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At the cutting edge of the future: Unravelling depredation, behaviour and movement of killer whales in the act of flexible management regimes in Arctic Greenland

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ABSTRACT

Fisheries are an important resource in many countries, across oceans and along coasts, and, even though it is usually neglected, they bring not only economic value with them but also social value, supporting an important web of cultural practices. Thus, any perturbation on the fish resources may cause a domino effect on both ecosystem and human populations. In this paper we focus on a marine mammal which is entering the Arctic in increasing numbers, the killer whales (*Orcinus orca*), a major predator that may not only reshape the rapidly changing marine ecosystems via top-down forcing but also affect fisheries and cultural costumes through a specific, socially transmitted behavioural factor: depredation. By assessing the current knowledge of the depredation issue at a global scale as well as the studies of killer whales in the North Atlantic and Arctic waters, we discuss whether an eventual emerging depredation on halibut fisheries in Greenlandic waters should be taken into consideration. We stress a more flexible and cutting edge management regime on the forefront of environmental change and future scenarios. We accentuate an increased recognition of wildlife management also including an understanding of people and that success will be determined largely by political, social and cultural factors. Finally, we conclude that Greenland, being on the cutting edge of change, has high potentiality for building research based on a co-production of knowledge of both natural science and traditional knowledge.

1. Introduction

As emphasized in a new AMAP report (Jacobsen et al. forthcoming) as well as by work done by Delaney et al. (2012), fisheries are an important resource in many countries, across oceans and along coasts. Besides, even though it is usually neglected, the industry brings not only economic value with it but also social value. In northern Greenland as well as settlements along the coasts of West and East Greenland, fisheries are an integral part of the land-based activities that hold these social and cultural values. Fishing, processing, distributing and consuming local fish link people to their history and their present cultural settings. Living through subsistence fishing, hunting and through an informal economy, these activities maintain individual well-being and social relationships and help define a sense of family and community (Nuttall, 2005). Fishing supports an important web of cultural practices, meeting social obligations as well as social relations due to its strong links to support hunting activities. In a mixed economy, which the majority of these settlements depend on, the small-scale fisheries serve as an ad hoc to cover expenses relating not only to fishing but also hunting and gathering for subsistence and cultural purposes (Delaney et al., 2012, Hendriksen and Jørgensen, 2015, Jacobsen et al. forthcoming), conducted with longlines- either by boat, by dog sledges (Fig. 1.) or snowmobiles.

Fisheries play a significant role in Greenland's national economy, producing over half of the total service and good export value, 57% of 4.2 billion in 2011 (Copenhagen Economics, 2013), financing the emergent welfare state and supporting national independence (Jacobsen et al. forthcoming). Consequently, a change of resource or a disturbance to the fisheries may not only have an impact on the

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Fig. 1. Hunter fishing with longline from the ice (Photo: Bjørn Stig Hansen).

national economy but also regional impacts on communities, cultures, social relations and well-being, which are of at least as imperative importance.

In the face of climate change, significant changes in biodiversity, movement of ecosystems, introduction of new species and increase in population of others pose a potential threat. Therefore, it is of the outermost importance to be prepared, to foresee and predict, and to learn from and be educated by scenarios as well as impacts and disturbances seen elsewhere, including potential readjustment of species distribution and abundance in the new open waters of the Arctic. Conservation programs and management regimes generally focus on the ecological and behavioural aspects of species and ecosystems, but there is an increasing recognition that wildlife management also includes an understanding of people (Decker et al., 2006) and that success will be determined largely by political, social and cultural factors (Clark et al., 1996, Clark and Rutherford, 2005; Decker et al., 2006; Bruskotter and Shelby, 2010; Westdal et al., 2013). Additionally, as the locals encompass knowledge from year-around surveillance and movement in a regional environment, it is important to build on their knowledge, their interactions with the environment and observations of animal behaviour, movement, variations, and changes to be able to meet the right and most precise management of resources.

In this paper, we wish to focus on a marine mammal which is entering the Arctic in increasing numbers, the killer whales (*Orcinus orca*); a major predator that may not only reshape the rapidly changing marine ecosystems via top-down forcing (Trites et al., 2006; Springer et al., 2008; Higdon and Ferguson, 2009; Higdon et al., 2012) but also affect fisheries through socially transmitted behavioural factors, such as depredation (Donoghue et al., 2003; Hamer et al., 2012). An increasing number of interaction incidents between marine mammals and fisheries have been reported throughout the world's oceans (Northridge and Hofman, 1999). The increasing numbers are not only due to more and wider anthropogenic movement but also caused by climate change and change of ocean currents. Among these conflicts fish depredation, defined as the removal of fish from lines by marine mammals, represents a worldwide major issue. Depredation has several consequences, such as socio-economic, including losses for fishers, and conservation complications for both marine mammals (risk of injuries and mortality, modification of energy balance, and foraging behaviour with new and easy prey sources) and for fish resources (losses due to depredation are mostly not accounted for in quota allocation processes and neither in stock assessments). These negative impacts stem from a marine mammal increasing in numbers, as well as interactions between fishermen and the killer whales (Orcas).

This observed behavioural trend might pose an immense threat to the cultural practices, the well-being of communities and the national economy. On the other hand, interactions with fisheries may have important conservation issues both for killer whales, due to a higher risk of mortality and a modification of energy balance by giving access to new prey sources, and for fish stocks, since the combination of both human and whales foraging may lead to an overexploitation to the stocks. Besides, at a larger scale we may expect disturbance of the ecosystem. Furthermore, in this study we emphasize that it is of significant importance to keep an eye open and collaborate in knowledge production – even though research may be conducted in areas that are spatially far apart, the problems they are facing are relatively close – in this way being at the forefront of developing both baseline data and feasible mitigation strategies towards the problem of depredation, which most likely will occur as ecosystems and environmental settings change. Thus, we advocate through our study that, thanks to the different knowledge, we might be able to anticipate the issue and take measures to avoid depredation to happen on Greenlandic fisheries. Indeed, prevention is better than cure, and as we observe at a worldwide scale solution, are difficult to implement.

We structure our reflection around a first statement of changing conditions in Greenland with the increasing number of killer whales observed, and then around a second statement about depredation at a worldwide scale. From these both statements, we finally discuss the impact of a possible depredation in Greenland, aiming on suggesting possible means to avoid this phenomenon.

2. Methods

This study is built on an ongoing PhD project at The Greenland Institute of Natural Resources and Climate Research Centre and a PhD project being conducted at the Centre d'Etudes Biologiques de Chizé (CNRS & Université de La Rochelle), France. It builds on natural and social sciences, as well as traditional knowledge. Moreover, it uses both a review of selected studies covering depredation seen around the Crozet Archipelago, as well as studies from the North Atlantic supplementing this review with local and traditional knowledge of killer whales, local perceptions, depredation, and encounters across the Arctic. This co-production of knowledge gives a divination and appliances to eventually meet both anthropogenic and marine ecosystem-based disturbances caused by more killer whales entering the Arctic ecosystems.

The local and traditional knowledge presented was collected through travels in Greenland and obtained by participant observations, informal interviews, and a notion of conversational

interviews with family, friends, local hunters and elders. Elements relevant for this study were coupled with the extensive review of selected studies covering depredation seen around the Crozet Archipelago, as well as studies from the North Atlantic, to meet the questions of contemporary concern presented.

Hereby, the study strives to meet the problems and solutions in relation to depredation of longline fisheries, which most likely will become a problem in Arctic Greenland. It serves as an eye opener and encourages how solutions may be found – meeting the local communities, quota allocation processes and stock assessments, co-management, the conservation complications and the well-being of the involved marine animals and humans – and, not least, to be prepared.

3. The new lead actor of the Arctic

Since the 1950s, the atmosphere and ocean have warmed unprecedented, leading to a decrease of the global amount of ice, to an increase of the sea level, and thus to multiple changes in ecosystems (IPCC, 2013). Based upon this warming up, predictions suggest that the Arctic sea ice cover will continue to shrink until the end of the 21st century, with an overall 94% surface reduction in the worst scenario. Consequently, former basins are now opening up, previously having been cut off. The effects, such as declining sea ice and warming, are likely to initially cause shifts in marine mammals' range and abundance. The killer whale has occasionally been hunting along ice edges and leads (Reeves and Mitchell, 1988) but typically avoiding heavy ice concentrations. The declining ice has now set the scene for a new lead actor, allowing the killer whale to penetrate farther into the Arctic environment and stay for longer periods of time (Higdon and Ferguson, 2009).

Thus, there have been made a large amount of studies on killer whales' distribution, behaviour and prey in Arctic Canada and Alaska (Laidre et al., 2006; Matthews et al., 2011; Higdon et al., 2012, 2014; Reinhart et al., 2013; Peterson et al., 2013; Higdon et al., 2014; Matthews and Ferguson, 2014). However, studies of this species along the coasts of Greenland are few (Jefferson et al., 1991; Higdon, 2007). Today only few abundance estimates, set by hunting reports and observations, set the basis of this knowledge (Lennert, 2016). Local observations, hold an important message of this species, and have to be exploited, as well as taken into account. Sightings of these whales have been increasing not only around Alaska and eastern Canada but also along the coasts of Greenland. The Ministry of Hunting, Fishing and Agriculture has experienced a significantly increasing rate in hunting of killer whales (Table 1). From being a rare hunting activity, it has now become regular, reflecting a change in abundance (Arvid-Rosing, 2013).

> "*There has come more Killer Whales along the east coast, and we have begun to take advantage of this. I was out on the first hunt where we were guided with knowledge of the animal, the hunt, the animals' movements, signals and reactions, through the VHF radio as the hunt went on* (Fig. 2)".
>
> Per, hunter from Tasilaq

As this new lead actor has entered, minke whales have almost disappeared from certain areas, which also explains the more excessive hunt of the killer whale. The effects of the killer whale reshaping the rapidly changing Arctic ecosystem are already occurring and might occur in a more tenacious manner.

> "*This summer I was hunting narwhals together with local hunters in Qaanaaq. We caught a narwhale which's' back was broken and the tale was crooked. The hunters began telling about a narwhale where there had been taken a huge bite or lump from its neck area. They also said it had been a strange year. The narwhals' behaviours have been strange. They are "aalerivoq" nervous because of "aarluk" the killer whales that increased in numbers up north*"
>
> Lene Kielsen Holm, researcher from GCRC

This marine predator is known to consume a broad range of prey including mammals, fish and birds. However, in other regions, it is known to have a high level of dietary specialization, consuming a specific and narrow range of prey (Bigg et al., 1987, 1990; Guinet, 1992; Ford et al., 1998, 2011; Pitman and Ensor, 2003; Foote et al., 2009; Ford et al., 2011; Higdon et al., 2012, Foote, 2012; Foote et al., 2014). As this paper reflects, through depredation it might become a serious competitor to the Inuit fishermen and hunters of Greenland. A recent study revealed how the depredation by marine mammals might be perceived as a strong competition by fishermen and that it impacts their fishing strategies (Richard et al., 2017). A shift of fishing behaviour may lead to both economic and ecological issues. Competition would increase the foraging effort, and so the costs, for fishermen with a similar or even a lower payback than without killer whales (Peterson et al., 2014). As fishermen are optimal foragers, we assume they would harness their environment in a short-term goal of energy maximization (Begossi, 1992; Aswani, 1998; Richard et al., 2017). This may result as an increase of the fishing effort on a ground in absence of killer whales at the expense of the patch quality, with a threat of fishing stock depletion.

Inuit throughout the Arctic have a complex relationship with killer whales. Killer whales are disliked because they drive other marine mammals away (Higdon, 2007; Westdal et al., 2013) and blamed for declines in harvested species (e.g. Wilkinson et al., 1995). Statements are conflicting but generally view killer whales as competition for food resources:

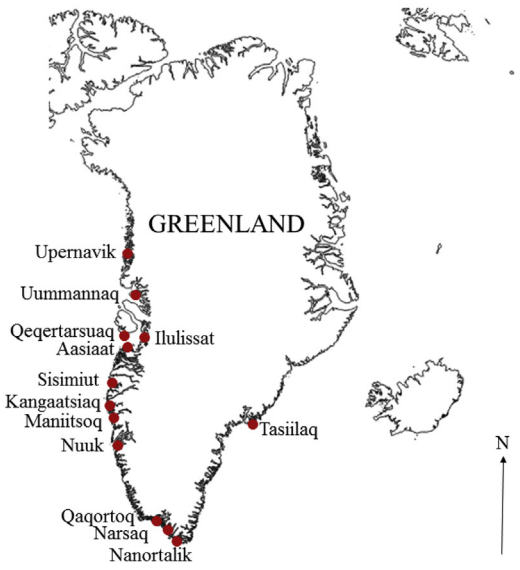
> "*When killer whales come too close to the coast, we usually sail out and fire a riffle to scare them off*".
>
> Hunter from Sisimiut

One can question if this relationship and tactic of scaring off killer whales has deeper roots of "packaged knowledge" from when killer whales in the past *have* been a competition with the hunters because of a larger abundance than today, as the Greenlandic Inuit philosophy of animal behaviour is already linked to this predator. *Aarluk* is the Greenlandic word for Orcas and when speaking of other animals that are either very shy, nervous, escaping or have disappeared -it grammatically and philosophy is linked to *Aarluk* even though it may be another predator or environmental setting doing the impact. *Aarluppai -the Orca has scared the animals away, aarlerivoq-is nervous because of Orcas* or the term *aarluppoq -is escaping from Orcas*, are used in the description of behavioural changes. On the other hand, statements and perceptions considering them helpful, making hunting easier for the Inuit, also occur:

> "*Killer whales sometimes guard the outlets of fjords so that prey cannot come out. It, in some way, makes a treasure chest of food where it, when hungry, can go in and pick what it wishes to eat. Some hunters also take advantage of this. Actually, killer whales result in prey being closer to the coasts, making it easier for us to hunt. Therefore I do not understand why some hunters chase them away, when they actually are helping us*".
>
> Apollo, hunter from Saattut

Table 1
Registered catch of killer whales along the coasts of Greenland.

Settlement	Year 2009	2010	2011	2012	2013	2014	Sum
West Greenland							
Aasiaat						1	**1**
Ilulissat		7		5	2		**14**
Kangaatsiaq			1		1	3	**5**
Maniitsoq		4	2		12		**18**
Nanortalik		2		1	5		**8**
Narsaq							
Nuuk			2		1		**3**
Qaqortoq						5	**5**
Qeqertarsuaq				1			**1**
Sisimiut			2		2		**4**
Upernavik	9	1	22	8		1	**41**
Uummannaq			5	17	4		**26**
East Greenland							
Tasiilaq	5	1	5	12	11	6	**47**
Sum	**14**	**15**	**39**	**44**	**38**	**16**	**173**



Source: LULI Piniarneq, NELE 19/8 2016 (data still under validation)

Fig. 2. Killer whale caught by local hunters outside Tasiilaq, East Greenland (Photo: Frede Kilme).

Arctic seals and whales typically avoid killer whale predation by moving into shallow waters along shorelines (Westdal et al., 2013); this behaviour providing hunters with easy prey (Gonzalez, 2001; Westdal et al., 2013) as emphasized by Apollo. Besides, hunters always refer to the killer whales as being extremely clever, resulting in precautionary behaviour when being around this marine mammal.

"*Killer whales are extremely clever and adaptive*".

Hunter from the Disko Bay

Or even stories of them hunting hunters:

"*I have heard stories of hunters in kayaks being hunted by killer whales as if they were seals*"

Marianne from Nuuk

The one thing, though, that never came up when talking and travelling with hunters was how this major predator, known to reshape and control the rapidly changing marine ecosystems via top-down forcing (Trites et al., 2006; Springer et al., 2008; Higdon and Ferguson, 2009; Higdon et al., 2014), could possibly affect fisheries through the socially transmitted behavioural factor: depredation. Depredation by killer whales was never mentioned as a problem in the localities that were sustainably dependent on longline halibut fisheries.

This behavioural trend, seen in other regions of the world and potentially having immense impacts on not only national economy but also cultural practices and the well-being of communities in the future, was not addressed on any level. Why? When we know that climate change is pushing ecosystems, abundances, and distribution of animals, why are these potential negative impacts not at all in the interest or in the eye of the beholder? Why not see it as critical and essential to be at the forefront of both collecting baseline data and developing feasible mitigation strategies for the

Fig. 3. Killer whales eating fish from longlines of the coasts of Crozet Island (Photo: B. Loyer © St Thomas Production).

problem of depredation and top-down effects, which most likely will occur as ecosystems and environmental settings change?

4. Cutting edges of new issues

As Greenland keeps on living, inattentive to potential problems moving up along the coasts, other countries and fishermen struggle to cope with depredation (Fig. 3). Orcas are a large problem in the southern oceans around the Crozet Archipelago where these whales have revealed a high level of dietary specialization. Around the Crozet Islands, depredation by killer whales accounted for 75% of the total depredation, which from an economic point of view showed a catch per unit of effort (CPUE: mass of fish caught per hook) reduction around 30% due to killer whale interaction between 2003 and 2013 (Gasco et al. 2015). This issue seems to be growing around Crozet Island. Indeed, Tixier (2012 and pers. comm.) has observed an increasing number of matrilines interacting with longlines over the years. As the relationships between matrilines are known, a further approach will be to determine whether the apparition of the depredation behaviour between matrilines follow the social relationship between them. This correlation should give information whether the depredation behaviour is socially transmitted or learned randomly around Crozet Archipelago. For comparison, Schakner et al. (2014) revealed that sperm whales in Alaska have learned the behaviour of depredation by social transmission. In a similar extent, depredation on traditional Greenland halibut fisheries by sperm whales has been observed in Norway since August 2014. This depredation behaviour used to be observed on demersal longlines in open waters off Norwegian coasts but never close to shore. There has been a major shift in the distribution pattern of sperm whales off the islands of Vesterålen in Norway, where a previously favoured feeding ground (a deep water canyon) has become less interesting for the whales. They have moved a bit closer to shore, adding yet another odontoceti to take into account. The Greenland halibut spawns at around 600 m off the continental shelf, and this is the area where depredation takes place (Simila pers. comm.). Is the change in the distribution pattern of killer whales related to migration of their resource due to climate change? Finally, it is of interest to understand that depredation behaviour may be opportunistically self-taught by some individuals. For instance, a poorly-known ecotype of killer whales, named Type D (Pitman et al., 2011), have been interacting for less than 10 years with the French longlines (Tixier et al., 2016), while this ecotype did not mix with the Crozet killer whales, avoiding any social transmission, the depredation behaviour has to have been opportunistic. However, this behaviour was then quickly spread within the rest of the populations of Crozet killer whales or Type D by social transmission. Apprenticeship is crucial for killer whales, especially to master foraging techniques which could be complex, such as intentional beaching (Lopez and Lopez, 1985; Guinet and Bouvier, 1995). It is thus not surprising to see females teaching juveniles how to depredate longlines as observed by fishermen around Crozet archipelago:

"*Worse than seeing killer whales eat Patagonian toothfish on our longlines, is seeing juveniles remove the fish and play with them before letting them go*"

Lieutnant of a French longliner.

Like the situation in southern oceans, in the North Pacific depredation has become a large problem in the Sea of Okhotsk. Fishermen report killer whale consumption up to 100% of the catch from bottom nets of halibut fisheries and 20–80% of longline fisheries (Belonovich pers. comm.). Likewise, after decades of a relative peaceful coexistence with cod and halibut fishers of the coast of Alaska, killer whales are now stalking individual fishing boats. The killer whales will wait all day for a fisher to accumulate a catch of halibut, to the lead in fishers on a high-speed chase to get away, robbing them blind (Hopper, 2017).

"We've been chased out of the Bering Sea"

Paul, co-owner of F/V Augustina (Hopper, 2017).

How would this impact the Greenlandic fisheries playing a significant role in the national economy of Greenland, producing over half of the total service and goods export value, 57% of 4.2 billion, and where halibut is one of the main sources? The number of killer whales is increasing in the North Atlantic and possibly Arctic Greenland. Therefore it is of uttermost importance to be at the forefront in a precautionary manner to not only meet the local fishermen but also quota allocation processes and stock assessments, co-management and the conservation complications as well as the well-being of the involved marine mammals getting an easy

meal.

Depredation along the coast of Greenland might additionally cause an increase in the level of trophic interactions due to increased competition for the same fish stock, resulting in either direct reduction (through removal of fish) or indirect reduction (through trophic cascades) of the targeted fish stock; both scenarios reducing the overall quantity of fish available.

As a result, this would hit the economy built on fishing abundance, and would cause critical issues for management agencies with important implications for fishermen, affect cultural practices, and influence other cetaceans, such as narwhals (*Monodon monoceros*). These odontocetes are, as killer whales, top predators especially feeding on halibut. These of which also are interacting with the catch distribution and movement of halibut as Apollo describes;

"*When the Narwhals enter our area, the halibut disappear, they hide. In old days we would stop fishing because it would be a waste of time*".

Apollo, hunter from Saattut

Having a circumpolar distribution, narwhals share on a history with the Inuit through traditional knowledge as well as being an important food resource. The hunting of this marine mammal is not only associated with provision of food but involves the aspects of travelling, and community values. The Greenlandic word for food, Kalaaminernit (piece of a Greenlander), does not only refer to meat or fish but has a cultural manifestation built on multisensory and multiple meanings (Petersen, 1985; Sowa, 2015; Lennert, 2016). The subsistence activities are not only of economic or nutritional significance but also an important element regarding both physical and mental well-being, as well as being an essential asset in preserving one's cultural roots and identity (Poppel and Kruse, 2009). Many of the coastal communities rely on these food sources because of poor infrastructure and low access to fresh food supply in the local stores. Therefore, a competition between killer whales and humans for resources, being fish or marine mammals, may have critical effects on the usually isolated communities relying not only on fisheries but meat resources that only can be obtained through hunting. In a mixed economy, which the majority of these settlements depend on, the small-scale fisheries serve as an ad hoc to cover expenses relating not only to fishing but also hunting and gathering for subsistence and cultural purposes (Delaney et al., 2012, Hendriksen and Jørgensen, 2015; Jacobsen et al. forthcoming). These fisheries and settlements will be affected and experience immense feedback effects; accentuating the importance of being on the cutting edge of which future scenarios might be met as well as solutions.

5. A test of solutions

Off the Crozet Islands, acoustic harassment devices (AHDs) have been increasingly implemented in various fisheries that suffer significant losses caused by depredation. However, the effect of AHD activation was generally most effective when the killer whales were exposed to the device for the first time, as they seemed to become habituated to AHD (Tixier et al., 2014).

"*We've tried all kinds of electronic sounds, music, whatever; anything that would confuse them. But whatever you do, it seems they adapt to it. They know the sound of everybody's propeller screw out there*".

Fisherman from Alaska (Peterson et al., 2013)

Likewise, the F/V Augustine of the shores of Alaska tried electronic noisemakers to ward off the animals, but the killer whales simply got used to them;

"It became a dinner bell,"

Paul, co-owner of F/V Augustina (Hopper, 2017)

In Arctic Alaska, the use of dummy buoys has achieved limited success. Nevertheless, acoustic decoys are being tested in field trials by SEASWAP, who are using playbacks to drive animals away from the fishing site during the terminal phase by either broadcasting biological meaningful sounds (e.g. sounds of marine mammal eating killer whale) that generate an avoidance response, or generating sounds intended to "jam" the bio sonar of species (Thode et al., 2015), or masking the sound signature of fishing vessels that are thought to attract the killer whales (McPherson et al., 2008; Hamer et al., 2012).

Physical mitigation technologies such as "net sleeves", pots, chain and cage devices have yielded mixed results as they generally require complex moving parts. Indeed, implementation of fish pots as an alternative fishing technique to longline suppressed depredation but did not provide economically sustainable catch per unit effort for the French automated longliners (Gasco et al., 2010). However, in the toothfish fishery off the Chilean coast, fishermen developed a manual longline method with fish protection through a 'net sleeve' called '*cachalotera*' from the Spanish name of sperm whale (Moreno et al., 2008). Even though this method requires a lower fishing effort, *i.e.* a lower number of hooks deployed per day, it was revealed efficient to avoid depredation by sperm whales (Moreno et al., 2008). Thus, this physical mitigation approach on longlines seems to be rather possible on manual longlines/more traditional fisheries. Furthermore, Derek J. Hamer et al. (2012) emphasizes that development of approaches should not only be focused on one certain "tool" but rather on compiling a "toolbox" of various strategies and solutions, because a single panacea for the problem of depredation is unlikely to emerge.

The question here is if these solutions will be accessible, manageable or affordable for the local fishermen operating from small dinghies during summer and fishing at ice margins from dog sledges in extreme cold weather (Fig. 1.). Furthermore, are the acoustic suggestions accessible when taking spontaneous trips out when weather, ice and other circumstances allow it? Also, how does one travel with pots, net sleeves, chain and cage devices when having 400 hooks to deploy? Can pots, nets, sleeves, chain and cage devises be modified to meet the ways of travel, fishing and depredation all together? Can these be built by fishers own innovative solutions and knowledge? In most cases it is hard to find good devices to avoid depredation, so another approach is to understand how whales interact and if some techniques, e.g. choice of environmental setting as used by the fishermen, could reduce the depredation by avoiding detection or limiting the number of fish withdrawn from the longlines. Such a technique might have the greatest potential as the traditional knowledge and observations already define local management regimes of resources within the small communities along the coasts. We thus suggest implementing a combined policy looking for physical mitigation solutions and for appropriate fishing strategies to avoid depredation. This policy should be discussed with fishermen since they are the first protagonists and are the most competent to find devices to protect the hooks on their longlines, as did the Chilean fishermen with the *cachalotera* (Moreno et al., 2008). However, scientists might bring better understanding to fishermen on their fishing strategies by using human ecology and assess which techniques may bring the

better catch per unit effort.

Known to consume a broad range of prey, including mammals, fish and birds, in some regions, but also to feed highly specialized, consuming a specific and narrow range of prey, in other regions (Foote, 2012), another important query is what would the natural diet of this marine mammal be along the coasts of Greenland, and how would it differ between Greenlandic regions (e.g. north v.s. east coast)? Would they feed on marine mammals only, or would they feed also on fish and on halibut specifically? In other words, would they be more likely to learn depredation on halibut fisheries by opportunism or by ease? This question is of main interest to foresee the potential impact of this new behaviour upon the Greenlandic halibut fishing stocks but also on other top predators that are important for sustainable living of Inuit. This problem emphasizes the importance to modify research and management to better understand the foraging behaviour, the movement and the distribution of this toothed whale. This crucial act would allow an evaluation of killer whales' potential impact on top predators and ecosystems, as well as the threat they face.

In the North-East Atlantic, killer whales are known to follow specific prey stock; nevertheless, their seasonal movement is still poorly understood. In the North Pacific, two genetically distinct populations forage on distinct prey and both types don't change their diet: the *transient* feeding on marine mammals and the *resident* feeding on fish. Around the Crozet Islands, scientists are more convinced that killer whales, known to hunt penguins, elephant seals and other marine mammals (Guinet, 1992; Guinet et al., 2000, 2014), were already feeding on Patagonian toothfish as a natural diet since killer whales immediately interacted with longlines, when the fishery was started in 1996, to remove toothfish whereas they have never touched to the grenadiers (*Macrourus* spp.), a by-catch fish commonly hauled. However, Crozet killer whales show a decrease of interaction with fisheries from October, when southern elephant seals come back to land for the reproduction period, to December, when weaned pups leave for sea (Tixier et al., 2016). Killer whales switching between fish and mammals when travelling from Iceland to Scotland (Samarra and Foote, 2015) and Norway has also been observed (Vongraven and Bisther, 2014). This type of preying might be the best tactic, i.e. preying on whatever resource is available and most abundant at a given environmental setting or location. This observation recognizes that the killer whale has an ability to shift between specialized feeding strategies adapted to different prey resources (Similä and Ugarte, 1993; Beck et al., 2012; Samarra and Foote, 2015). It also recognizes that a potential prey shift might occur in relation to resource availability along the coast of Greenland. Even though their movement follows a specific life stock, the new selection of prey could potentially change their foraging. Taking into account the hunter's quote about the killer whale being extremely clever and adaptive – this founded on his own observations and shared knowledge – it does not contradict this potential; it actually reinforces the theory. Understanding the extent of behavioural plasticity in foraging strategies and to what extent killer whales may switch prey types requires future studies, particularly combining seasonal behavioural observations and diet assessments in different feeding contexts (Samarra and Foote, 2015).

The Greenlandic killer whales seen in extensively larger numbers along the east coast of Greenland are most likely a sign of recent substantial changes in the ecosystems such as a change in the distribution and abundance of mackerel (*Scomber scombrus*). Killer whales are known to feed on this species (Nøttestad et al., 2014), thus, it emphasizes the importance of knowing the dynamics of killer whales' diet to better understand and predict their responses to variations in the availability of various prey (Samarra and Foote, 2015). The killer whales caught off the east coast had only remains of marine mammals in their stomach contents. This leads to the question if these whales have changed their diet from fish to marine mammals? Contrariwise, do they represent a separate group already feeding on marine mammals, since having increased in numbers because of the change of ice patterns and temperatures (Arvid-Rosing, 2013)? Another question is to what extent killer whales are moving in relation to the changes happening due to climate change affecting ecosystems. Just as ecosystems are altering and moving, killer whales must potentially move too. In the Disko Bay, West Greenland, a pod size of 40 individuals was caught in 2001 (Arvid-Rosing, 2013). This size corresponds to the pod sizes of the *resident* killer whales (fish-eating) studied off British Columbia and Washington State's coasts (Baird et al., 1992). Pods of killer whales are generally rare in such large numbers in these western North Atlantic and Arctic areas but might just indicate a natural (or unnatural) movement of fish-eating killer whales, as an analogy to the *resident* killer whales in the North Pacific. In this case it is important to build on management regimes handling this question, as hunting such large groups would have a crucial impact on the population, since pods are built on matrilineal family groups comprising one to four generations of individuals. Furthermore, explanation of the drop in caught numbers in 2014 (Table 1) is unknown as hunters from both the east and northwest coast of Greenland did not observe any major change in ice, break-up or movement of marine mammals. Explanations can lie in the movement of mackerel, capelin, other marine species feeding on these, excessive hunting or just as well anthropogenic disturbances such as increased ship traffic and tourism; disturbances that the hunters address themselves when it comes to other cetaceans and how they have changes distribution and movement. Even more so, understanding their movement will aid the knowledge of this whale's potential impact on local prey resources, being marine mammals or depredations, as well as ecosystems.

Indeed, it is unknown if killer whales visiting the west coast of Greenland are the same individuals as the orcas in eastern Canadian Arctic, since movements of killer whales in the western North Atlantic are complex (Heide-Jørgensen, 1988; Reeves and Mitchell, 1988; Lawson et al., 2008; Matthews et al., 2011). However, killer whales off the eastern Canadian coast are predominantly observed during summer, whereas killer whales off the western and south-western coasts of Greenland seem present throughout the year (Heide-Jørgensen, 1988), suggesting a possible migration from Canada to Greenland during winter. Additionally, Matthews et al. (2011) revealed a satellite track of a killer whale going through the Davis Strait from the Arctic waters (Prince Regent Inlet) to the open North Atlantic off Newfoundland, reinforcing hypotheses from previous studies of possible migration from Arctic waters to the Labrador Sea and the East Atlantic off Newfoundland, or along the North American coast (Katona et al., 1988; Reeves and Mitchell, 1988). In these waters, killer whales are mostly known to feed on marine mammals, but some killer whales have also been observed feeding on bluefin tuna (*Thunnus thynnus*), herring (Clupea harengus) and discarded fish near vessels fishing for Greenland halibut (Lien et al., 1988; Lawson et al., 2008). In an isotopic analysis Matthews and Ferguson (2014) confirmed that killer whales in the eastern Canadian Arctic forage upon narwhal, beluga, bowhead whales, and seals, but also revealed that killer whales off the coast of Newfoundland and Labrador may feed on both marine mammals and fish. Some genetic analysis and more tracking studies should allow for a better understanding of the killer whales' complex movements and their little-known population structure in this Arctic region.

By combining natural scientific studies with the knowledge already embedded in the waters along the coasts of Greenland, solutions might be found. Inspired by perceptions, this holistic

approach is not only a matter of data and observations but as much a matter of a process of community engagement, education as well as transmission of knowledge (Lennert and Berge, 2016). This approach is also implied by Hamer et al. (2012) and Gilman et al. (2006), who note that an acknowledgement of the conceptualization and development of some solutions may lie with the fishermen whose knowledge, experience and enthusiasm should not be underestimated or under-evaluated. There is already much local observation and knowledge along the coasts of Greenland covering movement, behaviour and variations of prey. The solution might even just build on a natural one, as expressed by Apollo: Just as narwhals cause a redistribution of halibut disappearing from an area, killer whales might have the same effect, therefore, in a natural way, not causing depredation conflicts. Again, Apollo's knowledge (see section 3.) contributes to understanding the distribution of stocks in a given environment as well as the variations of these; an important asset when striving to develop sustainable management regimes.

6. Conclusion

The degree and consequence of any impact is a function of the characteristics of the fishing community. As many Greenlandic communities built on fishing and hunting are remote and have limited economic opportunities of resident, the critical points are the vulnerability of a community to negative repercussions of management actions and the resilience the community has in being able to absorb these repercussions. Consequently, it is important to understand the ability and vulnerability of a community in order to successfully anticipate the impact, as well as to proceed at a pace that everybody can follow.

It is of paramount importance to hence an alternative understanding and perception by virtue of how organisms function and interact with their environment in order to prime our awareness of how systems might change in the future and to accentuate a flexible management approach.

Depredation is a problem that most likely will hit local fisheries of Greenland in the future. It is important that not only researchers but also policy makers and management agencies are at the forefront; that they meet the problem rather than be surprised; that they are proactive about not only dealing with depredation but also technologies to accurately assess the fish stocks and manage these if the depredation problem should occur to be in the same range as around the Crozet Archipelago, Alaska and the Sea of Okhotsk. Furthermore, only sparse knowledge covers the understanding of the movement and distribution of this toothed whale. Building on this knowledge is important for evaluating their impacts on top predators and ecosystems, as well as the threat they face. An understanding of killer whale movement will aid the understanding of prey specialization as well as the whales' potential impacts on local prey resources and ecosystems. Wrong handling of this may not only threaten the conservation of this cetacean population but also have an impact on the economic viability of longline fisheries and communities along the coasts of Greenland.

Indigenous and local observations deserve serious attention, especially when we seek to understand this dynamic world. In combination, the increased need for data, promotion of locally relevant knowledge, and management actions suggest that there are substantial prospects for more local engagement around the Arctic in the decades to come, and that an increase will contribute to more effective local conservation actions. Fishers, hunters and other communities relying on natural resources, as well as environmentally interested people are already using their own observations, thereby obtaining small-scale and regional management regimes following the variations of nature.

Greenland is privileged to already have communities conducting local management regimes of resources built on traditional knowledge and observations. Greenland has the opportunity to be a role model: Successfully combining this knowledge, already embedded in the waters along the coasts, with natural scientific studies, solutions might be found, inspired by perceptions and holistic approaches, which are not only being a matter of data and observations. Greenland has the potentiality to encourage the process of community engagement, education as well as transmission of knowledge. Hamer et al. (2012) and Gilman et al. (2006) noted it as crucial to acknowledge that the conceptualization and development of some solutions may lie with the fishermen. That their knowledge, experience and enthusiasm should not be underestimated or under-evaluated. Furthermore, when community members, fishers and hunters present their natural resource observations and knowledge to leaders, community-based documentation of natural resources can be a very effective tool in enabling communities to achieve a greater “voice” in municipal, national and corporate decision-making (Norden 2015).

Greenland, being on the cutting edge of change, has the potentiality for building research on the topics touched upon in this paper, basing the research on natural science as well as traditional knowledge. The question now is who has the audacity to take up this intriguing challenge that might answer not only questions in the regions around Greenland but in a spatial and global scale.

The purpose of this study was to draw a statement of the current knowledges about killer whales around Greenland and what is known around the world on this species, especially about their behaviour of depredation. Thus, through this statement paired with the current knowledge of environmental changes in arctic and more precisely around Greenland, we aimed at predicting possible scenarios of a depredation issue happening on the Greenlandic halibut fishery. However, our study is mainly speculative even though it is based on strong statements; so further studies are encouraged to strengthen our hypothesis and at least avoid the phenomenon of depredation to appear. Thus, we recommend that biologists lead serious studies on killer whales ecology in Greenland by setting up at first a follow-up of the population using photo-identification coupled with biopsy samples to assess the genetic diversity of these individuals. Thanks biopsies, it is also possible to get a better idea of killer whales' diet through isotopic analyses. Additionally to their diet, monitoring it is of interest to study their foraging behaviour using for instance bio-loggers or passive acoustic devices, since they are highly vocal animals. Besides, as we underlined in our study, it is essential to benefits from traditional and local knowledge. Indeed, hunters and fishermen are the first observers of the environment and so they have a special expertise which is precious to science. We then suggest opening a dialogue and collecting traditional and local knowledges within a database in order to depict a better picture of the situation, and engage them in innovatively finding solutions, meet changes, impacts and opportunities that might occur in the future.

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