/l	11.644	12.942	14.240	55.031	95.822	3	3
RBA	Filtered water	Ga	ug/l	<DL	0.001	0.003	0.008	0.014	3	3
RBA	Filtered water	Gd	ug/l	0.002	0.005	0.007	0.010	0.013	3	3
RBA	Filtered water	Hf	ug/l	0.001	0.001	0.001	0.001	0.002	3	3
RBA	Filtered water	Hg	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Filtered water	Ho	ug/l	0.000	0.001	0.002	0.002	0.002	3	3
RBA	Filtered water	K	ug/l	106.705	169.315	231.926	878.743	1525.560	3	3
RBA	Filtered water	La	ug/l	0.004	0.007	0.011	0.030	0.049	3	3
RBA	Filtered water	Li	ug/l	0.011	0.031	0.051	0.452	0.854	3	3

RBA	Filtered water	Lu	ug/l	0.000	0.001	0.001	0.001	0.001	3	3
RBA	Filtered water	Mg	ug/l	2368.821	2510.546	2652.272	4122.283	5592.293	3	3
RBA	Filtered water	Mn	ug/l	0.604	0.946	1.289	8.904	16.520	3	3
RBA	Filtered water	Mo	ug/l	0.054	0.061	0.068	0.124	0.179	3	3
RBA	Filtered water	Na	ug/l	6551.687	6787.703	7023.719	8358.411	9693.102	3	3
RBA	Filtered water	Nb	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Filtered water	Nd	ug/l	0.007	0.013	0.019	0.040	0.062	3	3
RBA	Filtered water	Ni	ug/l	0.257	0.288	0.319	1.093	1.866	3	3
RBA	Filtered water	P	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Filtered water	Pb	ug/l	<DL	0.005	0.010	0.015	0.020	3	3
RBA	Filtered water	Pd	ug/l	0.001	0.001	0.001	0.002	0.002	3	3
RBA	Filtered water	Pr	ug/l	0.001	0.003	0.004	0.009	0.013	3	3
RBA	Filtered water	Pt	ug/l	<DL	0.002	0.003	0.003	0.003	3	3
RBA	Filtered water	Rb	ug/l	0.043	0.103	0.163	0.554	0.945	3	3
RBA	Filtered water	Re	ug/l	<DL	0.000	0.000	0.000	0.001	3	3
RBA	Filtered water	Ru	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Filtered water	Sb	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Filtered water	Sc	ug/l	0.017	0.017	0.017	0.021	0.025	3	3
RBA	Filtered water	Se	ug/l	0.027	0.042	0.058	0.081	0.104	3	3
RBA	Filtered water	Sm	ug/l	0.002	0.003	0.005	0.009	0.013	3	3
RBA	Filtered water	Sr	ug/l	3.246	5.473	7.699	30.817	53.934	3	3
RBA	Filtered water	Ta	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Filtered water	Tb	ug/l	0.000	0.001	0.001	0.002	0.002	3	3
RBA	Filtered water	Te	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Filtered water	Th	ug/l	0.000	0.000	0.000	0.004	0.007	3	3
RBA	Filtered water	Ti	ug/l	0.140	0.188	0.237	0.349	0.460	3	3
RBA	Filtered water	Tl	ug/l	<DL	0.001	0.002	0.005	0.007	3	3
RBA	Filtered water	Tm	ug/l	0.000	0.000	0.001	0.001	0.001	3	3
RBA	Filtered water	U	ug/l	0.003	0.005	0.007	0.045	0.082	3	3
RBA	Filtered water	V	ug/l	0.203	0.609	1.016	2.143	3.270	3	3
RBA	Filtered water	W	ug/l	<DL	0.003	0.005	0.006	0.007	3	3
RBA	Filtered water	Y	ug/l	0.010	0.035	0.059	0.066	0.073	3	3
RBA	Filtered water	Yb	ug/l	0.001	0.003	0.005	0.006	0.006	3	3
RBA	Filtered water	Zn	ug/l	<DL	<DL	<DL	0.232	0.464	3	3
RBA	Filtered water	Zr	ug/l	0.029	0.035	0.041	0.052	0.062	3	3
RBA	Seaweed	Ag	mg/kg	0.038	0.038	0.039	0.070	0.102	3	2
RBA	Seaweed	Al	mg/kg	249.898	255.105	260.312	1025.257	1790.203	3	2
RBA	Seaweed	As	mg/kg	36.140	38.457	40.774	40.872	40.971	3	2
RBA	Seaweed	Au	mg/kg	0.007	0.008	0.008	0.010	0.012	3	2
RBA	Seaweed	Ba	mg/kg	9.582	9.587	9.592	19.450	29.309	3	2
RBA	Seaweed	Be	mg/kg	0.003	0.003	0.003	0.013	0.022	3	2
RBA	Seaweed	Bi	mg/kg	0.002	0.002	0.002	0.013	0.024	3	2
RBA	Seaweed	Ca	mg/kg	11882.138	11896.427	11910.715	12424.714	12938.712	3	2
RBA	Seaweed	Cd	mg/kg	0.301	0.413	0.524	0.539	0.554	3	2
RBA	Seaweed	Ce	mg/kg	0.317	0.320	0.323	2.532	4.742	3	2

RBA	Seaweed	Co	mg/kg	1.278	1.281	1.284	1.347	1.410	3	2
RBA	Seaweed	Cr	mg/kg	0.572	0.629	0.686	2.971	5.255	3	2
RBA	Seaweed	Cs	mg/kg	0.037	0.037	0.038	0.202	0.366	3	2
RBA	Seaweed	Cu	mg/kg	7.621	7.643	7.664	8.372	9.080	3	2
RBA	Seaweed	Dy	mg/kg	0.059	0.059	0.059	0.129	0.200	3	2
RBA	Seaweed	Er	mg/kg	0.032	0.032	0.032	0.064	0.096	3	2
RBA	Seaweed	Eu	mg/kg	0.019	0.019	0.019	0.038	0.056	3	2
RBA	Seaweed	Fe	mg/kg	439.112	443.196	447.281	1217.913	1988.545	3	2
RBA	Seaweed	Ga	mg/kg	0.103	0.105	0.108	0.431	0.753	3	2
RBA	Seaweed	Gd	mg/kg	0.070	0.071	0.072	0.187	0.301	3	2
RBA	Seaweed	Hf	mg/kg	0.013	0.013	0.014	0.028	0.042	3	2
RBA	Seaweed	Hg	mg/kg	0.005	0.007	0.008	0.008	0.008	3	2
RBA	Seaweed	Ho	mg/kg	0.012	0.012	0.012	0.024	0.036	3	2
RBA	Seaweed	K	mg/kg	25953.693	26088.728	26223.762	32105.918	37988.074	3	2
RBA	Seaweed	La	mg/kg	0.234	0.235	0.237	1.330	2.424	3	2
RBA	Seaweed	Li	mg/kg	0.158	0.159	0.159	0.746	1.333	3	2
RBA	Seaweed	Lu	mg/kg	0.004	0.004	0.004	0.007	0.011	3	2
RBA	Seaweed	Mg	mg/kg	8416.395	8509.236	8602.077	9432.412	10262.746	3	2
RBA	Seaweed	Mn	mg/kg	55.528	55.822	56.116	56.710	57.304	3	2
RBA	Seaweed	Mo	mg/kg	0.170	0.176	0.182	0.190	0.198	3	2
RBA	Seaweed	Na	mg/kg	15302.445	15433.595	15564.746	16843.498	18122.249	3	2
RBA	Seaweed	Nb	mg/kg	0.058	0.061	0.063	0.195	0.327	3	2
RBA	Seaweed	Nd	mg/kg	0.274	0.274	0.274	1.165	2.056	3	2
RBA	Seaweed	Ni	mg/kg	1.856	1.862	1.867	3.037	4.207	3	2
RBA	Seaweed	P	mg/kg	1990.071	2297.161	2604.251	2622.559	2640.866	3	2
RBA	Seaweed	Pb	mg/kg	0.046	0.047	0.047	0.315	0.582	3	2
RBA	Seaweed	Pd	mg/kg	0.024	0.024	0.024	0.025	0.027	3	2
RBA	Seaweed	Pr	mg/kg	0.059	0.060	0.061	0.298	0.536	3	2
RBA	Seaweed	Pt	mg/kg	<DL	<DL	<DL	<DL	<DL	3	2
RBA	Seaweed	Rb	mg/kg	13.705	13.707	13.708	16.129	18.549	3	2
RBA	Seaweed	Re	mg/kg	0.042	0.044	0.047	0.047	0.048	3	2
RBA	Seaweed	Ru	mg/kg	<DL	<DL	<DL	0.000	0.000	3	2
RBA	Seaweed	Sb	mg/kg	0.012	0.013	0.014	0.014	0.014	3	2
RBA	Seaweed	Sc	mg/kg	0.173	0.177	0.181	0.467	0.752	3	2
RBA	Seaweed	Se	mg/kg	0.044	0.044	0.044	0.058	0.071	3	2
RBA	Seaweed	Sm	mg/kg	0.066	0.066	0.067	0.221	0.375	3	2

RBA	Seaweed	Sr	mg/kg	672.571	677.750	682.930	683.283	683.636	3	2
RBA	Seaweed	Ta	mg/kg	0.001	0.001	0.001	0.001	0.001	3	2
RBA	Seaweed	Tb	mg/kg	0.010	0.010	0.010	0.024	0.038	3	2
RBA	Seaweed	Te	mg/kg	<DL	<DL	<DL	0.003	0.005	3	2
RBA	Seaweed	Th	mg/kg	0.012	0.012	0.012	0.280	0.548	3	2
RBA	Seaweed	Ti	mg/kg	43.788	45.537	47.287	125.822	204.357	3	2
RBA	Seaweed	Tl	mg/kg	<DL	<DL	<DL	0.015	0.030	3	2
RBA	Seaweed	Tm	mg/kg	0.004	0.004	0.004	0.008	0.012	3	2
RBA	Seaweed	U	mg/kg	0.830	0.839	0.848	0.862	0.875	3	2
RBA	Seaweed	V	mg/kg	1.824	1.839	1.854	4.163	6.471	3	2
RBA	Seaweed	W	mg/kg	0.005	0.005	0.006	0.018	0.031	3	2
RBA	Seaweed	Y	mg/kg	0.398	0.401	0.404	0.826	1.248	3	2
RBA	Seaweed	Yb	mg/kg	0.026	0.026	0.026	0.052	0.077	3	2
RBA	Seaweed	Zn	mg/kg	16.694	16.888	17.082	18.170	19.258	3	2
RBA	Seaweed	Zr	mg/kg	0.868	0.883	0.898	1.567	2.236	3	2
RBA	Soil	Ag	mg/kg	0.005	0.009	0.013	0.015	0.358	20	17
RBA	Soil	Al	mg/kg	18499.213	32310.205	45653.654	49778.783	70356.612	20	17
RBA	Soil	As	mg/kg	<DL	0.273	0.725	5.394	16.629	20	17
RBA	Soil	Au	mg/kg	<DL	<DL	<DL	<DL	0.004	20	17
RBA	Soil	Ba	mg/kg	28.031	50.574	84.361	174.571	331.901	20	17
RBA	Soil	Be	mg/kg	0.185	0.390	0.474	0.703	2.291	20	17
RBA	Soil	Bi	mg/kg	0.018	0.037	0.053	0.201	0.483	20	17
RBA	Soil	Ca	mg/kg	3665.426	6445.558	10412.358	17221.172	28808.614	20	17
RBA	Soil	Cd	mg/kg	0.080	0.093	0.123	0.210	1.104	20	17
RBA	Soil	Ce	mg/kg	13.094	24.147	32.272	45.048	94.962	20	17
RBA	Soil	Co	mg/kg	9.508	18.003	35.116	42.881	48.828	20	17
RBA	Soil	Cr	mg/kg	13.658	99.369	189.507	251.690	510.860	20	17
RBA	Soil	Cs	mg/kg	0.151	0.379	0.460	2.644	6.048	20	17
RBA	Soil	Cu	mg/kg	18.779	49.180	127.543	190.314	365.365	20	17
RBA	Soil	Dy	mg/kg	0.976	2.115	2.781	3.594	8.126	20	17
RBA	Soil	Er	mg/kg	0.531	1.154	1.543	2.030	4.544	20	17
RBA	Soil	Eu	mg/kg	0.353	0.539	0.782	1.021	2.217	20	17
RBA	Soil	Fe	mg/kg	17079.829	33648.066	55826.049	68296.423	100948.193	20	17
RBA	Soil	Ga	mg/kg	6.019	11.867	14.018	16.017	26.531	20	17
RBA	Soil	Gd	mg/kg	1.428	2.522	3.047	4.313	8.908	20	17
RBA	Soil	Hf	mg/kg	0.444	0.601	0.746	0.919	2.317	20	17

RBA	Soil	Hg	mg/kg	<DL	<DL	0.028	0.055	0.201	20	17
RBA	Soil	Ho	mg/kg	0.187	0.412	0.546	0.719	1.578	20	17
RBA	Soil	K	mg/kg	566.019	1201.686	1844.976	5935.711	9205.982	20	17
RBA	Soil	La	mg/kg	6.441	9.517	13.237	20.247	43.974	20	17
RBA	Soil	Li	mg/kg	3.991	5.557	7.136	22.720	32.653	20	17
RBA	Soil	Lu	mg/kg	0.065	0.142	0.187	0.242	0.558	20	17
RBA	Soil	Mg	mg/kg	4712.930	11258.968	14292.348	21064.539	43009.391	20	17
RBA	Soil	Mn	mg/kg	328.124	488.410	759.294	1054.272	1577.644	20	17
RBA	Soil	Mo	mg/kg	<DL	<DL	<DL	<DL	1.257	20	17
RBA	Soil	Na	mg/kg	454.428	744.319	1510.948	2024.001	4565.746	20	17
RBA	Soil	Nb	mg/kg	<DL	<DL	<DL	0.041	0.065	20	17
RBA	Soil	Nd	mg/kg	6.897	11.259	14.496	18.871	42.910	20	17
RBA	Soil	Ni	mg/kg	27.061	56.485	101.689	158.201	354.784	20	17
RBA	Soil	P	mg/kg	395.753	575.679	800.056	908.234	1177.313	20	17
RBA	Soil	Pb	mg/kg	1.072	2.122	2.853	6.712	17.329	20	17
RBA	Soil	Pd	mg/kg	0.005	0.011	0.019	0.025	0.038	20	17
RBA	Soil	Pr	mg/kg	1.707	2.787	3.461	4.747	10.979	20	17
RBA	Soil	Pt	mg/kg	<DL	<DL	0.007	0.010	0.014	20	17
RBA	Soil	Rb	mg/kg	2.900	6.478	9.369	41.186	82.466	20	17
RBA	Soil	Re	mg/kg	<DL	<DL	<DL	<DL	0.007	20	17
RBA	Soil	Ru	mg/kg	<DL	<DL	<DL	<DL	0.003	20	17
RBA	Soil	Sb	mg/kg	<DL	<DL	<DL	<DL	0.050	20	17
RBA	Soil	Sc	mg/kg	4.427	7.195	10.656	12.444	24.603	20	17
RBA	Soil	Se	mg/kg	<DL	0.087	0.183	0.238	0.771	20	17
RBA	Soil	Sm	mg/kg	1.537	2.523	3.148	4.085	9.091	20	17
RBA	Soil	Sr	mg/kg	26.718	40.649	66.969	136.041	247.470	20	17
RBA	Soil	Ta	mg/kg	<DL	<DL	<DL	0.001	0.003	20	17
RBA	Soil	Tb	mg/kg	0.179	0.370	0.467	0.609	1.370	20	17
RBA	Soil	Te	mg/kg	<DL	<DL	0.014	0.018	0.056	20	17
RBA	Soil	Th	mg/kg	0.623	1.268	1.870	5.125	9.153	20	17
RBA	Soil	Ti	mg/kg	243.927	347.238	401.088	439.491	529.019	20	17
RBA	Soil	Tl	mg/kg	<DL	<DL	<DL	0.241	0.512	20	17
RBA	Soil	Tm	mg/kg	0.073	0.157	0.203	0.276	0.613	20	17
RBA	Soil	U	mg/kg	0.169	0.410	0.552	1.411	3.213	20	17
RBA	Soil	V	mg/kg	44.747	79.190	114.866	157.302	199.141	20	17
RBA	Soil	W	mg/kg	<DL	<DL	<DL	<DL	<DL	20	17

RBA	Soil	Y	mg/kg	4.633	9.946	12.866	16.795	34.839	20	17
RBA	Soil	Yb	mg/kg	0.441	0.977	1.292	1.738	3.852	20	17
RBA	Soil	Zn	mg/kg	63.294	80.076	97.311	107.948	157.593	20	17
RBA	Soil	Zr	mg/kg	11.574	25.062	31.775	38.757	108.389	20	17
RBA	Unfiltered water	Ag	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Unfiltered water	Al	ug/l	6.893	29.876	52.858	717.993	1383.128	3	3
RBA	Unfiltered water	As	ug/l	<DL	<DL	<DL	0.141	0.282	3	3
RBA	Unfiltered water	Au	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Unfiltered water	Ba	ug/l	0.761	0.831	0.900	2.725	4.550	3	3
RBA	Unfiltered water	Be	ug/l	<DL	0.002	0.003	0.007	0.010	3	3
RBA	Unfiltered water	Bi	ug/l	<DL	<DL	<DL	0.001	0.001	3	3
RBA	Unfiltered water	Ca	ug/l	6162.431	6920.636	7678.841	11431.303	15183.766	3	3
RBA	Unfiltered water	Cd	ug/l	0.001	0.002	0.004	0.005	0.006	3	3
RBA	Unfiltered water	Ce	ug/l	0.019	0.133	0.247	0.362	0.478	3	3
RBA	Unfiltered water	Co	ug/l	0.019	0.103	0.187	0.833	1.479	3	3
RBA	Unfiltered water	Cr	ug/l	0.109	0.153	0.198	0.969	1.741	3	3
RBA	Unfiltered water	Cs	ug/l	0.001	0.002	0.003	0.007	0.011	3	3
RBA	Unfiltered water	Cu	ug/l	1.504	1.719	1.934	2.864	3.795	3	3
RBA	Unfiltered water	Dy	ug/l	0.009	0.017	0.024	0.049	0.074	3	3
RBA	Unfiltered water	Er	ug/l	0.007	0.010	0.013	0.027	0.042	3	3
RBA	Unfiltered water	Eu	ug/l	0.003	0.005	0.007	0.016	0.026	3	3
RBA	Unfiltered water	Fe	ug/l	22.540	134.793	247.047	742.092	1237.137	3	3
RBA	Unfiltered water	Ga	ug/l	0.005	0.012	0.019	0.178	0.337	3	3
RBA	Unfiltered water	Gd	ug/l	0.010	0.019	0.029	0.055	0.081	3	3
RBA	Unfiltered water	Hf	ug/l	0.001	0.002	0.003	0.003	0.004	3	3
RBA	Unfiltered water	Hg	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Unfiltered water	Ho	ug/l	0.002	0.003	0.005	0.010	0.015	3	3
RBA	Unfiltered water	K	ug/l	141.953	190.909	239.866	885.486	1531.107	3	3
RBA	Unfiltered water	La	ug/l	0.015	0.073	0.132	0.157	0.182	3	3
RBA	Unfiltered water	Li	ug/l	0.052	0.074	0.096	0.495	0.893	3	3
RBA	Unfiltered water	Lu	ug/l	0.001	0.001	0.002	0.003	0.004	3	3
RBA	Unfiltered water	Mg	ug/l	2747.379	3421.265	4095.150	4800.902	5506.654	3	3
RBA	Unfiltered water	Mn	ug/l	0.715	10.737	20.759	24.454	28.149	3	3
RBA	Unfiltered water	Mo	ug/l	0.029	0.035	0.041	0.095	0.148	3	3
RBA	Unfiltered water	Na	ug/l	6690.204	7056.943	7423.682	8442.623	9461.564	3	3
RBA	Unfiltered water	Nb	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Unfiltered water	Nd	ug/l	0.025	0.088	0.152	0.234	0.317	3	3
RBA	Unfiltered water	Ni	ug/l	0.261	1.123	1.985	7.006	12.027	3	3
RBA	Unfiltered water	P	ug/l	<DL	1.985	3.970	14.239	24.509	3	3
RBA	Unfiltered water	Pb	ug/l	<DL	0.011	0.023	0.033	0.044	3	3
RBA	Unfiltered water	Pd	ug/l	0.001	0.001	0.001	0.001	0.002	3	3
RBA	Unfiltered water	Pr	ug/l	0.005	0.019	0.033	0.050	0.066	3	3
RBA	Unfiltered water	Pt	ug/l	<DL	<DL	<DL	0.002	0.003	3	3
RBA	Unfiltered water	Rb	ug/l	0.125	0.140	0.156	0.602	1.047	3	3
RBA	Unfiltered water	Re	ug/l	0.000	0.000	0.000	0.000	0.001	3	3
RBA	Unfiltered water	Ru	ug/l	<DL	<DL	<DL	<DL	<DL	3	3

RBA	Unfiltered water	Sb	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Unfiltered water	Sc	ug/l	0.013	0.026	0.039	0.060	0.080	3	3
RBA	Unfiltered water	Se	ug/l	0.028	0.038	0.047	0.059	0.070	3	3
RBA	Unfiltered water	Sm	ug/l	0.010	0.022	0.034	0.057	0.079	3	3
RBA	Unfiltered water	Sr	ug/l	7.192	7.587	7.982	30.675	53.369	3	3
RBA	Unfiltered water	Ta	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Unfiltered water	Tb	ug/l	0.001	0.003	0.004	0.008	0.012	3	3
RBA	Unfiltered water	Te	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Unfiltered water	Th	ug/l	0.000	0.001	0.002	0.008	0.014	3	3
RBA	Unfiltered water	Ti	ug/l	0.261	1.628	2.996	8.399	13.803	3	3
RBA	Unfiltered water	Tl	ug/l	<DL	0.001	0.003	0.005	0.007	3	3
RBA	Unfiltered water	Tm	ug/l	0.001	0.001	0.002	0.003	0.005	3	3
RBA	Unfiltered water	U	ug/l	0.004	0.009	0.015	0.053	0.090	3	3
RBA	Unfiltered water	V	ug/l	0.425	0.734	1.044	2.862	4.681	3	3
RBA	Unfiltered water	W	ug/l	<DL	<DL	<DL	<DL	<DL	3	3
RBA	Unfiltered water	Y	ug/l	0.074	0.108	0.141	0.278	0.415	3	3
RBA	Unfiltered water	Yb	ug/l	0.007	0.008	0.010	0.022	0.034	3	3
RBA	Unfiltered water	Zn	ug/l	<DL	0.377	0.753	1.627	2.501	3	3
RBA	Unfiltered water	Zr	ug/l	0.043	0.066	0.089	0.130	0.171	3	3

Appendix 3 Update of contamination levels in mussels at Maarmorilik

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Previous environmental monitoring and research activities have found elevated concentrations of lead in mussels in the Maarmorilik fjord of the former lead/zinc mine as a result of mining (Søndergaard et al. 2019). In Greenland, mussels are often collected for human consumption. Elevated concentrations of lead in food can pose a risk to human health. The risk can be assessed by comparing the levels found in the mussels with the maximum accepted lead concentration in the Greenlandic diet. For mussels, this level is set to 1.5 mg/kg wet weight (EU 2011). Since the average dry weight percentage in the mussels is approx. 15% (Johansen et al. 2008), the maximum accepted lead level is equal to approx. 10 mg/kg on a dry weight basis.

The map below (Figure 1) is based on environmental monitoring in 2007 (Johansen et al. 2008) and shows the marking of the area where it is not recommended to collect mussels for human consumption. This corresponds to an area that extends to approx. 15 km on the north side off the mine. Data given in the map are mg/kg dry weight.

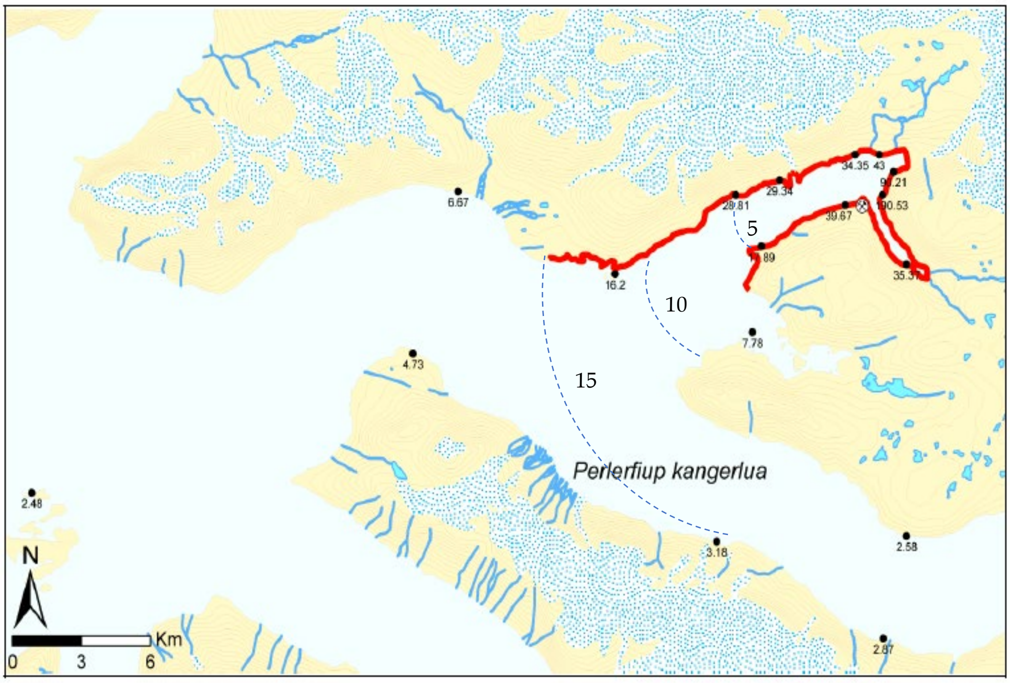

Figure 1. Map of the results of the 2007 monitoring. The red marking shows the area where it is not recommended to collect mussels for human consumption. The three dashed lines indicate the distance to the mine, i.e., 5, 10 and 15 km.

In the latest published work (2017) from the area, mussel lead concentrations were measured to 23, 28 and 80 mg/kg dry weight at three stations along a gradient from the mine site (Søndergaard et al. 2019). These results indicate that no significant change in pollution levels have occurred since 2007, but the 2017 survey did not have the same spatial resolution as in 2007 and is therefore unsuitable for a map update.

Further, the metal analyses forming the basis of the investigations so far were carried out on the entire soft part of the mussel, including the intestines, and therefore include whatever sediments, algae etc. present. However, it is normal practice that mussels are depurated (intestines emptied) before consumption to avoid sand grains while eating. Quality criteria in relation to mussels as food items are also based on mussel depuration (EU 2011; CEMP 1999; JAMP 2008).

In 2021, DCE recommended that international and Danish guidelines are followed in environmental monitoring studies in Greenland. Thus, for mussels, depuration before analyses is recommended as the gut content (sediments, algae etc.) of the mussels is assumed to consist of particles with a variable content of metals and as the content of metals in the gut is not an expression of the accumulated content of metals in the biomass of the mussel. How much sediment, algae etc. the mussels contain depends on, among other things, wave action stirring up the sediment in the intertidal zone and whether the mussels are collected on the beach or on rocks. The purpose of the depuration is thus also to correct for, e.g., weather and sampling time and site.

For practical reasons and to ensure historical comparability, environmental samples of mussels from Maarmorillik have so far not been depurated. This study undertakes a comparison of the metal content in depurated and non-purified mussels from the same stations, and the results are expected to show a continuation of the existing historical time trend when switching to depuration of mussels in monitoring studies.

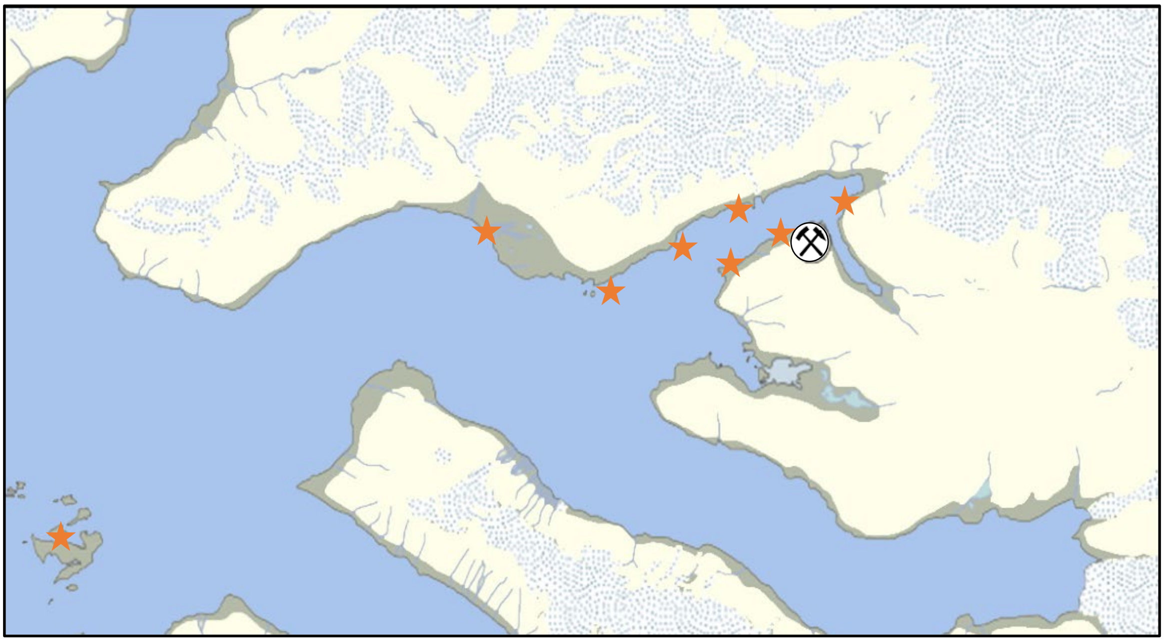

Figure 2. Map of the sampling sites in the 2022 monitoring studies.

In Greenland, the growth of mussels is limited compared to temperate conditions, and a 5 cm mussel is expected to be 5 years or older. Thus, a size-dependent relationship to the metal content is expected, and it is possible that mussel size should be included in the updated recommendations for mussel consumption.

In August 2022, three different size groups of mussels were sampled at 10 stations along a previously set pollution gradient from the mine (see the map in Figure 2). One set of mussels was depurated, while another was frozen immediately after sampling. Chemical analyses will be conducted in spring 2023, and the results will be used to A) update knowledge about lead and other metal concentrations in mussels at Maarmorilik in relation to human consumption relative to the last environmental monitoring, B) investigate whether mussel size and/or age has an effect on metal concentrations and, thereby, the recommendations for human consumption and to C) uncover the significance of the recommendations for the depuration of mussels compared to previous recommendations where mussels are not depurated.

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Appendix 4 Land cover classification

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The land cover classification for this report is based on satellite images captured by the Sentinel-2 satellites. These satellites collect data in 13 different spectral bands at various spatial resolutions (Table 1), and such a multispectral dataset is suitable for separating different land covers from each other. The product used here is atmospherically corrected (Level-2A). The whole classification framework was carried out in the cloud-computing environment, Google Earth Engine.

*Table 1. Sentinel 2 spatial and spectral resolution. *not used in this study.*

Band # and description	Centre wavelength (nm)	Bandwidth (nm)	Spatial resolution (m)
B1 Coastal aerosol*	443	20	60
B2 Blue	490	65	10
B3 Green	560	35	10
B4 Red	665	30	10
B5 Red-edge 1	705	15	20
B6 Red-edge 2	740	15	20
B7 Red-edge 3	783	20	20
B8 NIR	842	115	10
B8A Narrow NIR	865	20	20
B9 Water vapour*	945	20	60
B10 Cirrus*	1374	30	60
B11 SWIR 1	1610	90	20
B12 SWIR 2	2190	180	20

The model used for this land cover classification is very similar to the one described in Rudd et al. (2021). This framework analyses a time series of images to capture the seasonal changes of each pixel within the area of interest. In this case, all images taken from 01-05-2022 to 01-10-2022 were included. A preprocessing algorithm filters the dates and further masks out pixels that are flagged as cloud contaminated.

The final land cover map is constructed from four different layers in a hierarchical order.

1. Snow and Ice
2. Water
3. Bare rock and soil
4. Supervised classification (Random forest)
    a. Fell field
    b. Dwarf shrub heath
    c. Lichen-rich dwarf shrub heath
    d. Fen

This produces a map, where each pixel is assigned one of the seven classes.

The top layer consists of areas mapped as snow and ice. This algorithm examines all images captured between 1 June 2022 and 31 August 2022 and categorised whether each pixel is considered snow-covered or not. For a pixel to be considered snow covered it has to meet three criteria:

Normalized Difference Snow Index > 0.42
NIR band > 0.15
Green band > 0.28

If a pixel is considered snow covered in 80% of all the observations in this period, then it will be classified as snow/ice in the final map.

The second layer is made with a water algorithm, which detects water-covered areas. This algorithm consists of two steps, first is an analysis of the Normalized Difference Water Index (NDWI) to detect whether a pixel could be possible water covered or not. For a pixel to be considered water covered, its mean NDWI value has to be > 0. Secondly, since water and shadows from mountains have very similar spectral signatures, this framework includes an analysis to differentiate these areas from each other. This is done with a hill shadow algorithm, which detects areas that could be possible shadows based on a digital elevation model and the angle of the sun. If a pixel is considered possible water but is spatially located in a shadow area, then it will be excluded from the final water layer.

The third layer consists of all barren areas, which do not fall into the category of either snow or water. This is done through an analysis of the Normalized Difference Vegetation Index (NDVI), where the algorithm finds the maximum NDVI value for each pixel throughout the time series (Figure 1). If a pixel has a maximum NDVI value lower than 0.07, then it is classified as "Barren rock or soil".

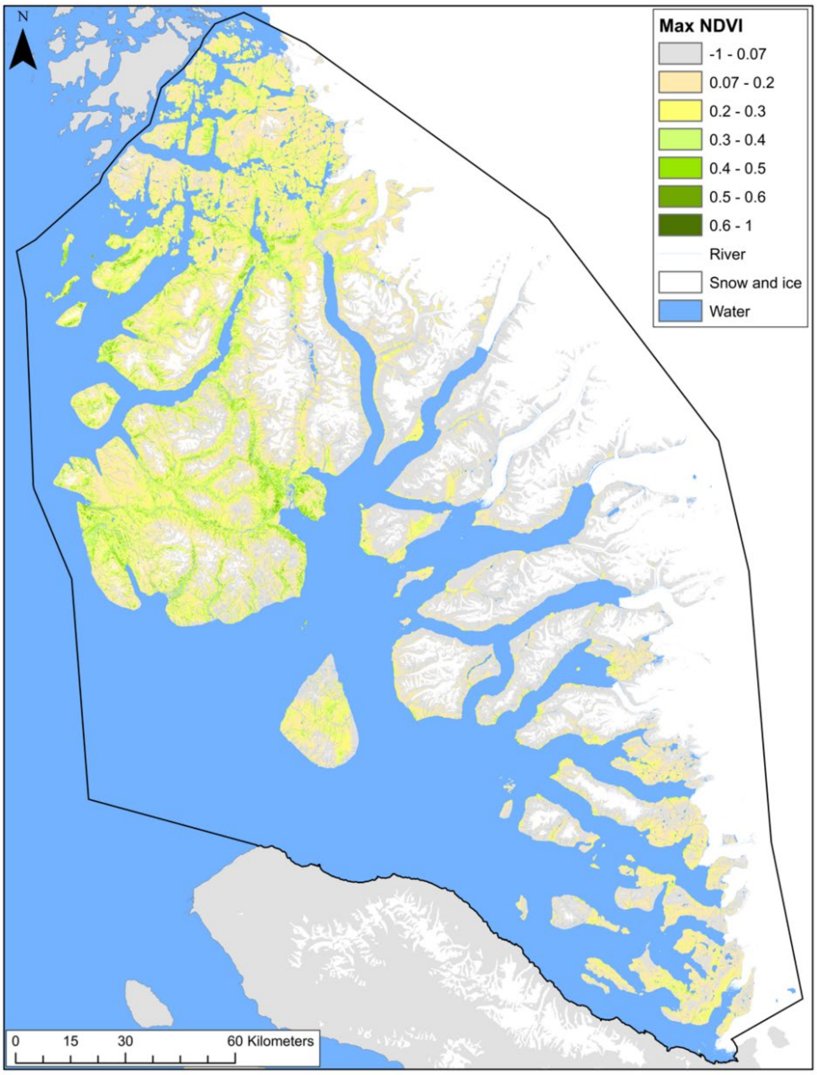

Figure 1. Max NDVI of each pixel in the period from 1 May 2022 to 1 October 2022.

After the snow, water, and barren areas are excluded, then the remaining areas will each be classified into one of the four land cover classes documented during the field campaign. This part of the framework starts with an algorithm to isolate the growing season of the individual pixels based on their NDVI values throughout the period. With the growing season isolated, then several remote sensing indices are calculated, from where features are extracted to be used as input for the classification. A digital elevation model is also included to obtain information about the topographical features. This process creates a total of 79 stacked features that form the basis for the classification. A Random Forest classifier, which is a supervised machinelearning algorithm, is trained by applying the ground truth points collected during the field survey in 2022 (Table 2).

Table 2: Ground truth points collected during the field campaign.

Vegetation class	Number of observations
Fell field	27
Dwarf shrub heath	34
Lichen-rich dwarf shrub heath	30
Fen	4

The Random Forest classifier was able to reach an overall accuracy of 83.2%, which is considered good. This indicates that the final land cover map (Figure 2) is trustworthy. A spatial analysis of the area of interest reveals the proportions of the terrestrial land covers (Table 3), excluding water and snow.

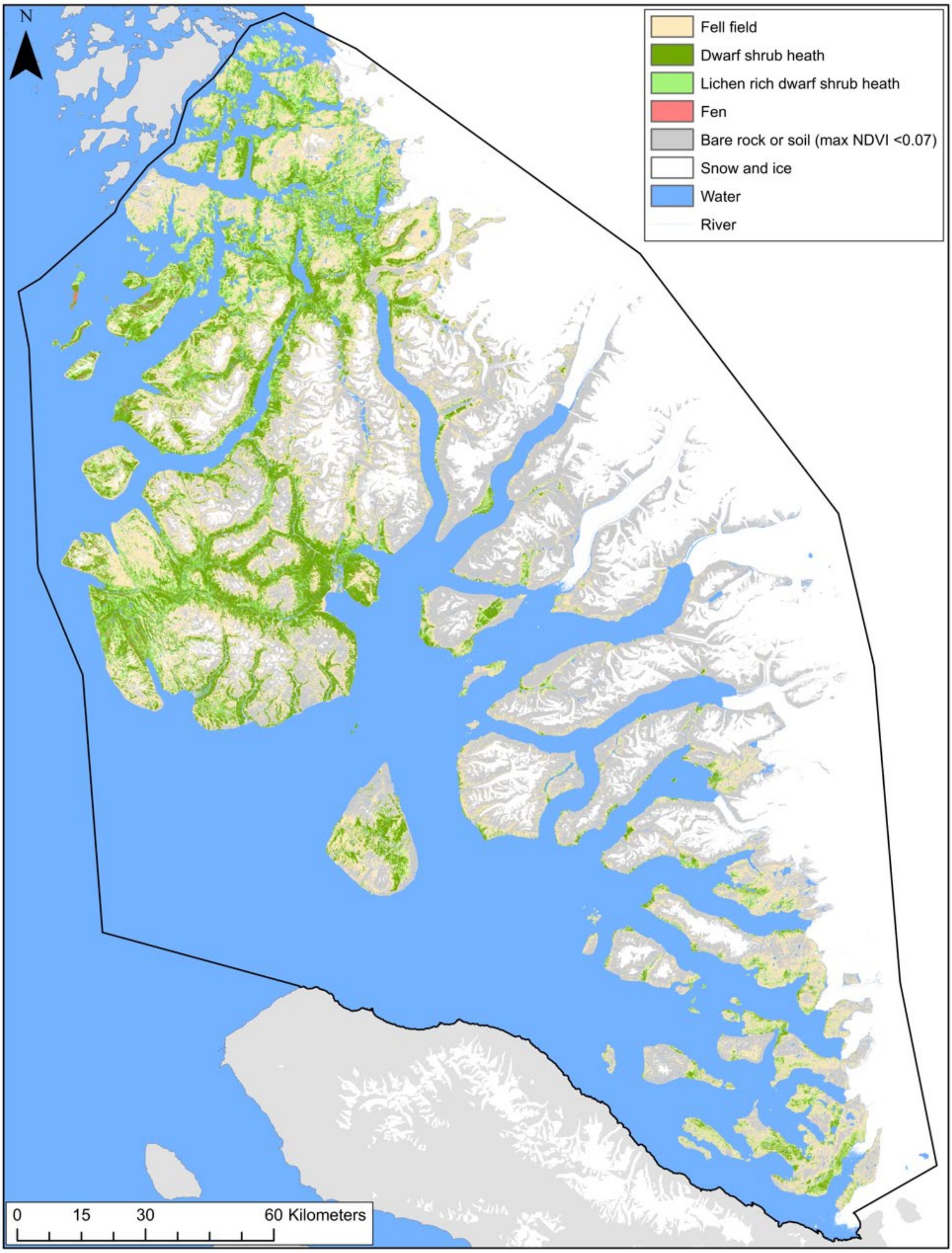

Figure 2. Final land cover map of the area of interest.

Table 3: The proportion of land cover within the area of interest (excluding water and snow).

Land cover class	Coverage in %
Fell field	32.2%
Dwarf shrub heath	17.2%
Lichen-rich dwarf shrub heath	11.0%
Fen	0.5%
Bare rock or soil (max NDVI <0.07)	39.2%

It should be mentioned that the number of fen ground truth points is very low and thereby provides the supervised classifier with limited information about this specific land cover. This could ultimately result in an underestimation of this class in the final map. However, since limited areas of fen were found during the field campaign, it might simply reflect that this land cover is occurring substantially less than the remaining land cover classes.

Moreover, this classifier is designed to assign each pixel to one of the classes by which it is trained. Other land cover types might be present within the area of interest but not found at the locations of the fieldwork. In such cases, these areas would be assigned to the class that they are most similar to.

To obtain more in-depth information about this classification framework, we refer the reader to Rudd et al. (2021).

Reference

Rudd, D.A., Karami, M. & Fensholt, R. 2021. Towards high-resolution land-cover classification of Greenland: A case study covering Kobbefjord, Disko and Zackenberg. Remote Sensing 13: 3559. https://doi.org/10.3390/rs13183559

UUMMANNAP KANGERLUA AND SIGGUUP NUNAA (SVARTENHUK) – REGIONAL ENVIRONMENTAL BASELINE ASSESSMENT FOR MINING ACTIVITIES

This regional environmental baseline assessment of mining activities in Uummannap Kangerlua and Sigguup Nunaa (Svartenhuk) is based on a project idea developed between Environmental Agency for Mineral Resource Activities (EAMRA), Greenland Institute of Natural Resources (GINR) and Danish Centre for Environment and Energy, Aarhus University (DCE/AU). The purpose of the project is to provide a basis for supporting environmentally sound planning and regulation of mining activities by summarising existing regional background information supplemented with new studies and making these results operational and easily accessible.

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