ONSHORE SEISMIC SURVEYS IN GREENLAND

Background information for preparation of Guidelines to Environmental Impact Assessment

Technical Report from DCE – Danish Centre for Environment and Energy No. 161 2020

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Data sheet

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Abstract: Onshore seismic surveys are carried out on land in search for hydrocarbon deposits below ground. Seismic surveys can cause damages to the vegetation, permafrost and landscape as well as disturb wildlife. This report contributes to the background information required to develop guidelines for how to conduct terrestrial seismic surveys in an environmentally responsible fashion.

Keywords: Seismic survey, hydrocarbon, oil, environmental effects, vegetation, terrain, environmental impact assessment, guidelines.

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Preface

These recommendations were requested by EAMRA in email on 7th February 2018 (EAMRA - ID no.: 770102-0030). As requested the recommendations are delivered in the format of draft guidelines. However, the administrative setup in the Greenland administration is only tentatively indicated and should be further addressed by EAMRA.

High Arctic landscape from Zackenberg area, Greenland. Photo: Line A. Kyhn.

Eqikkaaneq

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Pristine Arctic landscape in Northeast Greenland. Photo: Line A. Kyhn.

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Summary

This report contributes to the background information required to develop guidelines for how to conduct terrestrial seismic surveys in an environmentally responsible fashion. The report contains seven chapters that are briefly summarized in the following.

Ch. 1. Seismic surveys are conducted to examine hydrocarbon deposits deep below the surface of the Earth. There are a number of techniques to perform them, but generally a signal is transmitted into the ground and the resulting echoes and reflections are picked up by hydrophones placed on the surface. These reflections and echoes are hereafter analyzed. Seismic surveys may be carried out as 2D, 3D or 4D, which reflects the grid size and time dimension.

The techniques used to day are either a seismic vibrator, i.e. vibroseis, or explosives. Vibroseis are conducted by heavy trucks that vibrates a plate to the ground to project a low frequency signal downwards. The signal is then reflected and refracted before it returns to the surface and is recorded with geophones placed on the ground. Geophones can be wireless or inter-connected. When explosives are used, small amounts are ignited app. 4-10 m below the surface to create the low frequency signal. The reflected / refracted signal is recorded by geophones.

Ch. 2. Effects on the environment depends on the chosen method and on the time of year the survey is conducted. It is however often conducted with very large and heavy trucks, which can leave large imprints in the landscape by damaging the vegetation and the organic crust, whereby permafrost and hydrology can be altered leading to erosion and terrain damages such as thermokarsts and subsidences. Such disturbances can persist in the Arctic for over 70 years or disappear slowly with time. Seismic surveys can also cause strong disturbance reactions in wildlife and birds.

Ch. 3 and 4. Terrestrial seismic surveys were conducted in Jameson Land, East Greenland, in the 1980ies. The surveys were conducted both summer and winter. A number of environmental investigations as well as monitoring were conducted prior to, during and following the seismic surveys. The results of these are part of the foundation for the recommendations for mitigation proposed in this document. A number of possibilities exist whereby the disturbances may be decreased, which pertain to type of vehicle and season; amount of snow and hardness of the ground (frozen).

Ch. 5. The purpose of developing guidelines is to minimize the negative effects on the environment. DCE / GN recommends in this report that an Environmental Impact Assessment (EIA), alternatively an Environmental Mitigation Assessment (EMA) is carried out during the application process for conducting terrestrial seismic surveys. It is also recommended to conduct baseline studies in order to evaluate the adequate measures necessary to ensure as small as possible negative effect on the environment.

Ch. 6 and 7. A number of publications exists on the subject, which is reviewed a long with an overview of the background reports of the Greenland studies.

Sammenfatning

Sammendrag af baggrundsinformation om seismiske undersøgelser på landjorden

Denne rapport bidrager til baggrundsinformationen for at kunne udarbejde retningslinjer for, hvordan man miljømæssig forsvarligt kan udføre seismiske undersøgelser på landjorden. Dokumentet indeholder syv kapitler, der kort resumeres i det følgende.

Kap 1. Seismiske undersøgelser udføres, når der skal undersøges for kulbrinteforekomster i undergrunden. Der findes forskellige teknikker til disse undersøgelser. For alle gælder, at der sendes et signal ned i jorden, refleksioner opfanges og analyseres. Seismiske undersøgelser kan gennemføres i 2D-, 3D- eller 4D-former.

De teknikker, der anvendes i dag, er enten seismisk vibrator (vibroseis) eller sprængstof. Vibroseis består af en meget tung plade, der bringes til at vibrere. Pladen sender et lavfrekvent signal ned i jorden, det reflekteres og opfanges af en stribe geofoner, der er placeret på jorden i lange kabler eller koblet trådløst. Ved anvendelse af sprængstof sprænges små mængder i de øverste ca. 10 m af jorden og det reflekterede signal fra undergrunden opfanges af geofoner, der er placeret på jorden.

Kap. 2. Påvirkninger på miljøet afhænger af, hvilke metoder der anvendes og hvornår på året seismikken udføres. Der er dog ofte tale om meget store og tunge kørertøjer, der sætter store aftryk i landskabet ved at beskadige vegetation og det organiske lag, hvorved permafrost og vandafstrømningsforhold ændres. Smeltet permafrost kan føre til thermokarsts og sammenskred. Sådanne forstyrrelser kan i Arktis bestå i over 70 år eller forsvinde med tiden. Der er også ofte tale om kraftige forstyrrelser af fugle- og dyrevildt.

Kap. 3 og 4. Der er tidligere gennemført seismiske undersøgelser i Jameson Land i Østgrønland. Disse undersøgelser foregik både om sommeren og om vinteren. Både før, under og efter de seismiske undersøgelser blev der foretaget miljømæssige undersøgelser og overvågning. Resultaterne herfra er en del af grundlaget for anbefalinger om afbødende foranstaltninger i forbindelse med seismiske undersøgelser. Der findes i dag en række tiltag for at mindske effekterne af undersøgelserne. Det berører blandt andet køretøjstyper, snelagets tykkelse, jordens hårdhed (frossen) og årstid.

Kap. 5. Formålet med at udvikle retningslinjer er, at minimere påvirkninger af undersøgelserne på naturen. DCE / GN anbefaler i nærværende rapport, at der skal udarbejdes en 'Vurdering af Virkninger på Miljøet' (VVM, eng. EIA) – alternativt en 'Vurdering af Afbødende effekter på Miljøet' (eng. EMA) – når der ansøges om at gennemføre seismiske undersøgelser på land. Samtidig anbefales det, at selskabet skal udføre basisundersøgelser, således at man kan vurdere, hvilke pålæg der er nødvendige for at opnå en tilpas lille påvirkning.

Kap. 6 og 7. Der eksisterer en række publikationer om emnet. Her er samlet væsentlig litteratur samt en oversigt over baggrundsrapporter fra de grønlandske undersøgelser.

1 Introduction to terrestrial seismic surveys

This document provides information necessary for preparing guidelines for seismic surveys on land in Greenland. The document consists of an introductory chapter on the seismic operations, followed by a chapter on the environmental impacts of the methods, a chapter summarizing past experiences with seismic surveys in Jameson Land in the 1980'es, a chapter with suggestions for mitigation actions, and ends by recommending a concept for seismic exploration in Greenland based on experiences from Jameson Land in East Greenland and Arctic America (Yukon and Alaska). In the latter area there are decades of experience with regulation of seismic surveys.

1.1 Background

Seismic surveys are carried out to search for subsurface hydrocarbon deposits using sound projected towards the center of the Earth, and the sound source when surveying on land, is usually either a heavy vibrator or explosives.

1.2 Performance of seismic surveys on land

Hydrocarbon deposits have formed in sedimentary basins up to hundreds of millions of years ago by deposition of organic matter from which hydrocarbons has been generated ((Levy, 2015). Seismic surveys utilize that different rock layers and underground structures vary in density, and this means that the rock layers have different sound propagation properties. Transitions between the layers results in reflections and refractions of the received signal, and some of the signal energy is reflected back to the surface used in reflection seismics. In refraction seismics the focus is instead on the refracted signal. Depending on the density of the rock, some layers will provide stronger reflections than other layers. The reflections or pattern of reflections may disclose the depths at which sedimentary basins with hydrocarbons can be located. The reflections from the different subsurface structures are collected by receivers (geophones) placed in / on the surface (Evans, 1997). The data recorded from one signal (shot) at one geophone position is called a seismic trace. Seismic traces from several geophones and shots are then combined to form a map of the underground layers and structures. The depth of the different layers and structures can be calculated from the known speed of sound, the signal emission time and the reflection reception time.

Seismic surveys can be applied as 2D, 3D and 4D mode. 2D seismic surveys are extensive, performed along wide-spread lines with several km between lines and they may not even cross each other. 2D surveys are used to obtain a first view of the prospects of potential hydrocarbon deposits in an area. 3D surveys are intense with survey lines placed close together in grids, separated by few meters only (usually some 10ths m between), depending on the required resolution of the imagery. 3D seismics are applied to locate drill sites. 4D seismics takes time in to account, which means that the same area is assessed at different time intervals meanwhile the hydrocarbon deposits are being utilized. 4D seismics assess the remaining capacity of the hydrocarbon deposit.

Winter seismic survey in Jameson Land in the 1980ies. Photo: Christian Glahder.

1.3 The vibrator techniques

The vibrator technique is usually termed as Vibroseis and it is based on a heavy truck vibrating a baseplate that is connected to the ground. On top of this baseplate is mounted a heavy weight (a 'hold down') that presses the plate onto the ground. The vibrating plate hereby emits a low frequency signal (4-80 Hz) into the ground, called a sweep (Dean, 2016). The sweep can consist of different frequencies and vary in length. The sweep is compressed in to a short reflection pulse by a compressor. The signal energy can be increased by using several vibrators or by increasing the signal duration. The vibrator vehicle moves slowly along the pre-determined lines using GPS for navigation. It stops, emits a signal 8-20 seconds long, moves some 10 meters ahead, stops, emits a signal and so on (Dean, 2016). It is a slow process to cover a large area and many techniques have been developed to increase the efficiency. This includes using several transmitting trucks that moves in line or along parallel lines and either takes turn 'shooting' of shoots simultaneously. These methodologies serve to decrease waiting time (the slip time) and to increase the signal-to-noise ratio in the returning reflections. For example using three trucks in parallel can decrease the waiting time to zero using the so-called slip-sweep technique, where one truck is firing while the others are moving. This technique creates a single sweep in the final reflections and therefore increases the signal-to-noise ratio as well (Winter et al., 2014). However, the technique also increases the load and wear on the vegetation. Some techniques use up to 18 trucks at a time to increase efficiency, however unfortunately this technique does not decrease the total number of kilometers of tracks, which is a problem with respect to impacts on the vegetation and terrain.

Unwanted tracks from off-road driving. Photo David Boertmann.

The efficiency of seismic surveys is also dependent on the amount of geophones used and how they are placed with respect to the vibrator. The finer the grid of geophones, and the more that are included, the better the resolution of the recorded signal. Geophones can be deployed interconnected with cables or wireless. Wireless geophones are called ‘nodes’. Nodes can be deployed by foot, trucks, drones or helicopters depending on the chosen system (Dean et al., 2018). In 2018 the greatest challenge to the wireless technology is battery life and recharge time ‘en route’.

The received signals from a survey will afterwards be integrated into a model of the subsurface structures (see for example (Trupp et al., 2009).

1.4 Explosives

Explosives were the original method to create a signal strong enough to create reflections of sufficient signal-to-noise ratio to assess the different subsurface layers. Explosives are still used for example in areas inaccessible to trucks. The seismic signal is here created by detonating dynamite in a shothole drilled into the crust often about 10 m deep with a diameter 5-10 cm. The type of dynamite used has been refined especially for seismic surveys to increase the signal bandwidth and the timing of the signal. The important point using explosives is the transfer of energy downwards. The better the shothole is closed off by stamping on top, the less energy is lost, and the better the signal-to-noise ratio of the returning reflection (Levy, 2015). Therefore, the speed at which a hole can be drilled limits the production rate, whereas in vibroseis the long time to increase energy content and the waiting time limits production rate.

The explosive used is often nitroglycerin in gelatin capsules kept in a plastic container that is ignited via a wire (Levy, 2015), and therefore every explosion leaves ignition wires and plastic behind. Generally the clean up after operations is labor intensive (Levy, 2015). The shothole can be hand-drilled, drilled with hammer-drills mounted on heavy trucks or with drill rigs transported by helicopters depending on the ground properties and environmental concerns. Drilling fluids may be used to ease and increase drilling speed. The shothole itself is usually only causing minor impact to the vegetation. However, sometimes the energy goes upwards and creates a crater 1-4 m in diameter.

2 Environmental concerns from terrestrial seismic surveys

The most important environmental impacts of seismic surveys on land include: Damage of vegetation, soil and terrain and disturbance of wildlife. If not properly regulated and mitigated these impacts can be comprehensive and long lasting. Moreover the activities are energy consuming to a high degree, and emission of greenhouse gasses from a large survey can consequently be considerable.

Other effects of such surveys can be attraction of predators such as ravens, foxes, wolfs and polar bears to camps where they can find garbage and food. Further, seismic activities may lead to dispersion of non-native plant species, which may have invasive properties.

Aesthetic changes of terrain or landscape can be important in areas with tourism as a landscape with tracks, disrupted riverbanks, dead vegetation or a lack of natural fauna will alter the experience of a pristine environment – a perception central for tourism in Greenland.

Some areas are of course more sensitive to impacts from seismic surveys than other areas. As seismic surveys can impact rare vegetation or plants or displace wildlife, there is a risk of reduced biodiversity temporarily or in rare cases permanently. Knowledge of the area in question and its fauna and flora composition along with adequate mitigation is therefore necessary in order to protect biodiversity during seismic surveys. On the other hand, with regulation and proper mitigation, damages at an ecosystem level seems unlikely.

2.1 Potential impacts to the arctic vegetation from vibroseismics

The trucks used for vibroseis surveys are very heavy and impact the vegetation as they drive along. Also, the placement of geophones which may be inter-connected with very long cables can cause damages if deployed by trucks, as opposed to helicopters. It is also important to consider that supporting activities to the seismic surveys can induce physical impacts, for example where surface disturbance is concentrated e.g. foot traffic around a landing site, off-runway landings by wheeled aircrafts, waves from boat traffic, or repeated vehicle crossing over a river at the same site. Driving on a thick snow cover or prepared compacted snow roads will decrease the damages to the vegetation and landscape (see chapter 4).

2.1.1 Arctic plant growth

Arctic plant communities generally consist of fewer species than plant communities at lower latitudes (Bilings and Mooney, 1968), and these species are specifically adapted to the extreme conditions of the Arctic with low temperatures, a short growing season and nutrient depleted soil (see table 1). The arctic species are all characterized by being able to metabolize, grow and reproduce at temperatures just above freezing, however they grow very slowly and may take many years to reach the reproductive stage because of the short growing season (Bilings and Mooney, 1968; Billings, 1987). The growth rate in some species is higher than in temperate regions, however for a very short period of time, which means that the species during the growing season are more restricted by availability of nutrients and light if covered by snow (Cooper et al., 2011), than the low temperature in itself (Chapin, 1983). Some species may even survive being buried under snow for 1½ years (Billings, 1987). Arctic soils are generally nutrient deficient (Bilings and Mooney, 1968; Ulrich and Gersper, 1978) and plants respond to experimental addition of fertilizers by increasing the biomass both above and below ground (Jonasson et al., 1999). One reason for the limitation of nutrients is that the source of nutrients – the decomposing organic material - is frozen during the majority of the year (Billings, 1987; Chapin, 1983) and then taken up by microbes when the soil thaws during spring (Jonasson et al., 1999). This means that nutrients released from dead organic material is mainly available during autumn (Jonasson et al., 1999) when the soil microbial populations decline and release their nutrient content (Giblin et al., 1991), but not during the growing season when the plants require the nutrients to increase their biomass (Jonasson et al., 1996). The microbial biomass acts as a nutrient sink (Jonasson, 1997) and along with the nutrient deficient soil therefore restrict plant growth during the growing season.

Especially in the high Arctic, plant growth is considered water limited (Billings, 1987) because of the low precipitation and low moisture content in the soil (Gold and Bliss, 1995). The precipitation primarily arrives as snow and is available as surface run-off water during snowmelt before reaching rivers and being transported to sea. Snow drifts may persist throughout summer delivering meltwater to the soil directly below the snow drift. Especially slopes may be limited in moisture during the growing season.

The Arctic landscape is in fact a mosaic of microhabitats because the topography plays an important role in defining the local moisture content and temperature (Björn et al., 2004), and the plant species in each microhabitat will depend hereon and vary with it.

Table 1. Main restrictions for plant growth in the Arctic (Billings, 1987; Giblin et al., 1991; Jonasson, 1997; Jonasson et al., 1999; Jonasson et al., 1996; Ulrich and Gersper, 1978).

Low air and soil temperatures
Very short growing season
Long-lasting snowdrifts
Permafrost and shallow active layer
Flooding at thaw
Drought
Limited availability of nutrients
Slow decomposition due to permafrost
Nutrient buffer in microbes during growing season

2.1.2 The Arctic terrain

Permafrost is a typical feature in Greenland. To the north it is continuous and to the south more or less discontinuous. Above the permafrost layer the soil thaws every summer and forms the 'active layer'. The active layer varies in depth from about 40 cm in arctic deserts to 100 cm in wet areas depending on summer temperatures and soil type. South facing slopes may even reach 120 cm active layer. The continuous dynamic cyclic processes of thaw and freeze affects the Arctic terrain mechanically. It results in polygon patterns in the ground due to slowly vertical and horizontal sorting of material over decades

(Björn et al., 2004). Permafrost contains up to 50 % excess ice. Local melting events may result in subsides and formation of thermokarsts that may change run-off patterns and availability of water in an area (Bader and Guimond, 2004). Other natural mechanical processes that affects the terrain and landscape are spring flooding, erosion of riverbanks, slope processes, changes in river volumes for example due to extreme flooding events (Björn et al., 2004).

2.2 Disruption of vegetation cover

The arctic vegetation is generally sensitive to physical disruption because it is subject to conditions that restricts plant growth rate (table 1) and therefore the potential for revegetation after disturbances. The heavy trucks used for vibroseis may disrupt the vegetation by killing plants, removing whole plant or by removing the green parts. Removal of plants exposes the ground, which may lead to dust formation. Wind may move the dust onto living plants limiting light for growth during the short Arctic growing season. How damaged an area will be from a seismic survey, depends on the vegetation type, the survey activity and season. Some species grow faster and therefore may recover more quickly, as for example grasses in wet areas. Other species grow very slowly and may not recover from the wear of a seismic truck, for example Arctic bell heather (*Cassiope tetragona*) in dry heath land. Such damages in a heathland can be visible in the terrain as tracks left for decades (Aastrup et al., 2016; Hansen et al., 2012). Together with the hydrological changes described in the chapter below, the tracks from the heavy trucks may lead to regrowth of new and opportunistic species for which the altered conditions may be more optimal, and hence change the plant community in the area for a long period of time or even permanently. The machinery and people working at the seismic lines may themselves carry seeds introducing alien species. Terrestrial seismic activity may therefore scar the landscape for decades, if not permanently, leaving tracks, bare soil and by changing the vegetation cover over time. Key factors for vegetation damages are listed in figure 1.

Different areas in Greenland vary in sensitivity to disturbances from seismic surveys depending on the species composition and soil types.

Figure 1. Key factors for vegetation damages from terrestrial seismic exploration.

Key factors for vegetation damages

Terrain	**Level**	Intersected/Varied topography
Active layer	**Frozen (hard top)**	Unfrozen top
Snow depth	**Deep**	Shallow
Snow density (packing/type)	**Densely windpacked**	Powder
Snow density	**High**	Low
Vegetation type	**Wet**	Dry
Flora species composition	**Common**	Rare
Vehicle ground pressure	**Low**	High
Vehicle path width	**Narrow**	Wide
Vehicle traction	**Rubber**	Steel

Increasing risk of vegetation damage →

2.3 Effects on the permafrost

Driving over ground with permafrost may change the depth of the active layer. The active layer is the soil layer on top that thaws and refreezes on a yearly basis. The effect of the vehicles will depend on tire or track design, weight and timing. Driving early in the fall may result in driving over unfrozen ground with snow cover, which compacts the snow, reducing its insulation capacity and allowing the ground to freeze harder and deeper more quickly. This will reduce the depth of the active layer the following summer because it froze harder during winter due to compression from the vehicles (Bader and Guimond, 2004). The compression of the soil and / or the disruption of vegetation can lead to damages with wider effects. The vegetation insulates the permafrost against heat from the sun. When the insulating cover die or is torn off, the soil is exposed and stores heat, and the active layer increases. Because excess ice can constitute more than 50% of permafrost volume, the ground can subside into the vacant hole left by the melted ice, making sinkhole-like features, so called thermokarst (Bader and Guimond, 2004). Furthermore, the thawed soil can lead to changes in the hydrology due to the melting of stored ice and therefore intrusion of surface water. Even a small subsidence can expand substantially along the margins: If water begins to pool in the depression, the thermokarst will usually accelerate due to the efficient thermo-conductivity of water and waters ability to penetrate deep into any permafrost crack: Intruding water will increase the temperature and accelerate the permafrost thaw (Bader and Guimond, 2004). In areas with discontinuous permafrost, densely spaced seismic lines have the potential to completely remove permafrost and therefore transform the overlaying land cover type (Williams et al., 2013). The lack of regeneration of permafrost in this environment is due to a positive feedback between subsides and intruding water that prevents the top layer from being water unsaturated which is required to maintain permafrost (Jorgenson et al., 2010; Williams et al., 2013). It is therefore essential to consider and prevent potential impacts on the permafrost during seismic surveys.

The compression of the soil and the increased active layer also result in an increased greenhouse gas release from the nitrous oxide, methane and CO_2, otherwise stored in the permafrost (Billings, 1987; Elberling et al., 2010).

2.4 Effects on hydrology

Removal of vegetation and the corresponding increase in active layer thickness can also lead to hydrological changes in the soil as the thawed soil can lead to changes in run-off patterns, because it allows a free flow of water as opposed to tying water in a frozen condition. Compression of thawed soil under heavy trucks forces water in the soil away from the tracks also changing run-off patterns. The compressions left in the ground can act as drainage systems filling with water during snow melt. If the run-off increases drastically for example during spring and summer or in periods with rain, the increased run-off along certain paths can lead to thermokarst and erosion (figure 2). The changed hydrology alters the amount of available water in the ground and can therefore, over time, change the composition of plants in the area (Williams et al., 2013). Tracks seems as a simple effect on the terrain – but may have long lasting consequences for the plant community depending on the changes in hydrology.

Figure 2. A thermokarst in the Arctic landscape. Thermokarsts are created in areas where the permafrost layer melts, because permafrost contains up to 50 % water. When the ice melts the water runs off and carries soil with it. When soil and ice is removed below the surface, underground drainage systems may be created. At a certain point the remaining top soil can no longer support the weight of the surface and it collapses, leaving a hole in the landscape. Thermokarsts may expand because the melted ice may intrude deeper into the ground carrying heat and accelerating the thaw. Photo: David Boertmann.

2.5 Typical damages to the arctic vegetation from explosives

Explosives are often used where the landscape is too steep for the vibroseis trucks to perform. Explosives require holes to be drilled in which the explosives are placed – so called shot holes. The shot holes can be several meters to a hundred meter deep (Evans, 1997), depending on the subsurface material and target depths of the seismic survey. The vegetation is destroyed around the drilled hole and the soil will be exposed. It is very important that the top soil is compressed firmly on the explosives or that heavy mud fills the hole on top of the 333explosives in order to maximize the energy directed downwards into the crust. As a minimum each shot hole will leave behind a spot of bare soil. Larger surface disturbances typically occur when a charge cannot be placed at depth, such as when a drilled hole caves in or in soils with poor relief, or if a charge is not placed correctly and detonates in an upward direction (SAEExploration, 2015). Then the explosion may lead to formation of a crater and a wide spread of mud, soil and dust (SAEExploration, 2015). The exposed soil will be vulnerable to wind and water erosion. Even if the explosion takes place in winter the soil will be disrupted and may potentially lead to spread of soil and dust on the snow and on to the vegetation when the snow melts.

The footprint left in the terrain also depends on how the shot hole is drilled, how it is stamped off and on how the equipment is transported to and from the drill site. The drilling equipment may be lifted in by helicopter or driven in by trucks on land or on the snow in winter (Trupp et al., 2009). The shot hole may be drilled by hand-held augers, with large truck mounted hammer drills or with small drill rigs which will impact the drill site differently.

Besides the scar from the shot hole itself, the damages to the environment are the same as for vibroseis. If heavy trucks move over the terrain, tracks are left in the landscape with disrupted vegetation and all the potential and long-lasting effects as listed above for vibroseis.

The explosives used are typically nitroglycerin or nitrocellulose, but sometimes ammonium celluloid may be used as part of the cellulose. The explosive is a gelatin capsuled in plastic (Levy, 2015). After the explosion, plastic debris and wires to the detonator remains in the shot hole and potentially in the surroundings and needs to be collected. The clean-up after explosive seismics may therefore be very time consuming. There is also a risk of water contamination as the explosives are detonated in the ground.

2.6 Damages from receiving the seismic signal - Geophones

Geophones (ground motion sensors) are placed in lines perpendicular to the seismic acquisition lines, regardless of the charge type (vibroseis or explosives). It will depend on the ground properties, the desired resolution and seismic method how far apart receiver lines and geophones are spaced. In one 3D seismic survey in Alaska using explosives, receiver lines were spaced 272 m apart with geophones inter- spaced 50 m apart. The acquisition lines were spaced 420 m a part (SAEExploration, 2015). The potential effect on the environment from such a 3D survey is therefore not trivial. Placement of geophones in association with the seismic lines, whether explosives or vibroseis are used, will usually not in itself affect the vegetation and landscape, however, the transportation may cause tracks and secondary changes to permafrost and hydrology. Most geophones are placed in the ground with a spear (Dean et al., 2018) to increase the coupling between ground and geophone in order to enhance the energy transfer from ground motion to electric voltage (Evans, 1997). Several systems exists; some are inter connected with cables, others are wireless (so called nodal systems) (Dean, 2016; Dean et al., 2018; Yukon-Government, 2006). Generally there needs to be the same amount of geophones perpendicular to the seismic line in front of a ‘shot point’ as behind for each ‘shot’, which means that geophones are moved along, which will also tear the vegetation, depending on how they are transported and whether 2D or 3D seismics is employed. The more geophones that are placed, the finer the resolution of the resulting imagery.

2.7 Disturbances to wildlife from seismic surveys

Seismic surveys may disturb wildlife because they are perceived as dangerous (noise, smell, light as well as the physical appearance of novel objects), in a similar way as predators. Disturbances includes displacement (scaring away) and behavioral changes and effects vary from negligible to permanent displacement or population decline. Disturbances may for example have a strong impact on the energy balance of wildlife. The more disturbances, the more flight reactions and less time to forage and eventually to withstand periods with food shortage or with high energy demand such as the long movements for migrating birds.

Persistent disturbance may lead to animals being displaced from important areas for feeding, mating, calf rearing etc. which again may result in a population decline. Less pervasive disturbance may affect individual food intake, and thus lead to e.g. reduced fecundity (Frederiksen et al., 2017). In some circumstances, animals may habituate to disturbance and thus become more tolerant, particularly if the disturbance is unconnected to actual danger. However, the opposite may also occur, i.e. animals becoming increasingly sensitive to disturbance the more often it occurs. For example individuals in hunted populations will be shyer to human activities, than individuals from populations without hunting pressure. Sensitivity to disturbance is generally highest during periods when animals occur in small areas at high densities, and when their mobility is reduced (e.g. moulting birds) (Frederiksen et al., 2017). In addition, sensitivity to disturbance is often high and effects amplified when animals have offspring needing parental care.

Seismic surveys, which slowly move through the terrain, may impact wildlife briefly in a large region. However, shuttle traffic to a permanent facility, for example the camp site, has the potential to impact wildlife more continuously throughout the season. Helicopter used to sling geophones, personnel or drill rigs may disturb wildlife over a larger area because they are noisy, audible at great ranges (+10 minutes before they are visible) and because their appearance may be unpredictable.

Figure 3. Muskoxen in a classic protective formation with the calves in the middle caused by disturbance. Photo Line A. Kyhn

The most disturbance sensitive wildlife in Greenland are caribou (*Rangifer tarandus*), muskoxen (*Ovibos moschatus)*, geese (white-fronted goose *Anser albifrons flavirostris*, pink-footed goose *Anser brachyrhynchus*, canada goose *Branta canadensis*, brent goose *Branta bernicla* and Barnacle goose *Branta leucopsis*) and moulting seaducks (Aastrup et al., 2016; Hansen et al., 2012). Especially breeding and moulting birds, for example geese, are vulnerable to disturbance from helicopters (Mosbech and Glahder 1991) In Greenland, where these populations are hunted, the individual animals are shyer and therefore particularly sensitive.

The muskoxen (Figure 3) are most sensitive during winter, because their winter strategy is to move as little around as possible to save energy, primarily relying on fat reserves build up during summer foraging. Repeated disturbance during winter may force them to spend more energy and repeated disturbance during summer may hamper foraging and the build-up of fat reserves, thereby increasing mortality during the following winter (Hansen et al., 2012). Geese are present only in the summer and both the large flocks of moulting geese and the breeding birds are vulnerable to disturbance. Winter activities therefore will have the potential only to disturb muskoxen and caribou as well as the occasional arctic hare (*Lepus arcticus*). In winter 1985/86 seismic surveys were carried out in Jameson Land, East Greenland, and it was here shown that helicopters and snow scooters had stronger impacts on muskoxen behavior than the seismic “train” itself (Olesen, 1986). Due to the local and temporal characteristics of the disturbance from seismic activities, only small impacts on muskoxen and caribou can be expected from a single 2D seismic survey, however a large scale 3D seismic survey requires careful planning to reduce impacts. Especially regarding use of helicopters that are more unpredictable in time and space than the slowly moving vibroseis trucks.

Summer activities may impact the moulting and breeding goose populations. These occur especially in the relatively lush wetlands in the lowland areas. A single activity has the potential to displace geese from a large area, but they will probably re-occupy such areas the following season if activities are terminated. If exploration occurred over several years, it would likely take longer for geese to recolonize an area or they may be displaced permanently (Aastrup et al., 2016) . There will be a risk for effects at a population level for both geese, caribou and muskoxen, if exploration activities are more extensive and especially if they last for many years without proper mitigation (Hansen et al., 2012). The impacts can be reduced by careful planning and avoidance of the sensitive areas in the sensitive periods as will be discussed in chapter 4.3.9 below. Scientific evidence for disturbances of Greenland wildlife has recently been reviewed and reported (Frederiksen et al., 2017).

Camp activities may attract wildlife such as arctic fox, wolf, polar bears and ravens, if garbage is not disposed of thoroughly or if they are encouraged to come to the camp.

Muskoxen and polar bears may also pose a safety risk to the people working at the seismic lines as they may attack.

3 Past experiences with terrestrial seismic surveys in Greenland

The seismic vehicles and trailer camp from the winter activities at summer rest, Jameson Land in the1980ies. Photo: Christian Glahder.

ARCO Greenland A/S carried out winter seismic surveys in Jameson Land in the winters of 1985-86 and 1987-88, using vibrators as sound source. Summer seismics were carried out in 1988 and 1989 using explosives as sound source and helicopters for transport. Environmental studies and monitoring were carried out prior to, during and following the seismic surveys. The environmental studies were primarily focusing on geese, muskoxen and vegetation. A complete list of reports is given in appendix 1.

3.1 Winter seismic surveys

In the first season, the seismic data collection began in December and in the second season the program began in January. In total 734.1 km 2D seismic line data were collected using track mounted vibroseis trucks (TI Force 3X TK-2) with 48840 pound peak force. The mobile sleigh-mounted camp was pulled by steel-tracked caterpillars that was moved daily along the seismic lines. The seismic surveys left 4 types of tracks in the vegetation: 1) linear tracks along the seismic lines, 2) tracks from the trailer camp which moved close to the seismic lines dependent on the terrain, 3) tracks between the trailer camp and the seismic line, and 4) tracks after dozers preparing Twin Otter landing strips.

3.1.1 Environmental regulation of winter seismic surveys

The approval by the authorities at that time (Mineral Resources Administration for Greenland) of the winter seismic surveys required, that the active layer should be frozen and that there was an adequate cover of at least 20 cm of snow and / or ice to protect the vegetation. Therefore, seismic surveys could only take place in the period between November 15th and until thawing began in spring. After April 1st the supervisor could stop the survey within three days if deemed necessary to protect the active layer and the vegetation.

Vegetation maps were produced to help planning the seismic activities in a way so the most sensitive vegetation types were avoided as much as possible.

3.1.2 Damages to the vegetation and terrain

Before driving with heavy equipment like the vibroseis trucks and the trailer-camp (Figure 4) a dozer or a 'Nodwell' layed out a track to compact the snow. This was done at least 24 hours in advance, which also allowed time to let the compacted snow freeze up. The type of snow is important for this approach to be successful.

Figure 4. Moving the trailer-camp requires a huge effect preparing a track in the snow and dragging the entire camp train. Photo: Christian Glahder..

Studies (unpublished) after the seismic surveys describe three main types of damages to the vegetation:

Mixing of vegetation layer and upper layer of soil, was often caused by heavy equipment on an inadequate layer of snow when the belt 'circled round on the spot' or by light scraping of the upper layer by dozers. The damages, when inspected after a few years consisted of a mixture of dead plants and plant parts, living plants, and newly established plants.

Scraping off vegetation leaving open bare soil. These damages occurred when dozers scraped off too deep below the snow. Most of these damages were found on slopes and most had a limited extent as the dozer-drivers early in the season became aware of this type of damages.

Frost damages. These damages consisted of frost-sensitive plants like Arctic bell heather (*Cassiope tetragona*) standing dead with intact branches. They were often found on relatively long stretches where the snow had lost its insolating properties because of the compaction caused by the heavy vehicles.

Generally, the damages were regarded as limited without significant ecological effects. The tracks could be visible over several kilometers but scraping and mixing of active layer and vegetation did not cover more than a few hundred meters. Except on a few sandy slopes, no instances of water- or wind erosion was observed.

3.1.3 Lessons learned – winter seismic surveys in Jameson Land

The mobile sleigh-mounted camp was pulled by caterpillars that moved daily along the seismic lines. Damages to the vegetation and terrain were observed and reported, and inspection of the damages were studied in relation to snow cover (unpublished). These studies showed that the visibility of tracks and physical changes to the vegetation depended on snow cover thickness in 'dry heaths'; the thicker the snow cover, the fewer visible damages. For 'hummocky fen' the relationship was opposite; the less snow the less visibility of the tracks. This is explained by the tussocks being very sensitive to dozing of snow, and that dozing only occurred when there was a lot of snow. In general damages were typically observed in dry habitats where snow cover was thin or in areas where the snow was removed by the driving (e.g. on steep hill sides and river banks), vegetation and terrain were impacted (ruts and trails). Two types of damages were observed from the mobile sleigh-mounted camp: 1) Point damages, where the tracked vehicles had gone through the snow cover and peeled off the vegetation. This was especially on slopes. 2) Diffuse line damages, where tracks over long stretches were easily observable from helicopter, but less apparent from the ground, because there was still living vegetation in the tracks. Over longer stretches, broken stems and damaged plants were observed in the tracks, however over some short stretches the variation in vegetation was large enough to camouflage or diffuse the track. Some of these damages were still clearly visible in 1994, (pers. comm. Peter Aastrup) (Hansen et al. 2012) (Figure 5).

The vegetation types have different sensitivity to driving associated with seismic activities and, large, contiguous damages were only observed in two types of 'dry dwarf shrub heath' and in a 'snow bed' type. The type and degree of damage and visibility depend on the topography, soil conditions, and on the depth of the snow cover.

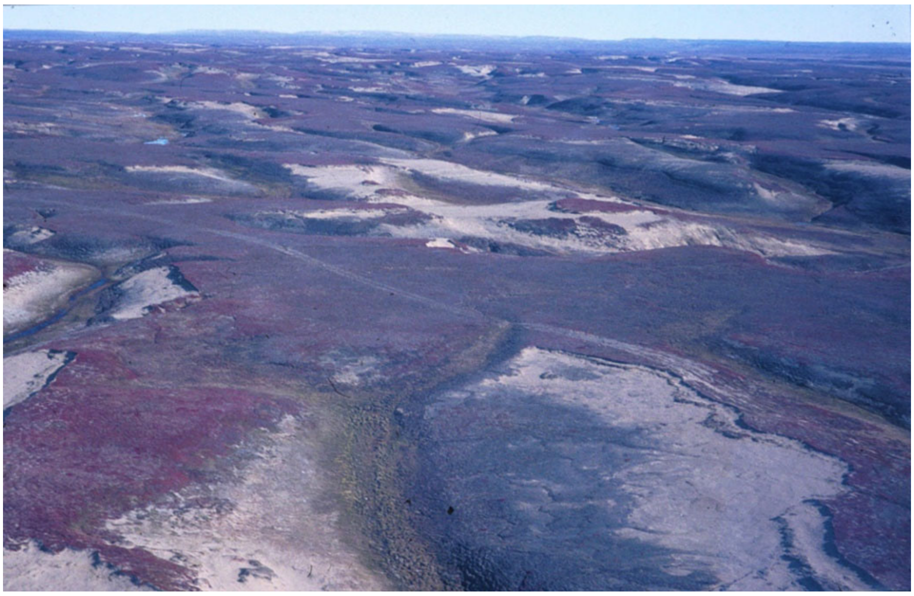

Figure 5. Tracks from the ARCO winter seismic operation in 1986 were still visible in Jameson Land twenty years later. This photo was taken in 1996. Photo: Peter Aastrup.

Most of the damaged areas occurred in the 'dry dwarf shrub heath', which is the dominating vegetation type in Jameson Land. The sensitivity and extent of damage in 'dry dwarf shrub heath' also depends on the composition of species. Arctic bell heather (*Cassiope tetragona*) and dwarf birch (*Betula nana*) were much more vulnerable to mechanical damage than alpine blueberry (*Vaccinium uliginosum*), mountain avens (*Dryas octopetala*) and Arctic willow (*Salix arctica*).

Fens, grasslands and lush dwarf shrub heaths were only affected by damage to a limited extent, because 1) seismic activities were minimized in these habitats by adjustments made possible by use of vegetation maps and by prior approval of planned routes, 2) they had a limited distribution and 3) they are normally covered by a relatively thick layer of snow.

The ecologically important foraging habitats for muskoxen: herb slopes, early snowbeds and Salix-snowbeds were affected to a limited extent due to their topographical distribution on south facing relatively steep slopes and in hollows in the terrain with deep snow.

Assessments made during helicopter flights concluded that damages were limited in extent. The regulation was considered sufficient, although it was concluded that a requirement of a snow layer deeper than 20 cm could have reduced the damages further. The greatest degree of visibility of mechanical damage to the vegetation occurred where the snow cover had been less than 20 cm or on sandy soil. Mechanical damages to the vegetation on horizontal ground, where the snow depth had been greater than 30 cm, were estimated as intermediary, while frost damages had the least degree of damage and visibility, despite being observable over kilometers from helicopter.

To sum up experiences from Jameson Land winter seismic surveys indicate:

1. Snow cover is important. The deeper the snow, the less impact.
2. Freeze up of soil is important. The more frozen the soil was the less impact.
3. Preparation of snow roads diminished damages for most vegetation types.
4. Vegetation maps helped planning surveys to minimize effects on the most sensitive and ecologically important vegetation types.

5. Line scouting was critical to place seismic lines appropriately with respect to topography and vegetation.
6. Timing of seismic surveys is important in relation to snow cover and frost.
7. Mechanical disturbances can be clearly visible, although the areal extent of such damages were small thanks to vehicle drivers following the guidelines.
8. Species composition of vegetation types highly affected the degree of damages. Vegetation types with frost sensitive species like Arctic bell heather (*Cassiope tetragona*) suffered from compaction of snow which reduces the insulating properties, while vegetation types with for example alpine blueberry or Arctic Willow are less sensitive.

3.1.4 Regulation of winter seismic exploration in Jameson Land, 1986-89

Winter seismic surveys were approved under the following conditions:

Seismic survey methods

i. Seismic surveys shall use the type of vibroseis trucks that were approved for use in the same terrain and used for the seismic surveys in 1985-86. For 1986, the general approval stated: The seismic program can be carried out using tracked vibroseis trucks.

Survey periods and survey areas

ii. Seismic surveys may only be carried out during periods where the active layer has such a carrying capacity and protective snow or ice cover, that the surveys can be carried out without vegetation or the active layer suffers mechanical injury.

iii. In especially robust areas, approved by the Greenland environmental authorities, seismic surveys may be carried out from 15. November until 1. January.

iv. In the period 15. November to 1. January, driving and placement of seismic lines may require approval by the Greenland environmental authorities. Prior to the approval, an official supervisor must have the opportunity to participate in the operator's reconnaissance of the area.

v. Seismic surveys must be completed before the thawing of the active layer begins, or protection from snow or ice sheet thaws. After 1. April the supervisor can require that the survey work, including driving shall be terminated within three days, if the supervisor deems it necessary in order to protect the active layer and the vegetation.

vi. In April, seismic surveys may not be carried out in muskox calving areas. The mentioned areas are indicated in Appendix 3 of the approval.

vii. In areas with sensitive vegetation as specified in Appendix 2 (of the approval), driving as well as the location of seismic lines can be required approved by the Greenland environmental authorities. Prior to such approval, the supervisor must have the opportunity to participate in the operator's reconnaissance. For approval, it will be a condition that the area in question has an average snow depth of at least 20 cm, when the vibroseis studies are to be carried out.

3.2 Summer seismic surveys

Arco Greenland conducted summer seismic surveys in 1988 and 1989 from June to September. The surveys were conducted using helicopter borne equipment and included the drilling of about 7500 holes for explosives. In total more 700 km seismic lines were shot. Five to six helicopters carried the equipment and personnel between drill holes as well as transported personnel between seismic lines and the camps.

The surveys encompassed:

1. Helicopter-reconnaissance of seismic lines.
2. A team of three to five persons that marked the seismic line with a flag for every 30 m.
3. Drilling of a hole for every 90 m. The bottom of the hole was loaded with a charge of dynamite for the seismic shot. Each drill hole encompassed three double-trips with a helicopter.
4. A seismic team of 5-6 persons that laid out geophones for recording seismic signals. Personnel moved by helicopter.

It was assessed that each seismic line included about 40 helicopter round trips.

3.2.1 Environmental regulation of summer seismic surveys

Pink-footed geese, barnacle geese, and muskoxen occur in most parts of Jameson Land. The geese breed and moult from June 1 to August 10 and then they leave the Arctic, while muskoxen occur year round.

The environmental regulations aimed to protect the geese, the muskoxen and the vegetation. The regulations built on definitions of sensitive periods and sensitive areas where the authorities must approve seismic activities, regulations of flying height for helicopters and fixed-wing aircrafts, and no-go areas for specific periods.

The approval of the seismic summer activities prescribed mitigation of damages to terrain and vegetation around the seismic shot holes.

Geese and Muskoxen

The regulations specified a. o. that:

i. Flights should be limited as much as possible, and wildlife should be disturbed as little as possible. Photo-safari flights were not allowed.
ii. In specified muskox areas flying heights should be at least 500 m.a.s.l. unless the work or aviation rules made it necessary to fly otherwise.
iii. In specified geese moulting or breeding areas helicopter and fixed-wing landings and overflights could not take place without prior approval from the authorities in the period June 1 to August 10. The authorities could stipulate that flying must be limited to specified corridors.

Vegetation and terrain

The regulations specified a. o. that (see full regulation in appendix 2):

i. The work may commence from June 15th.

- During the period June 15th June to August 10th seismic work is not allowed within the breeding and moulting areas designated for geese, and in areas with sensitive vegetation. Seismic lines needs on-site approval by the authorities.

ii. In the period August 10th to October 1st all seismic lines and shot hole points must be approved by the Greenland environmental authorities in areas with sensitive vegetation.

iii. Areas for infrastructure should as far as possible be selected so that the vegetation would be damaged as little as possible.

iv. Around shot-holes the terrain damages should be restored and vegetation put back.

v. Shot lines must be selected to be not closer than 30 m from streams, ponds and lakes.

vi. Shot lines should be selected ‘outside’ important sites like historic relics, pingos, triangulation points and other sites of historical interest

3.2.2 Monitoring of impacts to wildlife, vegetation and terrain

The goose populations and the muskox population were monitored by annual censuses in the years before, during, and after the seismic operations.

After the termination of the seismic activities (Mosbech and Glahder, 1990) concluded:

“The results of the surveys between 1983 and 1989 do not indicate that the seismic activities have had an impact on the numbers or distribution of Barnacle Geese in Jameson Land. Total numbers and distribution in the undisturbed years 1983, 1984 and 1989 were not significantly different from the disturbed years 1987 and 1988. In both the disturbed years and the undisturbed years, the total numbers varied between 80 % and 100 % of the 1983 count. There was no correlation between the disturbances and the total number of birds, but there were less moulting Barnacle geese in 1987 and 1989, where there was also an untypically large amount of snow and a late spring melt.”

Muskoxen

A review of the censuses and population structure studies by (Aastrup and Mosbech, 2000) concluded:

“The seismic operations 1987-1989 may have affected the muskox population. Significantly, lower yearling fractions during the years of the seismic operations indicate an increased winter mortality of calves. We cannot assess whether this was a consequence of the disturbances or if some other factors were involved. We examined some climatic parameters (temperature, freeze-degree days and wind) but the validity of available climatic data to the muskox population in Jameson Land is questionable. Seismic operations occurred all over the area and disturbances may have reduced the time available for feeding and increased energy expenditures. Olesen (1986) found that time spent standing and walking was increased six fold while time spent lying was halved when seismic disturbance occurred within 1 km from muskoxen in Jameson Land.

The population monitoring program was not sufficient to detect small decreases in population size that may have been related to oil exploration. On the other hand a more severe decrease in population size would have been detected; calculation by "Trends" showed that a decrease in a minimum order of 10 % per year could have been detected with a power of 0.95. The magnitude of changes in reproduction that a monitoring program should be able to detect is open to discussion. Because some negative effect on the survival of calves during their first winter was detected during this study it is concluded, that population composition data are essential and that a longer monitoring period is needed to detect effects of demographic change on population size.

We cannot conclude that the seismic operations had a significant negative effect on the calf survival although this may have occurred. During the seismic operations helicopter flights were prohibited below 500 m above ground level during the calving period and in spring in the areas with highest densities of muskoxen. A possible negative effect on the muskox population seems to have been temporary during years with seismic exploration. However, it cannot be excluded, that climatic factors were involved. On Banks Island, for instance, the rate of increase varied much in the absence of seismic operations (Nagy et al., 1996)."

Below is listed the lessons learned from the seismic summer program executed by Arco.

3.2.3 Lessons learned – summer seismic surveys in Jameson Land

1. Solid collection of baseline data about the ecology and distribution of geese and muskoxen created an important basis for locating sensitive areas and periods.
2. The principle of protection of sensitive areas and periods proved to be an operational and effective tool for protection of wildlife and vegetation.
3. Thanks to collection of comprehensive ecological baseline data and regulations based on these, it was possible to complete an extensive seismic exploration program without serious impacts on wildlife and vegetation.

4 Mitigation of impacts from terrestrial seismic surveys

Muskoxen in an East Greenland landscape. Photo: Line A. Kyhn.

It is possible to mitigate effects of terrestrial seismic surveys on wildlife, vegetation and landscape by deploying 'low-impact seismic practices'. Low-impact seismic practices refer to approaches that reduce the footprint and impact of seismic exploration activity on the vegetation and landscape for example by 'winter only seismics' and using low ground pressure vehicles (AMAP, 2010). Besides the technique itself, mitigation can be accomplished by careful planning and regulation, as was done in Arctic Yukon (Yukon-Government, 2006) and Alaska (Resources, 2013), and as was done in Jameson Land in the 1980'es. Insights from the regulation in the Arctic American countries were obtained during a study visit to Alaska during winter 2016 with a number of meetings with the issuing authorities in Alaska (Boertmann et al., 2016). The backbone of this regulation as well as of the regulation in Jameson Land in the 1980'es is that seismic surveys are carried out in winter on snow covered frozen ground. The surveys are carried out in winter because the vegetation is protected under the snow and ice from the impacts of the heavy vehicles, and all logistics involved in the operation. Further, the frozen ground reduces the impacts on the permafrost with secondary risks of subsides and thermokarst, especially in water saturated areas. This regulation requires continuous monitoring of the snow distribution and depth, and of ground hardness before a season and area can be opened for seismic exploration, as well as it requires monitoring during the seismic operation to assess when the snow can no longer sustain the weight of the vehicles and protect the vegetation. In Alaska, the tundra is opened for seismic exploration when the threshold of table 2 is met. The seismic operation has 72 hours to leave the area when the thresholds of table 2 is no longer met. The system works well in Alaska and mitigates to a large degree the damages that were observed prior to enforcement of these guidelines.

Table 2. Threshold for onset of the seismic season in Alaska (Resources, 2013).

The seismic season opens when:	➢ the snow is > 15 cm thick (level) or > 23 cm (slopes) ➢ the ground is < -5 °C at 30 cm depth ➢ the ground is hard
The seismic season closes when the thresholds are no longer met. The seismic survey then has 72 hours to clear the area.	

The behavior and operating practices of seismic and survey crews is an important component of impact mitigation. To assure the successful achievement of mitigation actions, it is essential that the rational for certain operating practices are well understood by crews and those activities be monitored. Only companies that can document experience in successfully carrying through winter seismic surveys in the Arctic should be allowed to work in Greenland.

The list of suggested mitigation measures below is *not* exhaustive and other possibilities may exists. The suggested mitigation actions are summarized in table 3 at the end of the chapter. The mitigation actions listed below are intended as suggestions for the Greenland environmental authorities to include in their guidelines for terrestrial seismic surveys, not as final regulation.

4.1 Mitigation of effects from vibroseis

The main concern of vibroseis is the wear on and associated effects on the vegetation and the visual changes of the terrain from the vibroseis trucks, as described above, as well as disturbances of wildlife. These effects may to a large extend be mitigated by only allowing vibroseis on snow with a sufficient depth when the ground has hardened to a certain degree, and with regulations on how and where to cross rivers and crests, how and where to prepare winter roads on the snow, and which areas and periods to avoid with respect to wildlife. Further vehicles should be operated in a manner such that the vegetative mat is not disturbed and blading or removal of the tundra vegetation must be prohibited.

The required snow depths in Alaska is 15 cm (6 inches) in level areas and 23 cm (9 inches) on slopes, in addition the ground must be frozen and have a maximum temperature of -5 ºC at 30 cm depth before vehicles may drive off road (table 2). A study showed that especially the hardness of the ground influenced the damages from the heavy machinery (Bader and Guimond, 2004), why seismic surveys should be limited to after the ground has hardened to this extend. The experiences from Jameson Land showed that the required snow depth of 20 cm was too little to protect especially the dry heath vegetation. The required minimum snow depth should therefore be more than 20 cm in Greenland where the vegetation is different and the topography more varied than in Alaska. Such an approach means, that the start date for terrestrial seismic surveys cannot be fixed from year to year, but will vary with snow cover and snow depth, as in the case in Alaska and Yukon (Resources, 2013; Trupp et al., 2009; Yukon-Government, 2006). It also means that the snow cover and ground hardness should be monitored in areas where seismic surveys are expected or planned, which requires timely planning during the application process (see chapter 5). In addition, the depth of the estimated sufficient snow cover will depend on the underlying vegetation type, as some species and vegetation types are more resilient than others. Mapping of the vegetation with respect to sensitivity will therefore allow planning of the seismic operation with respect to the least impact on the environment. Especially dry areas, such as *Cassiope* heaths, are vulnerable to heavy vehicles both summer and winter. Firstly, because Arctic bell heather (*Cassiope*) is very sensitive to frost and may die if the snow pack is pressed firmly around the plants from the heavy vehicles, as was observed following the seismic surveys in Jameson Land in the 1980's (Hansen et al., 2012). Secondly, because the arctic conditions restrict regrowth after disturbances, especially in dry heaths. The most resilient areas with respect to revegetation are the wet areas, as the regrowth here is much faster. Where the seismic surveys conducted in Jameson Land in the 1980's were conducted on snow in winter, and where the trucks moved over level snow-covered wet vegetation types, few visible changes where left the following year (Anders Mosbech pers. comm.). However, where the trucks crossed river banks or crests or where the vegetation was disturbed or cut off in dry heaths, the tracks were in places still visible some 20 years later (David Boertmann, pers. comm.). Many studies were performed with regards to snow depth and profile, vegetation type and vegetation damages during the 1986-89 studies in Jameson Land and reports hereon are available for future environmental impact assessments. A list of all the reported studies can be found in appendix 1.

4.2 Mitigation of effects from using explosives

First of all the use of explosives should only be chosen as the exception, where vibroseis trucks cannot be used, or where vibroseis trucks will cause greater damages than the use of explosives. This may for example be on steep slopes, and special permits should be required to carry this out.

The damages from explosions can be mitigated somewhat. First, explosive seismic surveys should be carried out in winter in order to be able to limit vegetation damages from driving, as for vibroseismics, and following the same thresholds before the survey may commence. Otherwise seismics using explosives should be carried out using helicopters to carry all equipment. Secondly, when explosives are to be used, damages may be mitigated somewhat if the charge is small enough and placed deep enough, to avoid cratering and spread of dirt and dust. To minimize ground disturbances, drilling crews should run a loading pole down the shot hole to ensure that the hole is open and drilled to the target depth. If the hole is not open, the driller should rerun the drill pipe down the hole to open it further, and should again use the loading pole to verify that the hole is clear and drilled to the target depth. A maximum of two drilling attempts should be made before moving to the next hole location. If a shot hole cannot be drilled beyond a certain threshold depth, a charge should not be placed in the hole. The hole should instead be backfilled with cuttings and the crew should move to an alternative location. This modification of source charge strength based on depth minimizes shot point error (SAEExploration, 2015). The seismic company should set, test and argue for the threshold depth / charge size before actual shooting begins. All attempted drilling at source point locations shall be logged by the drill crews. Ground disturbances shall be documented and reported to the Greenland environmental authorities, and holes shall be backfilled with drill cuttings or native soils, and tamped to be at level with the ground surface.

Dust and dirt on the snow will accelerate snow melt and may therefore change run-off patterns and lead to subsides. Aquifer protection and suitable plugging should also be considered. Misfired charges must be disabled and removed. The site must be cleaned up for plastic, wires and other debris and the ground and vegetation restored to the best possible extent. Vegetation damages must be reported to the Greenland environmental authorities, and a plan for restoration prepared and carried through at the expense of the damaging company.

4.3 Mitigation of effects from geophone placement

The seismic signal, whether from vibroseis trucks or from explosives needs to be positioned and re-collected. The method with the smallest footprint on the vegetation and landscape is using nodes, i.e. wireless geophones deployed by helicopter or driving on snow in winter. Helicopters can be used to transport sling loads of nodes to pre-determined positions and be laid out by personal on foot. Nodes are typically inserted into the ground or snow by 10 cm spears. The personal can be flown in by helicopter in the morning and picked up at the end of the day. This means that the helicopter only needs to land on the line two times per day, and the overall foot-print can therefore be reduced to almost zero from that of walking people and small spears.

Cable connected geophones will inevitably lead to a greater wear on the vegetation, unless it can be laid out by helicopter or drone.

During and / or after final geophone pick up, clean-up crews must walk each line of the project and remove all debris from with the seismic survey, including any wood laths and survey flagging. All debris that is collected must be stored carefully with respect to winds and wildlife and be disposed off properly. See the ‘Field rules’ (Link) issued by the Greenland authorities.

4.4 Mitigation of camp activities

Supporting the survey is a whole community, with workshops, kitchen facilities, dormitories, laboratories, power generation plants, and sewage facilities built upon huge sleds and pulled by steel tracked and or rubber tracked vehicles (Bader and Guimond, 2004). All camp activities including wastewater, liquid and solid waste and oil products must follow the ‘Guidelines for waste handling from temporary work camps’ (Naalakkersuisut) or ‘Field rules’ (Link), depending on the number of person-days in the camp. For camp activities exceeding 300 person-days, the ‘Guidelines for waste handling from temporary work camps’ must be followed. Person-days are defined as the sum of days each person has spent in the camp within one year to be counted from the establishment of the camp in a calendar year. As an example 15 people spending 30 days in a camp gives a sum of 450 person-days. A crew of about 50 persons will exceed 300 person-days in a week, and the ‘Guidelines for waste handling from temporary work camps’ seems most appropriate for terrestrial seismic surveys. The relevant documents can be found here.

4.5 Mitigation of fuel pollution

Storage of fuel shall follow the ‘Field rules’ (Link).

During equipment and vehicle storage or maintenance, the site shall be protected from leaking or dripping fuel and hazardous substances by the placement of drip pans or other surface liners designed to catch and hold fluids under the equipment/vehicle, or by creating an area for storage or maintenance using an impermeable liner or other suitable containment mechanism.

During fuel or hazardous substance transfer, secondary containment or a surface liner must be placed under all container or vehicle fuel tank inlet and outlet points, hose connections, and hose ends. Appropriate spill response equipment, sufficient to respond to a spill of up to 20 L, must be on hand during any transportation or handling of fuel or hazardous substances. Trained personnel shall attend transfer operations at all times.

At all times, when a vehicle stops for longer than 15 minutes a drip pan must be placed under the engine to prevent oil spills. All oil spills must be reported to the Greenland environmental authorities and appropriate handling and clean up must be described and carried out by the permit holder and at the expense of the damaging party.

4.6 Mitigation of vegetation disruption

Driving on snow only and only when the ground has hardened to a certain degree is recommended. Driving should be with low ground pressure vehicles. Vehicles should be operated in a manner such that the vegetative mat is not disturbed and blading or removal of the vegetative layer should be prohibited. Mushroom cups or blade covers should be used to reduce /topsoil disturbance. Vehicles that have gotten stuck should not be abandoned anywhere.

The acquisition lines should be oriented so as to minimize driving on vulnerable vegetation and crossing rivers- and crests. Avoid crests for example for crossing rivers. Line changes should be planned to take place on the beach or over shallow riffle river areas. Where those areas do not exist, or if snow bridges cannot be satisfactorily built to prevent damage of the river banks an environmentally preferred location should be identified by the Greenland environmental authorities.

No driving should be allowed in the spring and early summer when the ground is water saturated. Summer driving should only be allowed as the rare exception, and then only with low ground pressure vehicles, such as ‘rolligons’.

The final acquisition grid and seismic program should be approved by the Greenland environmental authorities before any activity.

Periodic site inspections should be conducted during and following winter operations. If vegetation damage is located, a rehabilitation plan must be prepared and executed by the damaging party.

4.6.1 Helping regrowth

Severe damages to the vegetation must require that regrowth is assured. In case of such impacts, the damages must be documented and reported to the Greenland environmental authorities and a plan for regrowth must be developed together with the authorities following site inspections and executed by the damaging party.

4.6.2 Invasion of non-native flora and fauna

Non-native invasive species may inadvertently be introduced into an area with crews and equipment. This can displace and even eliminate native flora and fauna. Because vehicles and machinery may carry exotic seeds and animals, vehicles and machinery that have been used in other countries must be cleaned prior to commencement of work in Greenland. In addition, equipment that has been used in low arctic Greenland should be cleaned before use in high Arctic Greenland.

4.7 Mitigation of subsides and thermokarst

Allowing winter seismics only with low ground pressure tires while observing thresholds for ground hardness and temperature as well as snow cover thickness will mitigate subsides and thermokarst, as well as permanent thawing of permafrost. Especially care must be executed in water saturated areas to ensure that the ground is sufficiently hard.

No driving in spring when the ground is water saturated.

Driving in summer only as a rare exception and then on rolligons or other correspondingly low ground pressure vehicle.

4.8 Mitigation of dust spread

Dust spread is mainly a problem in summer and is best mitigated by preventing disruption of the vegetation cover exposing bare ground, and by avoiding mischarges during explosive seismic surveys that may lead to dust spread and cratering. Bare soil will lead to dust spread and may result in erosion. Disruption of vegetation cover can be mitigated by following the guidelines above.

Soil on the snow should be avoided and removed, because it will settle on the vegetation following thaw. Soil polluted snow should be removed to rivers where it will be taken to sea during spring.

Plants that have been covered in soil or dust should be watered to remove the soil.

4.9 Mitigation of disturbance of wildlife

It is primarily caribou, muskoxen and geese that are vulnerable to disturbance from seismic surveys in Greenland. However by careful planning, for example by avoiding activities and traffic (helicopters and snow mobiles) in especially sensitive areas and periods these impacts may be mitigated. The 'Field rules' (Link) designate 'areas important to wildlife' which are areas especially sensitive to disturbance for relevant species and here activities are regulated in order to reduce disturbance (Link). Seismic surveys should be planned to exclude activities in these areas and periods. The strategic environmental impact assessment (SEIA) for Disko / Nussuaq (Aastrup et al., 2016) and for Jameson Land (Hansen et al., 2012) also describes the most sensitive areas for caribou, musk oxen, geese and sea ducks, and these SEIAs should be consulted during the Environmental Impact Assessment process, as well as when planning a seismic survey.

Aircraft operators should be made aware of the potential effects of low-flying aircraft on wildlife and take the appropriate actions (maintaining altitudes above 500 m whenever possible) to minimize those effects. Aircrafts should where possible move in a predictable manner following straight lines.

To protect fish habitat, surveys of larger lakes and rivers that may support winter populations will identify where winter water withdrawals (for example for construction of ice roads) need to be restricted. Water depths in fish bearing waters must have adequate unfrozen water to provide habitat and avoid depletion of dissolved oxygen. For summer water use, it is also important to understand which rivers may support anadromous Arctic char populations, and sufficient water levels should be maintained (Frederiksen et al. 2017).

Wildlife may be disturbed by both the noise, smell and light of seismic activities (Figure 6). The noise and smell is omnipresent, however the light pollution is only during the dark season. The use of light in camp sites should be restricted so as to focus light inside the camp only. Lights should be turned off where- and whenever possible. Noise should also be minimized at the camp site.

Figure 6. Noise, light and smell may disturb wildlife over large areas. Here a camp during the winter seismic campaign in Jameson Land in the 1980ies. Photo: Christian Glahder.

Wildlife such as Arctic fox, Arctic wolf, polar bear and raven may be attracted to the camp site by the smell from cooking and garbage (Figure 7). Temporary camps should be managed in a way that discourage wildlife interest and reward (strict camp rules regarding feeding wildlife, managing cooking facilities and food wastes, trip lines, deterrent guidelines etc.). All camp activities should apply to the 'Field rules' (Link) and 'waste handling guidelines' that can be found here. Garbage should be stored securely in bear safe containers as described in the 'Field rules'. Ensuring that crews are aware of potential wildlife interaction concerns and the results of abandoning food remains and drink containers is very important. Polar bears attracted to the camp site may also be problematic and dangerous, and it is proposed that *all personnel* must be thoroughly trained in bear encounters to protect themselves and the bear.

Muskoxen, may be problematic and potentially aggressive and a minimum distance of 100 m must be observed at all times.

Fishing and hunting should not be allowed.

Figure 7. Polar bear scavenging on a dump site. Bears, wolves, foxes and ravens may be attracted to the camp site by the smell from kitchen, sewage and dump sites. Proper handling of garbage is very important for the safety of humans and bears. Photo: David Boertmann.

Mitigation using prepared hard-frozen tracks, ice bridges and ice roads

Experiences from Jameson Land in the 1980'es showed a good effect in protecting the vegetation by preparing tracks 24 hours in advance of the vibroseis train (see chapter 3). This was done by having a dozer or a 'Nodwell' lay out a track to compact the snow. This compressed the snow allowing it to freeze up and harden before the entire seismic train arrived a day later. The success of this method, however, depended on the snow. Snow with a high content of larger crystals had a reduced carrying capacity (Holt, 1985) and therefore a reduced support of the heavy trucks. In Alaska ice-roads are constructed over water courses and where the traffic is expected to be most intense.

Snow ramps, snow / ice bridges or cribbing should be used to cross frozen water bodies to preclude cutting, eroding or degrading of their banks. Snow ramps and snow / ice bridges should be substantially free of soil and debris and of sufficient thickness to support vehicles. Snow / ice bridges should be removed or breached, and cribbing removed after final use or prior to breakup, whichever occurs first. In order to ensure the mitigative success of a winter-only-seismic program, the construction processes of such ice roads and ice-bridges should be overseen by the Greenland environmental authorities, and the construction plans should be site-specific to accommodate different soil properties and sensitivities, as well as to approve the local water source. Local water bodies such as anadromous lakes may be sensitive to withdrawal of water during winter. Increased communication between companies and the Greenland environmental authorities, especially in-person contact with contractors will contribute to the success of these mitigation practices.

Table 3. Résumé of potential impacts and possible, but non-exhaustive, mitigation actions.

Impacts	Mitigation
1) Impacts to terrain and vegetation Thawing of permafrost Erosion Subsidence Thermokarst Changes to hydrology	• Seismics only on snow covered hard frozen ground (Thresholds for snow depth and ground hardness should be established) • Avoidance of sensitive areas and areas with rare species • Use of prepared hard frozen tracks • Use of low ground pressure vehicles • Avoid crossing of rivers and crests
2) Impacts to wildlife Disturbance	• Avoidance of sensitive areas and areas with rare species • Avoidance of sensitive periods and areas. • Safety zones and heights for flights of helicopters and fixed wing aircrafts.

The mitigative measures shall moreover be evaluated for their own potential environmental impacts. For example the use of helicopters for transporting drill rigs or other equipment will be the best way to protect sensitive vegetation and terrain, but it have also the potential to disturb sensitive wildlife in an area.

Muskoxen in an East Greenland landscape. Photo: Line A. Kyhn.

5 Proposed set-up for guidelines for terrestrial seismic surveys

5.1 Objectives

The objectives of the proposed concept for guidelines is to minimize the impacts from terrestrial seismic surveys on the environment. The possible effects are outlined in chapter 2, following a non-exhaustive list of mitigation actions in chapter 4. The main objective of the proposed concept for guidelines is to reduce the risk of significant population impacts on flora or fauna. Secondly, the objective is to reduce aesthetic damages to the pristine arctic landscape by protecting the vegetation cover and terrain.

5.2 Regulatory set-up

Terrestrial seismic operations will lead to impacts on the environment, and DCE suggest that guidelines for terrestrial seismic surveys are conducted as an Environmental Impact Assessment (EIA) process as outlined in table 4, where the company has to deliver an EIA during the application procedure. If the projects during the scoping phase is judged to have only minor impacts to the environment, the company can be requested to deliver an Environmental Mitigation Assessment (EMA) instead of an EIA. An EMA is a reduced EIA focusing on the mitigation of environmental impacts from the activities.

The EIA should describe all potential impacts of the planned activities applied for, including all aspects of the camp, such as establishment, moving and closing the camp, sewage and waste handling, handling of fuel, safety, wildlife interactions etc. The relevant legislation and guidelines from the Greenland authorities regarding camp and field activities can be found here.

The purpose of the scoping phase is to identify all environmental issues including local knowledge to be addressed in the EIA report and should be used to plan the environmental study program of the project. The scoping should therefore identify all issues which may impact the environment. The Greenland environmental authorities should publish the company's project description and scoping documents for public pre-consultation for 35 days in accordance with the provisions of *The Mineral Resources Act*. The company should evaluate the comments received during the public consultation and consider revision of the project as a result of the public consultation.

A detailed plan for the EIA process, including an environmental study program, should be forwarded to and approved by the Greenland environmental authorities, prior to the start of the EIA process. The plan should include a preliminary assessment of the potential environmental impacts of the project.

Table 4. Suggested steps for preparation of an EIA/EMA before project approval.

Step	Topic
1.	Scoping phase. After preliminary consultations between the company, EAMRA[1] and their scientific advisors (DCE[2]/GINR[3]) the company prepares a scoping report and forwards it to EAMRA.
2.	EAMRA makes the company's scoping report available for public consultation for 35 days.
3.	EAMRA and its scientific advisors decides whether the applied project requires an Environmental Impact Assessment (EIA) or an Environmental Mitigation Assessment (EMA).
4.	The company evaluates the comments received during the public pre-consultation and considers revision of the project.
5.	The company prepares a final scoping report for approval by EAMRA.
6.	The company prepares an environmental study program including a program for environmental baseline studies, project-related studies and other studies in consultation with EAMRA and EAMRA's scientific advisors. This program should be prepared and kept updated to secure data necessary to produce the final EIA/EMA. The program should be approved by EAMRA involving consultations on a regular basis.
7.	The company proposes a table of contents or Terms of Reference (ToR) for the EIA/EMA to EAMRA.
8.	EAMRA and EAMRA's scientific advisors review the proposed ToR for the EIA/EMA and provide feedback. ToR needs approval by the authorities.
9.	The company forwards an EIA/EMA draft to EAMRA.
10.	EAMRA and EAMRA's scientific advisors review the EIA/EMA draft and provide feedback.
11.	The company forwards a revised EIA/EMA draft including appropriate revisions to EAMRA EAMRA approves the document for the public hearing process.
12.	EAMRA publishes the revised EIA/EMA draft for public consultation for minimum 8 weeks in accordance with the Mineral Resources Act. During the consultation period, public hearings should be organized in towns and villages which are particularly affected by the activities.
13.	The company prepares a white paper which addresses the questions and comments raised during the public consultation and hearing meetings.
14.	EAMRA and EAMRA's scientific advisors review and give feedback on the white paper to the company.
	The company submits a final EIA/EMA draft including the white paper to EAMRA for Naalakkersuisuts approval. If Naalakkersuisut decides to grant a seismic program permit, EAMRA will use the EIA/EMA as a basis document for defining terms and requirements for approval of the company seismic program.
	[1]EAMRA: Environmental Agency for Mineral Resource Activities, Greenland Government [2]DCE: Danish Centre for Environment and Energy, http://dce.au.dk/en/ [3]GINR: Greenland Institute of Natural Resources, www.natur.gl/en.

5.3 Environmental Study Program

The company should prepare an environmental study program including a program for environmental baseline studies, project-related studies and other studies in consultation with the Greenland environmental authorities and their scientific advisors. The program should include relevant issues listed in box I and II. The program should be prepared and kept updated to secure that data necessary to produce the EIA are available. The program should be developed in cooperation with the Greenland environmental authorities and their advisors.

The environmental study program shall include

- Environmental baseline studies
- Project-related studies
- Other environmental studies.

The purpose of the environmental baseline studies is to describe the state of the environment prior to seismic exploration. Baseline studies are needed in order to assess the potential and actual environmental impacts from the seismic operation, and that these do not exceed those described in the EIA and accepted by the authorities (See box I & II).

Project-related studies include defining start date for the seismic operations as well as assigning seismic lines, where in time and space the operation may lead to the least impacts on the environment. Project related studies should include studies on snow depth, density and distribution as well as on ground hardness, mapping of areas with sensitive vegetation, distribution and migration of wildlife, designation of sensitive areas and time for wildlife, and mapping of the area with respect to where and how rivers and crests may be crossed with the least impact to the environment (See box I & II).

Other environmental studies may include topics that need to be clarified for the EIA (see the Strategic Environmental Impact Assessment of the area), such as mapping of permafrost, measurements and mapping of active layer (see box I & II).

The program for environmental baseline studies, project-related studies and other environmental studies should be developed in consultation with the Greenland environmental authorities and their scientific advisors and it shall be formally approved. All environmental data collected in connection with seismic activities shall be submitted to DCE / GINR for inclusion in the environmental databases maintained for the Greenland Government. Data should be submitted to DCE / GINR in formats agreed to by the all parties.

5.4 Environmental Impact Assessment (EIA)

The purpose of EIA guidelines is to make companies aware of the environmental issues which must be addressed as part of an EIA at an early stage in the project.

Aims of the EIA are

- To describe the nature and the environment, as well as evaluate the possible environmental impacts of the proposed project
- To provide a basis for the consideration of the proposed project for Naalakkersuisut (the Government of Greenland)
- To provide a basis for public participation in the decision-making process
- To give the authorities all information necessary to determine the conditions of a permission and approval of a proposed project.

Thorough identification and analysis of potential impacts on the environment in relation to the specific landscape, flora, vegetation and wildlife, will allow planning of the seismic operation with respect to the least impact on the environment from the activities. Such analysis should be explicit and incorporated in the EIA. *All* potential impacts on the environment along with the possibilities for, and choice of, mitigation actions (see examples in table 3 and chapter 4) should be addressed. This pertains to all aspects on shore (see chapter 2) as well as offshore and nearshore if the operation arrives by vessel. In box I and

II are listed the key elements to be incorporated in the EIA, which will allow setting the start date of winter seismic operations.

> **Box I:**
>
> **Key elements in an EIA for onshore seismic activities regarding terrain and vegetation**
>
> Equipment specifications and methods including vehicle ground pressure and traction
>
> Detailed terrain map
> Detailed vegetation map with indication of sensitive areas & periods
>
> Description of expected snow conditions during survey
> Description of expected active layer during survey
>
> Description of planned monitoring of snow and active layer up to and during survey season
>
> Description of planned driving and survey lines and how the program is mitigated and adapted using synoptic monitoring data and the expected resulting impact on vegetation and terrain.

5.5 Basis for the EIA

The seismic exploration should be carried out in accordance with good international practice and in a safe and environmentally acceptable manner, e.g.:

- The Best Available Technique (BAT), Best Environmental Practice (BEP) and Best Practicable Control Technology (BPT) shall be applied at all times. References should be made to BAT reference documents (BREF documents).

- Emissions from non-road mobile machinery (e.g. excavators, bulldozers, front loaders, back loaders, drilling and seismic equipment) should as a main rule comply with EU environmental standards (EU directives on emissions from non-road mobile machinery etc.). US or DK standards should be used if EU standards not are available. Other standards may be used, if they according to BAT, BET and BPT represent a better solution.

- All relevant national rules and guidelines in Greenland must be met.

- All relevant international rules, guidelines and conventions must be met (also IMO Ballast Water Convention, IMO MARPOL etc. for operations arriving by vessel).

- The threshold values for discharges / emissions and environmental quality criteria determined by the Greenland environmental authorities must be met. Dilution of waste water, process water and other water with river water, for example in order to comply with the threshold values, is not an acceptable practice.

- The environmental management shall comply with the requirements set out in ISO 14001 or equivalent standard. A self-control program shall be set up to ensure and document that discharges / emissions to the environment, activities, handling and other processes comply with requirements and limits specified by the Greenland environmental authorities.

Box II:

Key elements in an EIA for onshore seismic activities regarding wildlife

Timing of seismic operation in relation to sensitive periods for relevant fauna
List of relevant fauna

Detailed seasonal maps of sensitive areas for each species
Description of expected disturbances to relevant species
Description of planned mitigation actions for the relevant species
Description of planned wildlife monitoring during surveys

5.6 Content of an EIA

The suggested, but potentially not exhaustive EIA contents are listed in table 5.

Photo: Line A. Kyhn

Table 5. Content of an EIA.

The following elements should as a minimum be included in the EIA:

- An **extended non-technical summary including maps and figures**. The document should be easy to read and understand for the public and decision makers as a stand-alone document.
- An **introduction** describing the project, its background and objectives.
- A thorough description of the state of the **environment** before the start-up of seismic operation.
- A description of the **seismic project** including how to define start and end date.
- A description of considered **alternatives** and why they were rejected.
- An assessment of **environmental impacts** of the project, with an evaluation of alternative options to the preferred project option.
- **Cumulative impacts** of existing and expected future already planned projects that could influence the conclusions of the EIA.
- An **environmental management plan (EMP)** describing management, control and mitigation of the identified impacts, emergency plans for unplanned events (fire, transport accidents and releases to the environment) and training programs for employees related to, for example, environmental matters.
- An **environmental monitoring plan** describing how all aspects relevant to environmental issues will be monitored, such as changes to permafrost, vegetation, discharges to water, use and handling of fuel and chemicals, and their effects on the environment and disturbance of wildlife. Please be aware that the established environmental baseline (Environmental Baseline Program) must cover all items included in the monitoring plan.
- An assessment of issues related to any **archaeological findings**.
- **Public consultation**.
- **Conclusions**.
- **References** used in the EIA process and **glossary** of terms and abbreviations.

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List of appendices

Appendix 1: List of all study and monitoring reports produced during the seismic surveys in Jameson land 1986-1989.

MINISTRY OF ENERGY
MINERAL RESOURCES ADMINISTRATION FOR GREENLAND

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LIST OF REPORTS ON BACKGROUND STUDIES ETC. IN JAMESON LAND IN CONNECTION WITH EXPLORATION AND POSSIBLY PRODUCTION ACTIVITIES IN THE REGION.

I. Reports prepared by or for the Greenland Environmental Research Institute (GM).

1. "Literature on Jameson Land concerning Vegetation, Bird-life and Terrain Sensitivity" (March 1981), prepared by GM. (E)
2. "Musk Ox Studies in Jameson Land, 1982" (December 1982), prepared for GM by Wildlife Biology Station Kalø. (?)
3. "Studies of Geese in Jameson Land, 1982" (December 1982), prepared for GM by Zoological Museum, Copenhagen University. (?)
4. "Effects of an All-Terrain Cycle (ATC) on Fen Vegetation in Jameson Land, Northeast Greenland" (October 1983), prepared for GM by Greenland Botanical Survey, Botanical Museum. (E)
5. "Effects of an All-Terrain Vehicle (ATV) on Plant Communities in Jameson Land, Northeast Greenland" (October 1983), prepared for GM by Greenland Botanical Survey, Botanical Museum. (E)
6. "Marine Mammals and Marine Birds in Scoresby Sund: Hunting and Occurrence, 1983" (December 1983), prepared for the Mineral Resources Administration and GM by the consulting firm Danbiu ApS. (S)
7. "Botanical Studies in Jameson Land, 1982" (1983), prepared for GM by Greenland Botanical Survey, Botanical Museum. (?)
8. "Botanical Studies in Jameson Land, 1983" (February 1984), prepared for GM by Greenland Botanical Survey, Botanical Museum. (S)
9. "Studies of Geese in Jameson Land, 1983" (February 1984), prepared for GM by Zoological Museum, Copenhagen University. (S)
10. "Musk Ox Studies in Jameson Land, 1983" (May 1984), prepared

for GM by Wildlife Biology Station Kalø. **(?)**

11. "Transportation Corridor between Constable Pynt and Central Jameson Land, East Greenland" (December 1984), prepared by GM and GFU. **(E)**
12. "Snow Studies in relation to Vegetation, Jameson Land, 1984" (1984), prepared for GM by Greenland Botanical Survey, Botanical Museum. **(?)**
13. "Aerial Surveys of Ringed Seals (Phoca Hispida) in the Kong Oscars Fjord and Scoresby Sund Areas (East Greenland) in June 1984. A Preliminary report." (1984), prepared by GM. **(E)**
14. "Reactions of Ringed Seals (Phoca Hispida) to a Low-Flying Aircraft in the Scoresby Sund and Kong Oscars Fjord Areas, East Greenland. A Preliminary Report." (1984), prepared by GM. **(E)**
15. "Distribution of Marine Mammals in the Scoresbysund Area, Off Liverpool Land and in Kong Oscars Fjord in September 1983" (1983), prepared by GM. **(E)**
16. "Distribution and Abundance of Narwhals in the Scoresby Sund area, Off Liverpool Land and in Kong Oscars Fjord in September 1983. Int. Whal. Comm. Scientific Committee 1984, paper SC/36/SM 11" (1984), prepared by GM. **(E)**
17. "Snow Investigations in Relation to Vegetation - Jameson Land, East Greenland, October 1984" (January 1985), prepared for the Mineral Resources Administration and GM by the consultative firm Danbiu ApS. **(E)**
18. "Marine Mammals in East Greenland - A Literature Search" (January 1985), prepared for the Mineral Resources Administration and GM by the consultative firm Danbiu ApS. **(?)**
19. "Aerial Count of Marine Mammals in Fjord and Sea Areas Around Jameson Land, September 1984" (April 1985), prepared by GM. (D)
20. "Marine Mammals in East Greenland (a Literature Search)" (January 1985), prepared for GM by the consultative firm Danbiu ApS. **(?)**
21. "Musk Ox Studies in Jameson Land 1984-85 and the Populations Ecology 1982-85" (August 1985), prepared for GM by the Wildlife Biology Station Kalø. **(partly in English).**
22. "The Geese in Jameson Land. Results of Studies 1982-84." (August 1985), prepared for GM by the Zoological Museum, Copenhagen University. **(?)**

23. "Study of some All-Terrain Vehicle's Effect on Vegetation and Soil in Jameson Land, 1982-85" (December 1985), prepared for GM by Greenland Botanical Survey. (S)
24. "Little Auks in Scoresby Sund, 1985" (December 1986), prepared for GM by the Zoological Museum, Copenhagen University. (S)
25. "Oceanographic, Ice and Meteorological Conditions in Jameson Land, East Greenland" (March 1986), prepared for GM by Geophysical Institute. (?)
26. "Fresh Water Biological Reconnaissance in Jameson Land, 1985" (March 1986), prepared by GM. (S)
27. "Disturbance of Musk Ox in Connection with the Winter Seismic Work in Jameson Land, January-March 1986" (September 1986), prepared by GM. (S)
28. "Vegetation Mapping of Jameson Land 1982-86" (December 1986), prepared for GM by Greenland Botanical Survey. (S)
29. "Aerial Surveys of Ringed Seals (Phoca Hispida) in Kong Oscars Fjord and Scoresby Sund Areas, June 1984. Final Report." (February 1988), prepared by GM. (S)
30. "The Geese in Jameson Land. 1987." (July 1988), prepared by GM. (S)
31. "Assessment of the Impact of Helicopter Disturbance on Moulting Pink-footed Geese and Barnacle Geese in Jameson Land" (May 1989), prepared by GM. (E)
32. "The Geese in Jameson Land. 1988." (July 1989), prepared by GM. (?)

II. Reports prepared by or for the Greenland Field Investigations (GFU).

1. "Literature Study of Meteorological, Ice and Hydrographical Studies, East Greenland 1980" (July 1980), prepared for GFU by the Danish Hydraulic Institute. (?)
2. "Geotechnical Report No. 1" (December 5, 1980), prepared for GFU by the Danish Geotechnical Institute. (?)
3. "Environmental Studies Offshore East Greenland, 1980 - Meteorological, Hydrographic and Ice Investigations" (April 1981), prepared for GFU by the Danish Hydraulic Institute. (E)
4. "Environmental Studies Offshore East Greenland, 1981 - Ice,

Meteorological and Hydrographic Conditions" (January 1982), prepared for GFU by the Danish Hydraulic Institute. (?)

5. "Ambient Noise in the Sea Off Scoresbysund, East Greenland" (January 1982), prepared for GFU by the consultative firm Ødegaard & Danneskjold-Samsøe. **(E)**
6. "Evaluation of the Navigation Possibilities to and from Jameson Land" (February 1982), prepared for GFU by the Danish Hydraulic Institute. **(?)**
7. "Physical Environment in Carlsberg Fjord and Flemming Fjord" (March 1982), supplementary report to the report listed in point 6. **(?)**
8. "Geotechnical Report No. 2" (April 4, 1982), prepared for GFU by the Danish Geotechnical Institute. **(?)**
9. "Pre-investigation Report, Jameson Land, 1982", prepared by GFU.
10. "Geotechnical Report No. 3" incl. 4 annex files (January 27, 1983), prepared for GFU by the Danish Geotechnical Institute. **(?)**
11. "Pre-investigation, Jameson Land, Station 133, 1982" (January 1983), prepared by GFU. **(?)**
12. "Geotechnical Report No. 4" (June 9, 1983), prepared for GFU by the Danish Geotechnical Institute. **(?)**
13. "Geotechnical Report No. 1-2" (October 5, 1983), prepared for GFU by the Danish Geotechnical Institute. **(?)**
14. "Overland Transportation, Flemming Fjord, Jameson Land, 1983" (October 1983), prepared by GFU. **(E)**
15. "Supply Base, Flemming Fjord, Jameson Land, 1983" (October 1983), prepared by GFU. **(E)**
16. "Background Studies in Jameson Land, 1982-83" (October 1983), prepared by GFU. **(E)**
17. "An Analysis of Ice Conditions in Flemming Fjord, East Greenland" (November 1983), prepared for GFU by the Danish Hydraulic Institute. (E)
18. "Pre-investigation, Jameson Land, 1983" (1983), prepared by GFU. (D)
19. "Snow Conditions in Jameson Land, April 1984" (1984), prepared for GFU by the Geographical Institute, Copenhagen University. (E)
20. "Snow as a Wearing Surface for Vehicular Traffic - Jameson Land, East Greenland" (April 1984), prepared by GFU. **(E)**
21. "Photo Registration, Jameson Land" (April 1984), prepared by

GFU as supplementary report to the reports listed in points 19 and 20. (D)

22. "Transportation Corridor between Constable Pynt and Central Jameson Land, East Greenland" (December 1984), prepared by GM and GFU. (E)
23. "Snow Studies, Jameson Land, October 1984" (January 1985), prepared by GFU and GM with consulting assistance by the Geographical Institute, Copenhagen University. (E)
24. "Geotechnical Report No. 5" incl. 2 annex files, (February 11, 1985), prepared for GFU by the Danish Geotechnical Institute. (D)
25. "Geotechnical Report No. 6" incl. 2 annex files, (February 11, 1985), prepared for GFU by the Danish Geotechnical Institute. (D)
26. "Preliminary Climate Studies, Jameson Land, East Greenland" (May 1985), prepared by GFU. (E)
27. "Test and Work with GFU-Seiga-ATV Vehicles" (1985), prepared by GFU. (D)
28. "Geotechnical Report No. 7" (September 30, 1985), prepared for GFU by the Danish Geotechnical Institute. (D)
29. "Geotechnical Report No. 8" (October 24, 1985), prepared for GFU by the Danish Geotechnical Institute. (D)
30. "Geotechnical Report No. 9" including 1 annex file (March 21, 1985), prepared for GFU by the Danish Geotechnical Institute.
31. "Snow Conditions in Jameson Land, April/May 1985" (April 1986), prepared by GFU. (E)
32. "Automatic Measuring Stations, Jameson Land" (April 1986), prepared by GFU. (D)
33. "Geomorphology, Jameson Land, Climate" (June 1986), preliminary edition, prepared by GFU. (D)
34. "Geotechnical Report No. 10" (July 1986), prepared for GFU by the Danish Geotechnical Institute. (D)
35. "Transport Corridors in Central Jameson Land" (December 1986), prepared by GFU. (D)
36. "Geotechnical Report No. 11" (January 19, 1987), prepared for GFU by the Danish Geotechnical Institute. (D)
37. "Geotechnical Report No. 12" (January 23, 1987), prepared for GFU by the Danish Geotechnical Institute. (D)
38. "Geomorphology, Jameson Land, Part-Report No. 1, Main Regions" (June 1987), prepared by GFU. (S)

39. "Geomorphology of Jameson Land - Region 5" (December 1987), prepared by GFU. **(E)**
40. "The Automatic Temperature Measuring Stations, Jameson Land, Summer 86 and 87" (January 1988), prepared by GFU. **(D)**
41. "Geomorphology, Jameson Land, Part-Report No. 3, Region 3" (October 1988), prepared by GFU. **(S)**
42. "Geomorphology, Jameson Land, Part-Report No. 4, Region 8 and 11" (April 1989), prepared by GFU. **(S)**
43. "Geomorphology, Jameson Land, Part-Report No. 5, Region 9" (June 1989), prepared by GFU. **(S)**
44. "Clima, Jameson Land" (July 1989), prepared by GFU. **(E)**
45. "Geomorphology, Jameson Land, Part-Report No. 6, Region 7 and 13" (January 1990), prepared by GFU. **(S)**
46. "Geomorphology, Jameson Land, Part-Report No. 7, Pingel Dal, Ørsted Dal and Coloradodal" (March 1990), prepared by GFU. **(S)**
47. "The Automatic Temperature Measuring Stations, Jameson Land, 1988 and 1989" (April 1990), prepared by GFU. **(S)**

III. Reports prepared by Greenland National Museum.

1. "Report on Greenland National Museum's Archaeological Reconnaissance in Jameson Land, Scoresbysund District, Summer 1982", prepared by Greenland National Museum. **(D)**
2. "Report on Greenland National Museum's Archaeological Reconnaissance in Scoresbysund District, Summer 1983", prepared by Greenland National Museum. **(D)**
3. Report on Excavation of 2 Winter House Ruins, FM 70 E I-IV, 1 A&B, in Jameson Land, 1983", prepared by Greenland National Museum. **(D)**
4. "Report on Greenland National Museum's Archaeological Reconnaissance in Scoresbysund District, Summer 1984", prepared by Greenland National Museum. **(D)**
5. "Mapping of Culture-Historical Interests in Jameson Land and Scoresbysund, 1982-84" (1985), prepared by Greenland National Museum. **(D)**
6. "Mapping of Culture-Historical Interests in Jameson Land 1985" (1986), prepared by Greenland National Museum. **(D)**
7. "Archaeological Reconnaissance in Jameson Land, North East Green-

land. Summer 1986" (1986), prepared by Greenland National Museum. (D)

8. "Report on Greenland National Museum/KNK's Archaeological Reconnaissance in Jameson Land, North East Greenland, summer 1987" (1987), prepared by Greenland National Museum. (D)

9. "Mapping of Culture-Historical Interests in Jameson Land 1988" (January 1989), prepared by Greenland National Museum. (D)

Code for Abbreviations.

(D): Report only in Danish.

(S): Report in Danish including English Summary.

(E): Report available in English.

ONSHORE SEISMIC SURVEYS IN GREENLAND

Background information for preparation of Guidelines to Environmental Impact Assessmentr

Onshore seismic surveys are carried out on land in search for hydrocarbon deposits below ground. Seismic surveys can cause damages to the vegetation, permafrost and landscape as well as disturb wildlife. This report contributes to the background information required to develop guidelines for how to conduct terrestrial seismic surveys in an environmentally responsible fashion.

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