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Review

What happens when the ice melts? Belugas, contaminants, ecosystems and human communities in the complexity of global change

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ABSTRACT

In general, it is important to examine the whole spectrum of interrelated fields while comprehending pollution, climate change or the environment, because some of their relevances are expected and others not. This study aims at comparatively examining different but interrelated ways of acquiring and communicating information on environmental changes, focusing on pollution in the Arctic, in particular Greenland. In the context of climate change, it discusses how heavily polluted and stressed Arctic marine ecosystems may be affected when ice melts. Bridging cultures of knowledge, this study claims that traditional knowledge together with natural science and studies of contaminants in Arctic marine ecosystems can indicate behavioural factors, elements acting as additional stressors on animals and communities relying on them. Furthermore, it explains the role of scientific engagement with local communities in not only the identification and verification of stressors, enhancing our understanding of them, but also the proposal of solutions to related problems.

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Contents

1. Introduction

Media impressions often indicate the Arctic as a pristine environment. The Arctic is usually visualized as a place with magnificent landscapes, calving glaciers and astounding wildlife. However, it is also an environment that is threatened by climate change, where polar bears roam with the disappearance of icescapes and Inuit communities are intimidated by diminishing sea ice, coastal erosion and loss of resources. The Arctic has also been affected by pollutants and contaminants from industrialized areas of the south. The Arctic, outside of the Russian North, has limited industry, almost no agriculture and only a few local areas, where organohalogen compounds (OHCs) have been used for pest control. At present, it is one of the regions of the world with high levels of pollutants. Contaminants, such as heavy metals and persistent organic pollutants (POPs), are present in marine ecosystems, biomagnifying themselves by their transport inside complex ecosystems, thus affecting the health of indigenous population. This results in the highest levels of contaminants found in humans (Dietz, 2008). Although substantial effort has been made to understand their origins, including transport, geographical and temporal trends as well as toxicity and biological effects, the complexity

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of the additional effects of climate change increases the relevance and importance of contaminants.

The following are the questions of concern: What happens when the ice melts?; and how will these heavily polluted and stressed marine ecosystems be affected when the ice melts, and what impact will this have on coastal communities near glaciers and ice environments?

In this study, the author focuses on Greenland, a region with high levels of toxins. It is important to understand the interrelationships between climate, environmental change and pollutants. Beluga whales are taken as an example in this study, and the stressors affecting not only this marine mammal but also communities along the coasts of Greenland are discussed. Studies conducted on pollutants in the Arctic and the traditional knowledge are also referred. The knowledge acquired by this way is unique, emphasizes the behaviour of beluga whales in this region, and helps understand the multiple stressors that they might face in the future, when the ice melts. The possible combined effect of pollutants and climate change on the beluga whales and the Inuit communities is also discussed.

2. Complexity of environments

Complexity of our environment should be considered in pollution and climate change, including the changes, future outcome and their effects on the environment. The environment provides conditions for the development, growth and damage of living things in it. Living things do not simply exist in the environment; rather, they constantly interact with it. The response of organisms changes with the conditions of the environment, which consists of a complex web of interactions among plants, animals, soil, water, temperature, light and other living and non-living things.

The following two important facts are needed to be considered: First, the perception of the terminology of the environment and environments in change (including the surrounding conditions) and second, the importance of an interdisciplinary approach in understanding environmental changes with regard to pollution, climate change or simply the environment. This study aims at investigating the different but interrelated ways of acquiring and communicating knowledge of pollution and environmental change in the Arctic, in particular Greenland.

In order to understand the different aspects of climate change and its effect on the environment and living beings, it is important to know how the global climate changes in general. The climate of an area depends on the interactions of a large number of elements, including solar insulation and radiation, and atmospheric circulations such as air pressure, wind, temperature and humidity (Born and Böcher, 2001). Furthermore, atmospheric circulation is directed, influenced and deflected by mountain ranges, pools of ocean waters of varying temperature, basins season and other chaotic elements (Gunn, 1984). Life systems change with these elements, making the comprehension and prediction of pollutants extremely complex.

Recently, the Godthåbsfjord, West Greenland, having terminating glaciers, glacial ice throughout the year and seasonal sea ice cover during winter, has been found to have two annual circulation phases, but currently been inferred to have four complex and distinctive circulation phases and current inflow (Mortensen et al., 2011, 2014), after many years of investigation of this complex fjord system. Thus, it has to be found whether the change of environmental settings has caused the addition of two more phases, with their signal becoming stronger, or whether the general knowledge of the fjord system has improved. In either case, this verifies that it is important to constantly monitor the environment to identify and understand future changes, such as changes caused by glacial melt-off; change of inflow from the West Greenland current, outflow, salinity, surface water temperature and stratification and changes altering the distribution and redistribution of contaminants and the scenarios of ocean acidification (OA) that might affect marine ecosystems and human communities.

In this study, the following elements are considered important for the physical environment of the fjord system: the sea, the currents and the oceans. Although we tend to treat them separately, the oceans interact in numerous ways with the atmosphere, the lithosphere (the earth's crust and upper mantle), the cryosphere (ice caps, glaciers and sea ice; areas where water is found in solid form) and the biosphere (marine and terrestrial living organisms). For example, the climate represents a dynamic state of the atmosphere, and it influences and, in turn, is influenced by processes carried out on land and in the oceans with response times ranging from a few days to hundreds of thousands of years. Furthermore, this emphasizes the complexity. Another example of interaction, and a vital component of the ocean's circulation pattern and the global climate, is the thermohaline circulation, which is an interaction between the temperature and salinity of seawater that are controlled by surface processes, causing dense water masses to sink, and thereby helping drive a global 'ocean circulation' of water movement (Pinet, 2009). This vertical flow of water – seen by the downwelling near Greenland as the warm saline water from the Irminger current, originating from the Gulf Stream, meets the cold Arctic seas – supplies dissolved oxygen to the deep sea as cold polar water, and, with its rich content of dissolved oxygen, sinks and slowly spreads across the sea floor for hundreds to thousands of years before welling up to the surface, reaching all the way to the Indian Ocean and Pacific Ocean. In addition to this complex knowledge of ocean currents, the deep water currents are directed by the bottom topography of oceans (Born and Böcher, 2001). Climate changes influence the deep water flow, because various atmospheric effects, such as evaporation, precipitation, sea ice formation and glacial melting, directly control the density of seawater that drives the global thermohaline circulation. Movement of subsurface water helps reduce atmospheric temperatures of the earth by adverting cold, deep polar waters to the lower latitudes while inducing the surface transports of warm subtropical and tropical waters to the temperate latitudes (Pinet, 2009). Thus, climate changes result in complex threads of feedback on heat exchange between air and water, which alter climate and ocean circulations. Warmer climate in the Arctic influences the surface water temperatures, the melting of glaciers and Greenland's ice cap, and thereby the inflow of freshwater to the North Atlantic Ocean. A misbalance in the dilution of saltwater and the water density influences this large and complex system both with routine effects and effects with a reservoir response that may first be observed in years or millennia to come.

Oceans are also viewed as an important contributing factor to the atmospheric CO_2 uptake and marine CO_2 exchange in connection with the Arctic Ocean's carbon cycle. Melting ice affects CO_2 exchange as a net sink or a source of CO_2 to the atmosphere (Søgaard, 2014). The worst atmospheric effect on the oceans, OA, is expected to be higher in areas of melting ice; however, as this implies, global warming might, to some extent, compensate for these effects (AMAP, 2013). In Greenland, the oceans have a stronger sink for CO_2 because of the higher biological carbon uptake and undersaturation induced by the input of glacial meltwater,[1] indicating that increased melting in connection with climate changes accelerates the processes, affecting the carbon dynamics and increasing the sink for CO_2 in the fjord system influenced by the melting glaciers (Meire et al., 2015). It can be regarded as a positive effect, but an increase of CO_2 uptake will result in OA. This would possibly undermine marine ecosystems, thereby damaging zooplankton and primary producers, some of the most important links of the Arctic marine ecosystem. Studies show that OA affects copepods differently across their different life stages and metabolism stages, and these effects suppress reproduction (Cripps et al., 2014) and damage population, and

[1] The strong CO_2 uptake can be explained by the thermodynamic effect on the surface water pCO_2 resulting from the mixing of fresh glacial meltwater and ambient saline fjord water, which results in a CO_2 uptake of 1.8 mg C kg^{-1} of glacial ice melted (Meire et al., 2015).

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may do so to other species in the same or other trophic levels, whereas considering the diversity of species, *Calanus* spp. only show minor responses to manipulated high CO_2 levels (Lewis et al., 2013). It is also important to consider the fact that the studied plantonic species cultured in laboratories do not exhibit genetic adaptation abilities as those in natural environments, which evokes the question whether the tested species react naturally. This, again, verifies the complexity and interrelationship between systems in connection with the global climate and the variations that have been and may be experienced in future.

> "*We are missing knowledge when it comes to ocean acidification. The idea is that the increasing amount of CO_2 in the atmosphere affects the balance of the carbon system in the oceans and then the pH value drops. This should dissolve the calcareous shells of some of the microscopic algae and animals. But at the same time the algae use CO_2 in the photosynthesis and other species of microscopic algae thrive better with more CO_2. We know that algae today, for example in the Nuuk Fjord and in Disko Bay easily can handle low and high pH values (from about 6 to 10). Photosynthesis increases the pH, and algae have been able to survive through time. Some of the pH decline we see in the Arctic happens also because the sea ice is disappearing and less ikaite in the ice dissolves. This reduces the surface water pH. Some of the pH drop is due to human emissions of CO_2 but other changes in microbial activity in the ocean can also play a role. Nature is complex*".
>
> [Søren Rysgaard, 2015]

At present, there have been signs of both salinity and CO_2 affecting our complex system not only climatically but also in relation to pollutants. It is important that these should be interpreted as regional settings. Low salinity and the presence of pollutants have threatened the ecosystem of the Baltic Sea. The dissolution of chemicals depends on the salinity and temperature. Together with the reduced salinity, it can increase the uptake of heavy metals by certain marine species, for example, the Baltic blue mussel, in which metabolic rates and enzyme activities change with salinity and temperature (Pfeifer et al., 2005), thereby altering the uptake and distribution of pollutants in the trophic layers. Awareness of this fact is less in Greenland.

2.1. Ecosystems and climate change

Changes of fish species related to climate change in the Arctic and around Greenland are expected in future. The changes of fish species, triggering changes of the biodiversity and food webs in the North Atlantic, might have not only ecological but also economical consequences on ecosystems, which, at present, have contributed to 39% of the global marine fish landing. Furthermore, these might play a crucial role in the distribution of contaminants. Marine biological interchanges begin when barriers (e.g. land bridges, mountain ranges, waterways and basins), existing over geological timescales, are disrupted, allowing the dispersion and exchange of species between historical isolated ecosystems. Particularly, in Greenland and the Arctic, biodiversity has been separated from larger biotic interchange because of the basins representing inhospitable conditions, such as low temperature and low productivity, maintaining the distinct fauna of the Arctic. Earlier, a warmer climate, with the reduction of sea ice, is expected to change currents, melt-off, surface water temperatures and animal diversity (Vibe, 1967). At present, these changes, together with pollutants, expanding and even escalating in the future, have possibly provided larger interchanges of marine species. The increase of warm currents can transport propagules in coastal environments, thereby increasing primary production, introducing new species of fish and altering the deposition and redeposition of contaminants. The interchange of competitors or predators between previously isolated regions can introduce new trophic interactions, resulting in reorganization of food webs and decline of local species population and/or biomass (Vibe, 1967; Vermeij, 1991a; Vermeij, 1991b; AMAP, 2002; Edelist et al., 2013; Wisz et al., 2015). The marine environments and ecosystems are being affected by eutrophication (Goolsby, 2000), selective overfishing (Myers and Worm, 2003), destructive practises such as bottom trawl and blast fishing (Morton and Blackmore, 2001; Meysman et al., 2006), upwelling due to change of currents, storminess, change of biological processes causing resuspension and redeposition of sediment-based contaminants and contaminant sinks and introduction of invasive species (Lewis et al., 2003). All of these bring contaminants with them that biomagnify through the trophic layers of the Arctic marine ecosystem, not least OA. These contaminants together with the changes of other environmental elements will be an additional stress factor in the impact of contaminants on animals (Philippart et al., 2011).

Some pollutants will sink, some will enter the ecosystem and some will revolatilize into the atmosphere. The partition of POPs that are released into the atmosphere does not only vary according to their physico-chemical properties, but is influenced by temperature, climate change and the whole system of elements (Jianmin et al., 2011).

Glaciers and ice acted as long-term reservoirs for heavy metals, sequestering and preserving airborne contaminants during the peak emission years 1950–1970, which will be released during the periods of melt-back (Blais et al., 1998; AMAP, 2002), together with airborne contaminants from industries of Asia, Europe and North America that have followed the natural wind patterns (Boutron et al., 1991, 1995; Sherrell et al., 2000; AMAP, 2002). At present, the airborne PAHs have been bound to particles,[2] with a run-off from Greenland of approximately 14 t/year entering the Arctic. The Arctic polar regimes also served as the global sink for airborne mercury (Hg). Two-thirds of Hg deposited in snow or ice have been estimated to revolatilize, and the remaining one-third entering aquatic environments through meltwater. It is also important to note that in general, ice melts in the most productive period, the bloom of the primary production. The following paragraphs address these questions: How will this result in higher biomagnifications? Or will it affect it at all? How will these deposited contaminants in snow and ice be redeposited in the future, and how will this affect the communities and animals living among these toxic flows? Will it be as first-hand exposure?

In general, glaciers melt as a result of high temperatures. Temperature has long been known as a parameter that modifies the chemistry of a number of chemical pollutants, resulting in significant alterations in their toxicities, for example, in fish. It is also accepted that a higher temperature increases the rate of uptake of pollutants via changes in ventilation rate in response to an increased metabolic rate and decreased oxygen solubility (Kennedy and Walsh, 1997; Schiedek et al., 2007). However, observations show that higher temperatures in the Arctic not only alter pollutants and toxicity thereby affecting fish species, but also increase the uptake of pollutants and decrease the tolerability of higher temperatures in the presence of certain organic chemicals. The multiple stressors can result in male-dominated populations and have negative effects on reproduction, immune systems, electron transport to mitochondria, neurological disorders, ceractic heart rate, endocrine and vitamin homeostasis, development and skeletal systems, liver and kidneys, hormones and behaviour in different species (Schiedek et al., 2007; Gabrielsen, 2015; Sonne et al., 2015).

Accumulated contaminants affect predators when a food resource disappears due to overfishing or when resource availability or temperature changes. The sudden use of large quantities of stored fat in stressed periods results in a change of metabolism and an immediate 'overdose' of contaminants, as these contaminants enter organs, blood and soft tissues from fat. The toxic metabolites increase with biomagnification (Gabrielsen, 2015). The latter not only shows how complex it is to understand the transport of contaminants and interactions in a changing

[2] Hydrocarbons related to fossil fuels, petrogenic PAHS, and pyrogenic PAHS are formed as trace contaminants by incomplete combustion of organic matter such as wood, fossil fuel, asphalt or industrial waste (Nahrgang, 2015).

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environment, and how these multiple stressors might affect ecosystems in the future, but it also infers how little knowledge we acquire about the actual outcome of the interaction of all these elements.

3. Use of traditional knowledge

In order to clearly understand the effects of climate change on marine biology, it is necessary to regularly observe fjords, coasts and their surroundings. It must include observations of climate conditions, wildlife and vegetation, which are the basis for human survival. Not only weekly and monthly, but daily observations have to be made. Thus, traditional knowledge plays an important role in understanding not only the climate changes, but also the fate of pollutants in this complex system. Hunting and fishing populations constitute a rich depository of environmental knowledge, which can be used to enhance scientific research and observations of a changing environment. Retention of a unique environmental knowledge by them should be acknowledged as an important proxy to understand the interaction between elements, both natural and non-natural, in the Arctic. Thus, it is important to bridge these cultures of knowledge.

A Millennium of Changing Environments in the Godthåbsfjord is a collection of information obtained from travels with old hunters, talks and interviews related to the topic of this study. This does not exclude information obtained from the author's family and friends and through her own observations. With this knowledge, the author wishes to demonstrate how local knowledge or traditional knowledge together with natural science and studies of the fate of contaminants in the Arctic marine ecosystems can indicate behavioural factors and elements that might act as additional stressors on animals and communities relying on them. It is important to note that this method can be used in other areas of the Arctic, in relation to not only indigenous life economies but also 'modern' economies built on fisheries and local knowledge acquired from communities relying on specific livestock. It can also be used by researchers, who have acquired knowledge about a specific environment through years of travel.

4. Getting the pollutants in Greenlandic settings straight

As mentioned in Introduction, the Arctic is popularly regarded as a pristine environment. However, it is not devoid of pollutants in the sea, snow, stratigraphic layers of glaciers and the marine ecosystems. Some areas of the Arctic have the highest exposure levels to persistent toxic contaminants, because of the long-distance transport of contaminants, long marine food chains including slow-growing species (Dietz, 2008), the global currents, air streams and, in general, the global emission of pollutants to this large system. Thus, the Arctic acts as the global sink of these pollutants. High toxicity levels are observed not only in marine environments but also in terrestrial environments, particularly in humans exposed to high levels of Hg, polychlorinated biphenyls (PCBs), dichlorodiphenyl dichloroethene (DDE), POPs, oxychlordane and toxaphene (Mulvad et al., 2007). The diet of a community is based on the top predators of the marine ecosystem, which are identified as the main source of exposure of contaminants. The high levels of contaminants are recognized to potentially affect children's mental development, resist infections and disturb hormones that are important for growth and sexual development (Dewailly and Weihe, 2003; De March et al., 1998, Dietz, 2008).

> "*The favored food mattak is among the most contaminated products. Toxins stay in the body and the women transmit the contaminants to their children when they give birth and nurse. Therefore, from a medical point of view one should basically stop eating marine mammals*".
>
> [Henning Sloth Pedersen (Sermitsiaq, 2015)]

Despite advising the Inuit population to minimize their intake of internal organs, mattak (adipose tissue) or animals of higher trophic levels, nutritional importance of these food sources should not be ignored. A change of diet may cause other health risks, with some being recognized throughout the Arctic, such as diabetes and obesity (Lynge, 1999). It may also cause symptoms of lack of vitamins and minerals, which are sustained by the cultural settings of the interaction of human and nature and hunting, thereby producing negative effects to the mental well-being. However, there have been contradicting studies that might undermine the literal truth of the risk regarding contaminants:

> "*We found that a regular intake of seal and whale meat was associated with higher lung function, with an effect in line with the effect of regular intake of vegetables. Blubber from whales, seals have a high content of anti-oxidants, and is among other things the main source of vitamin C in the Arctic*".
>
> [Dr. Celeste Porsbjerg, (Baines et al., 2015)]

> "*Our results suggest that in situ carcinoma is rare among Inuit and that, their traditional diet, which is rich in omega-3 polyunsaturated fatty acids and selenium, may be an important protective factor*".
>
> [(Dewailly et al., 2003)]

As a comment to Henning Sloth Pedersen's article, Henriette Berthelsen writes:

> "*Some years ago, we were told by the researchers that selenium influences the detoxification of heavy metals in a positive way and that selenium is found here in much higher levels than elsewhere. Selenium is found in fish, the meat and Greenlandic waters. Perhaps this explains why my family who have been fishermen and hunters all their lives, and lived on their catch, had no more heavy metals than others. They were healthy*".

This comment resembles many of the comments and discussions of the general public in relation to this article.

It is also important to note that Greenlanders live in a mixed-economy lifestyle, combining a subsistence economy and cash income, where a change in suspension will have large effects on a household.

An animal that implements all these elements – food, nutrients, culturally defined human–nature interactions and mental well-being – is the beluga whale.

> "*In the days of hunting with kayaks, schools of Beluga were usually pursued by a few hunters together, and the sharing game with each hunter was according to his role in the hunt. There was the "owner" he who first harpooned the Beluga, and there was his first "helper", who was the second to harpoon the whale, and the second "helper" and so on. The role of the individual determined his share, and the community was usually allocated a hunting share. Thus, knowledge of the behavior of the Belugas gave the skilled hunter an opportunity to be the first one to put a harpoon in the prey animal. This gave him respect and authority*".
>
> [Jens Dahl (Fehr and Hurst, 1996)]

This quote not only explains the value of this animal as a resource, but also the importance of knowing the behaviour of the people's hunted prey. Thus, the authors tries to explain what might happen when the ice melts in this complex system of environmental and climatic changes; changes in both the belugas and communities relying on these marine environments.

4.1. Qilalugaq Qaqortaq—the white whale

> "*The Beluga can be used as a biological indicator of a healthy arctic environment through the integration of climatic and ecological information*".
>
> [(Brennen, 2007)]

The beluga whale, *Delphinapterus leucas*, is called 'Qilalugaq qaqortaq' (the white whale) in Greenlandic. Beluga whales are

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circumpolar in distribution, feed on higher trophic levels following the ice and are hunted by indigenous people all over the Arctic. The value of this whale is amplified by both traditional knowledge of their behaviour and the cultural landscapes.

> "*My family moved to Qassinguit when the settlement of Ummanaq was closed. The settlement was just at a corner of a fjord, which the beluga would turn when migrating out of the fjord. My family had a house higher up so that they could keep an eye on the belugas*".
>
> [Angunnguaq, old hunter from Kapisillit]

The beluga whales have high levels of important nutrients: 200 g of meat has 280% Fe of the daily value (DV), 86% vitamin B-12 (DV), 104% selenium (Se, DV) and 106% protein (DV). Furthermore, 100 g of beluga whale oil generated by the consumption of mattak supplies 72% fatty saturated acids (DV), 46% vitamin A (DV), 57% vitamin D (DV) and 28% vitamin E (DV) (www.fda.gov). Thus, beluga whale diet is invaluable in these regions, as fruits and vegetables are costly, and are not readily available because of bad infrastructure.

> "*The sea ice is very important to the very existence of the Iñupiat people. The sea ice provides us with the rich vitamins and other minerals we need for our bodies to exist in the cold weather. The sea ice is a cashless subsistence way of life for our food. Other than the need for gas, the Iñupiat gather clothing and rich food from the sea ice. Our stomachs know when fresh food is available at different seasons of the year. We fill our ice cellars with the fresh food from the sea ice. This is the acquired taste of the Iñupiat people. I know because now at 61 years of age, my stomach is hungry when there is no fresh food on the table*".
>
> [Nancy Neakok Leavitt (Gearheard et al. 2013)]

Catching beluga whales is not only associated with providing food, but involves the aspects of travelling, hunting and community values. The Greenlandic word for food, Kalaalimernit (peace of a Greenlander), has multisensory and multiple meanings. It does not simply refer to meat or fish of local origin (Petersen, 1985 & Sowa, 2014). The subsistence activities are not only economic or of nutritional significance, but also an essential asset in preserving one's cultural routes and identity (Poppel and Kruse, 2009), as well as an important element in regards to both physical and mental well-being.

> "*When hunting with my family, we first of all travel; we travel through landscapes of smell, landscapes of sight and landscapes of history. It is a movement through a virtual map built upon stories, place names and history. When coming home with the catch, the meat is processed together with the children; it is shared with relatives and eaten with the family. When eating the meat, one can taste the smells that one has travelled through during one's hunt. One can taste what the animal has eaten and a palette of memories arise and are shared at the table of the hunt, recipes, memories of childhood and memories of environments. Hunting does not only bring food to the table but has a great social related importance*".
>
> [Ann Eileen Lennert, Nuuk]

One of the other negative effects of not gaining the same access to 'traditional foods' or nourishing its cultural importance to health is the rapid change of diet from traditional to processed foods, which has lead to an increased number of cases of obesity, cardiovascular disease and diabetes, together with the aforementioned well-being issues. It is observed throughout the Arctic that factors such as procurement of traditional knowledge, regulated hunting, restricted access to land (among others in connection with large-scale industries) and decrease in wildlife density are caused by not only environmental and climatic changes but also the increase of large-scale industries, pollution and noise, which have an impact on the well-being of society. In this regard, the decline in mental and physical well-being cannot be explained simply by maladaptation, discourses and change of perceptions and cultural and social changes. The hypothesis is that diet plays an important role in the mental health of circumpolar people and the Greenlandic society. Nancy K. McGrath-Hanna et al. state that omega-3 fatty acids and other rich nutrients in the traditional diet have positive effects on mental health and that the depletion of these fatty acids is associated with an increased risk of depression and possibly suicide. Furthermore, this outlines the importance of traditions and gaining access to familiar environments to both preserve mental health and achieve well-being via traditional food. Thus, the Beluga whales are of such high importance in their diet (McGrath-Hanna, 2003).

4.2. Characteristics contributing to vulnerability of the species

There have been only few studies conducted on contaminant levels and their exposure to beluga whales. The presence of pollutants is evident, but their distribution in the whales varies between different regions along the coasts of Greenland, and therefore depends on migrations routes and seasonal areas (Rydahl and Heide-Jørgensen, 2001; Dietz, 2008). In order to determine their effects and characteristics, long-term series are required, similarly to St. Lawrence Estuary (SLE), Canada (Letcher et al., 2010), where these whales have been studied for approximately 20 years, because of the ease of gaining access and examining stranded animals. Considering the diversities in region and population, these studies can still be used to determine the mechanism of pollutants affecting the belugas across the Arctic. The belugas from SLE have high concentrations of POPs including OHC. In addition to the responses to contaminants, pollutants and OA presented earlier, the whales with high levels of POPs had severe lesions (likely lethal), widespread infections and a high rate of neoplasia (De Guise et al., 1995a, 1998; Letcher et al., 2010; & Martineau et al., 1987, 1994). In general, the beluga whales have a long lifetime, delayed sexual maturity and low reproduction rate. The females, in particular those with calves, are philopatric to specific areas, being extremely tenacious in the occupation of their traditional areas of assembling, despite continued disturbance and the threat of being killed (COSEWIC, 2004a, 2004b). The whales' distinct summering and wintering areas are maintained culturally through maternal lines and defined migration routes (Turgeon et al., 2012). This strong adherence to specific areas is a large threat as it, on the contrary, may hinder recolonization of previously habituated areas, as observed in the Godthåbsfjord region in West Greenland.

> "*In early fall, the beluga whales would begin migrating out of the fjords. The belugas travelling out from the Ameralik fjord would be driven by kayaks to Qaquk. This area would become so shallow at low tide that the whales would strand and they would then be able to catch them very easily, as the whales would not be able to escape. This we did for many years, where we killed hundreds of whales, painting the waters red*".
>
> [Marius, old hunter from Kangeq]

Marine mammals with very limited range, including those to which sea ice is an important part of the habitat, such as the belugas, are particularly sensitive (Simmonds and Isaac, 2007).

> "*Hunters are complaining that no narwhals, belugas or bowheads are to be found this winter, the reason being the unusually small amount of sea ice in West Greenland this year. Systematic counts during the past 17 years show that the whales follow the ice as it moves west, which is why hunters are unable to find the animals this year*".
>
> [www.natur.gl]

The colour of their skin also implies the importance of ice environments to them in relation to camouflaging and avoiding attacks of predators of the sea; this is also observed when hunted by local hunters.

"*When the hunters approach*, *the beluga whales flee to the sea ice because they know that they can hide there*".

[Jens Erik, young hunter from Sisimiut]

Furthermore, tides and currents determine the movement and choice of habitats of whales.

"*Beluga whales are very sensitive to currents and follow the currents and tide*; *it was therefore easy to predict how they would swim out of the fjord*".

[Vittus, old hunter, Qornoq]

Melting of the ice not only changes their habitats, but also allows killer whales to gain easy access concurrently with less sea ice and cause change of currents, change of ecosystems, OA, habitat loss, increased shipping, noise, ecotourism, pollutants and stress.

In general, environments always have been evolving and changing, but the speed of their change is one of the largest threats to the beluga whales. This is because their ability to respond to rapid changes is limited. These changes might be derived from human activities, climate changes, pollution, habitat loss and disturbances resulting from increased industrial development, natural resource exploration, shipping activity and ambient noise. Ambient noise is one of the most important stressors, which causes displacements and stress. Beluga whales are very susceptible to noise of ocean vessels and seismic activity, and they respond to sudden changes in sound level more negatively than to continuous sound. Most belugas respond to noise from oil drilling by moving away (Awbrey and Stewart, 1983). Local observations reinforce this:

"*The beluga whales are very sensitive to sound. They never come close to our settlement because of all the noise that we make with our boats and activity*. *But when a storm has paralyzed our small settlement for several days*, *the beluga whales suddenly come all the way to our shores*, *until the peace is disrupted*".

[Apollo, hunter from Sattut]

"*If someone suddenly speeds up in the dinghy*, *the whales suddenly change their breathing and swimming trends and therefore unpredictable to read and hunt. Suddenly*, *they are popping up all over the place. It is important to be very quiet*".

[Jens Erik, young hunter from Sisimiut]

Marine seismic exploration can have significant negative impacts, potentially leading to delayed winter migration and subsequent ice entrapment (Heide-Jørgensen et al., 2013); the impacts that hunters have pointed out in community meetings with oil companies along the west coast of Greenland.

Another noise source comes from nature-based tourism:

"*Narwhals and especially beluga whales are very sensitive to noise*; *because of the cruise ships coming more and more to our hunting regions*, *the whales have disappeared. Now we have to decide if we wish to do tourism or hunt our traditional way*. *But this meat is extremely valuable for us because we cannot buy good meat in the store or vegetables*".

[Hunter, Illoqqortoormiut]

Nature-based tourism or eco-tourism offers several ways for people to enjoy nature. Although this type of tourism is strictly defined as an environmentally responsible travel form that contributes to conservation of biodiversity, sustains the well-being of local people, stresses local involvement, includes learning experiences of tourists, promises considerable economic rewards, employment and so on (Hoyt, 2001; & IFAW, 1999), the following questions are posed: Does this tourism, as established, really achieve a heightening appreciation of the environment, sustaining the well-being of local people, and at what cost?; Does it destroy the resources on which it depends as an addition of stressors to a marine mammal?

4.3. Fate of the Beluga

The contaminant 'cocktail' of environmental and climate change stressors might have one or more of the aforementioned effects on the beluga whale, because the corrective measures have been taken very recently. It is clear that stress caused by global climate change may reduce the potential to resist and recover from toxicant exposure. One challenge is to deal with the complexity of multiple stressors in natural environments, including chemical stressors. A combination of toxicant stress and environmental stressors, such as subsequent changes, heat stress, change in prey, change of habitat or anthropogenic influence, can often result in a 'stronger than additive effect' on animals. The mechanism of animals coping with these environmental stressors varies across species, specific combinations of stressors, the trophic level and response level. Thus, it is difficult to generally predict the mechanism of individual-level responses to climate and environmental changes and pollutants. Furthermore, the same animal species may react differently in different regions because of the given regional setting that may only have minor differences but major impact on the response and fate of that species. In order to understand these complex relations globally and regionally, long-term data series are required, where traditional knowledge may be highly beneficial.

Hunters could indicate stressors such as noise, traffic and exploitations, and also their mechanism of affecting not only the whales but also their own access to an important subsistence resource. Furthermore, they implied the importance of ice and currents as the natural habitat of the belugas, which is an additional stressor for environmental change. Together with the 'homing effect' of the belugas in these regions, these multiple stressors might provoke a change of metabolism and sudden 'overdose' of contaminants. The contaminants stored in the fat entering organs, blood and soft tissues in combination with the impacts of multiple stressors observed in other animals might result in observations similar to the belugas of SLE.

The communities of Greenland continue to rely on locally harvested food. This makes them vulnerable to the effects of environmental contaminants that concentrate in the Arctic food chains. This also resulted in reduced harvest in these areas and increase of effects overcoming other environmental stressors. It is evident that the successful long-term occupation of Greenland has only been possible because of their adaptive capacity (in social, economic and cultural practises) to adjust to climate and environmental variations and change, move around and search new opportunities. Humans and nature have been interacting for thousands of years. All cultures are adaptable to some degree; some cultures following nature's flow, some retarding it and others hurrying it. For cultures in the Arctic, the mobility and flexibility play a crucial role. The distinctive character of Inuits has always been their mobility and adaptability to cold winters with snow and ice and summers with vegetation, and a broader diversity of animals to be gathered and hunted. The more flexible, mobile and sentient a culture is with its environments, the higher is its probability of becoming isomorphic with its preferred regional climate. The latter is also highly relevant regarding animal movement related to environmental variabilities in the sensitive Arctic, where adaptation to inter-annual changes is necessary for survival – of both humans and animals.

"*When the beluga whales disappeared from Kangeq*, *we just caught seals instead*".

[Marius, old hunter from Kangeq]

"*We have always adapted*. *Environments have always changed*, *and we still adapt. This is just our way of life*, *our culture*".

[Marius, young hunter from Nanortalik]

A question remains unaddressed: What happens when humans are suddenly subjected to additional effects, impacts and stressors of the marine ecosystems that they depend on?

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5. Conclusion

Long perceived remote and pristine environments, the Arctic and Greenland have emerged to be extremely sensitive to contaminants and climate and environmental change. Regarding the environment, being a complex interaction of many elements, Niels Bohr expresses, 'prediction is very difficult, especially about the future', particularly when accounting for the fate of pollutants in the future. We are only in the preliminary stage of exploring and understanding these complex interactions. Predictions and outcomes will change; some will be wrong, while others will form the basis for new studies, theories and scenarios.

It should be considered that the multiple stressors and variations of contaminants in environments are extremely regional. In most cases, Greenlandic trends and settings are consistent with those revealed, using longer and better time series from other parts of the Arctic. Trends and predictions show a clear response in relation to different environmental settings and contaminants, but many of these trends have been investigated over very few sampling years to provide a clear picture of year-to-year variation, the onset and end of these changes and the relative changes over time. All of these could provide useful information on the response time of different contaminants at different trophy levels and for different regions (Dietz, 2008).

Studies show how animals are affected by the cocktail of stressors and pollutants, usually for the worse; but has Darwin's evolution theory been taken into account, as most data focus on the average and not individual variation in a species? Darwin's theory states that evolutionary change comes through the production of variation in each generation and differential survival of individuals with different combinations of these variable characters. Individuals with characteristics that increase their probability of survival will have more opportunities to reproduce, and their offspring will also benefit from the heritable, advantageous character. Therefore, over time, these variants will be widespread in the population. We might be surprised in the future not only at how contaminants and climate interact but also how animals and ecosystems will be affected.

Acquiring the knowledge of what will happen when the ice melts is one of the most serious concerns, which has to be advocated, studied and understood. This being in relation to both depositing and redepositing, biomagnifications and degradation of contaminants, but also, as the hunters amplified, the larger stressors, anthropogenic disturbances, for the beluga whales. These disturbances are related to not only the hunters' own movement in the environments but also issues that are typically associated with temperate regions; shipping, exploration, tourism, noise and disappearance of ice will destroy the habitats for many ecosystem components. Many types of stressors act synergistically, which makes it more difficult to discriminate between the various environmental threats in the field. In order to make right decisions concerning future actions, we need to improve our monitoring methods (Schiedek et al., 2007), have longer regional time series and be more sensitive to separate stressors. Traditional knowledge combined with natural science and studies of the fate of contaminants in Arctic marine ecosystems can indicate behavioural factors and elements that might act as additional stressors on animals and communities relying on them. The knowledge of the hunters is important for conservation and co-management. As mentioned earlier, it is important to note that this method can be used in other areas of the Arctic, not only in relation to indigenous life economies but also 'modern' economies built on fisheries and local knowledge generated in communities relying on specific livestock; or it can be used by researchers, who have acquired knowledge about a specific environment through years of travel.

Only little is known about the complex environments of Greenland, the fjords, the shores, the oceanography and the ecosystems, among many remote and inaccessible areas, which might play a crucial role in understanding the distribution and fate of contaminants in the Greenlandic settings. An engagement of local communities is crucial, as it encompasses agricultural, scientific, technical, ecological, medicinal and health- and biodiversity-related knowledge from both remote and local environments. The fact that pollution does not only disrupt hunting activities but also affects social relations, well-being and identity makes the engagement of the communities even more crucial. Engagement can verify not only stressors and understanding but also solutions that are explicit in a cultural context: In conclusion, it is not only nature that matters to humans but also humans that matter to nature.

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