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Transitions of social-ecological subsistence systems in the Arctic

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Abstract: Transitions of social-ecological systems (SES) expose governance systems to new challenges. This is particularly so in the Arctic where resource systems are increasingly subjected to global warming, industrial development and globalization which subsequently alter the local SES dynamics. Based on common-pool resource theory, we developed a dynamic conceptual model explaining how exogenous drivers might alter a traditional subsistence system from a provisioning to an appropriation actions situation. In a provisioning action situation the resource users do not control the resource level but adapt to the fluctuating availability of resources, and the collective challenge revolve around securing the subsistence in the community. An increased harvest pressure enabled by exogenous drivers could transform the SES to an appropriation action situation where the collective challenge has changed to avoid overuse of a common-pool resource. The model was used as a focal lens to investigate the premises for broad-scale transitions of subsistence-oriented SESs in Arctic Alaska, Canada and Greenland. We synthesized data from documents, official statistics and grey and scientific literature to explore the different components of our model. Our synthesis suggests that the traditional

Arctic subsistence SESs mostly comply with a provisioning action situation. Despite population growth and available technology; urbanization, increased wage labor and importation of food have reduced the resource demand, and we find no evidence for a broad-scale transition to an appropriation action situation throughout the Western Arctic. However, appropriation challenges have emerged in some cases either as a consequence of commercialization of the resource or by severely reduced resource stocks due to various exogenous drivers. Future transitions of SESs could be triggered by the emergence of commercial local food markets and Arctic warming. In particular, Arctic warming is an intensifying exogenous driver that is threatening many important Arctic wildlife resources inflicting increased appropriation challenges to the governance of local harvest.

Keywords: Climate change, conservation, fish and wildlife, globalization, socio-ecological systems, subsistence, sustainability

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1. Introduction

The concept of social-ecological systems (SES) reflects that nature and society are interdependent and constantly coevolve, often in a non-linear fashion (Berkes and Folke 1998). Of particular importance are SES transitions, which entail fundamental transformations of the system's structure and processes that ultimately change how governance challenges are defined and understood (Olsson et al. 2006). A SES transition can be triggered by endogenous feedbacks between the society and the natural system (Lambin and Meyfroidt 2010). For example, unsustainable resource use might invoke a SES transition with either a continued exhaustion of the resource and a collapse of the resource stock, or a changed behavior towards a more sustainable resource use. The particular outcome has been the focus of a large number of recent studies (e.g. Gutiérrez et al. 2011; Cinner et al. 2012; Hausner et al. 2012; Fleischman et al. 2014), and depends on a number of interacting factors pertaining to the governance system in place, local norms-and rules, properties of the resource system and its users as well as the contextual situation (Dietz et al. 2003; Berkes 2007). However, a SES transition can also be triggered by exogenous drivers that emerge independently of the internal SES dynamics, but which can change the conditions for the interactions between nature and society (Lambin and Meyfroidt 2010). Governmental policies may, for example, impact local traditional governance systems resulting in a less (or more) sustainable utilization of a common-pool resource (Borrini-Feyerabend et al. 2013). Similarly, climate change, globalization, changed demography, economic growth, market integration and technological innovation are all factors that might have pervasive impacts on all parts of the SES, and in particular the demand and pressure on local natural resources (Young et al. 2006a).

This paper investigates if and how exogenous drivers could trigger broad scale transitions in subsistence-oriented SESs in the Western Arctic (i.e. Arctic Alaska, Canada and Greenland). By subsistence we mean “harvesting of natural, renewable resources to provide food for one’s own household, for gifts for others, and for exchange outside the market economy” (Poppel and Kruse 2009, 39). We focus on the tundra areas (i.e. the areas north of the treeline) in North America and Greenland. This area is dominated by Inuit, Iñupiat and Yup’ik cultures, and the people who live there are highly dependent on fish and wildlife resources for sustaining local livelihoods and cultural identity (Nuttall 2007; Huntington 2013; Chapin III et al. 2015). The wildlife and fish resources in the Arctic typically consist of migratory species with a fluctuating distribution and abundance; e.g. beluga whale, ice-dependent seals, caribou and migratory fish and birds. The indigenous people have traditionally coped with fluctuating resources through a number of adaptations, including flexible hunting and fishing practices, a diverse diet, customary sharing networks, a mixed household economy, and local sets of norms and rules with respect to harvesting (Wolfe 1984; Berkes and Jolly 2001; Usher et al. 2003; Robards and Alessa 2004; Parlee and Berkes 2008; Magdanz et al. 2011; West and Ross 2012). The accelerating changes associated with global warming combined with large natural variability in Arctic ecosystems, the development of extractive industries, increased dependence on formal employment and cash income; and reliance on imported foods and fuels are all factors that can change the premises for the management of fish and wildlife (West and Ross 2012).We postulate that exogenous drivers under certain conditions could change the feedback between resource users and wildlife and fish resources, fundamentally altering the SES and the associated governance challenges.

Based on common-pool resource theory, we first present a dynamic conceptual model for possible transitions of subsistence-oriented SESs and the major exogenous drivers that might invoke such transitions. Guided by the model, we review the general properties of the traditional resource-use systems in the Western Arctic. We assess the status and the recent development of drivers expected to be important, and finally assess whether transitions have taken place. The synthesis seek to answer the following research questions: Is there evidence of broad scale transitions in Western Arctic subsistence-oriented SESs? How does these SES transitions relate to exogenous drivers? Finally, we reflect on how future changes in exogenous drivers could change these systems.

2. A dynamic conceptual model for SES transitions in subsistence-oriented communities

Many of the conditions causing SES transitions on local scales have been documented through decades of research on common-pool resources, and were recently systematized into a SES framework by Ostrom (2007, 2009) and McGinnis and Ostrom (2014). The common-pool resource literature originally characterized resources by two fundamental features (Ostrom et al. 1994): (i) subtractability, which occurs when the exploitation of a resource by one user reduces the amount of the resource available to others, and (ii) excludability, which refers to how costly it is to control the resource-access of potential users. Variations along these two dimensions have been used to delineate four types of goods: Private goods (high excludability, high subtractability), toll goods (high excludability, low subtractability), common-pool resources (low excludability, high subtractability), and public goods (low excludability, low subtractability). In the following we assume that the resource users harvest renewable resources (e.g. fish and wildlife resources) in which the exclusion of other users is costly (i.e. low excludability), and we will accordingly concentrate on the variation along the "subtractability-axis" which delineates public goods from common-pool resources. The characterizing of renewable resources in relation to subtractability is however not trivial. This is because subtractability might vary along a continuum, often depending on the stock of the resource itself (Young 2007). This is known as "congestability" (Weimer and Vining 2005), implying that if a renewable resource is plentiful, then a relatively small withdrawal allowing the resource to regenerate, will have little impact on the resource situation for other users. Subtractability will according to this mechanism be positively, although not necessarily linearly, related to the proportion of harvest rate to stock size (i.e. the harvest pressure). Thus, any factor causing an increase in harvest pressure could in principle change a public good into a common-pool resource and vice versa.

The variation along this axis is particularly important because the two types of goods are associated with different governance challenges (Hinkel et al. 2015). Common-pool resources are associated with appropriation challenges because individual resource users will have incentives to maximize their own consumption of an exhaustible resource at the expense of others (Ostrom 1990). On the other hand, public goods can suffer from provisioning problems due to free-riders in situations where a costly collective investment is needed to utilize the resource. Hinkel et al. (2015) termed the former an "appropriation action situation" defined as "those in which actors face a collective challenge to avoid the overuse of a collective good". In contrast they defined the "provisioning action situation" as "those in which users face a collective challenge to create, maintain or improve a collective good". In the following we will elucidate how these two action situations depend on the characteristics of the resource system, and how exogenous drivers might change a subsistence-oriented SES from a provision action situation to an appropriation action situation (Figure 1).

Ostrom (2009) argued that large resource systems with low predictability and high resource unit mobility make it less likely for resource users to self-organize to avoid overexploitation. Interestingly, the same resource characteristics make it difficult for resource users to sustain a sufficient flow of resources over time, suggesting that overexploitation in general might not be an issue in the first place.

Migrating resources with large temporal variation in availability are particularly challenging, and such resource systems might take the form of what Pimm (1982) termed “donor-controlled systems”, in which the resource users do not control the resources by harvest, but on the contrary adapt to their fluctuating availability. By definition, the resource users have little impact on the resource stock in such systems, and subtractability is accordingly low. Moreover, the major collective challenge for households and communities will be to efficiently harvest, distribute and store the resources rather than self-organize to avoid over-use. To reflect the dynamic character of such resource systems, we will use the term donor-controlled systems referring to cases where the large variability of the resources limits the resource users’ ability to maintain a high harvest rate over time. In the terminology of Hinkel et al. (2015), the SES would correspond to a provisioning action situation in which the resource users face a challenge to maintain and develop the local collective partnership to secure local food resources for harvesting, processing and distributing among community members.

Because the resource users have little influence on the resource stock, donor-controlled systems are resilient to changes induced locally by the subsistence users themselves (i.e. endogenous drivers). However, exogenous drivers affecting harvest efficiency, resource demand and the state of the resource stock could potentially increase the harvest pressure and thereby transform the system into an appropriation action situation (Figure 1). For example, Fleischman et al. (2014) showed how the Atlantic bluefin tuna fishery has changed from low to high subtractability and thereby challenged the SES’s governance institutions. The Atlantic bluefin tuna stocks move over large areas and have therefore traditionally been able to escape overexploitation due to their mobility. New technologies such as GPS, sonar and spotter planes providing information about the spatial location of the tuna has, together with high market prices, increased the access to and demand for the resource. As a result, the harvest pressure has increased, leading to increased subtractability, and a change in the governance challenge from one of provisioning, to an appropriation challenge to avoid over-harvest.

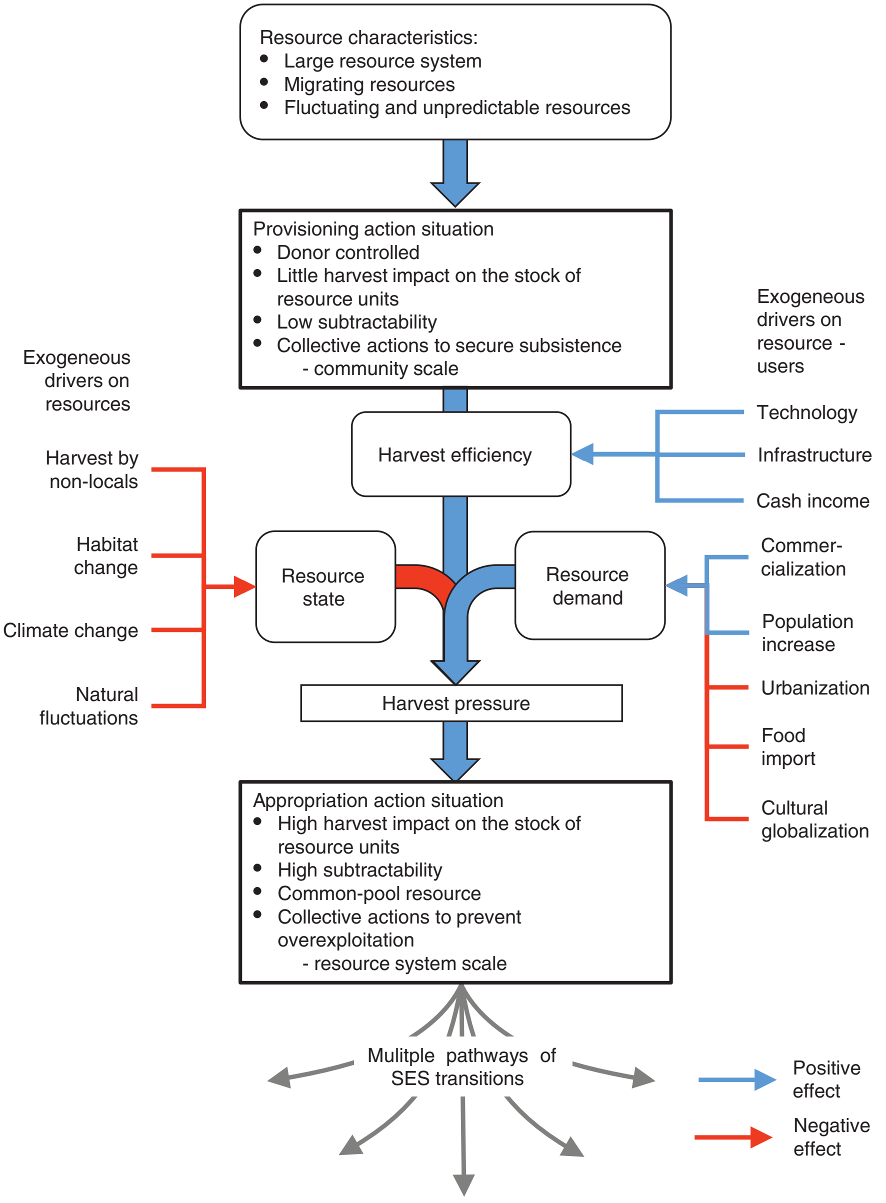
Some exogenous drivers work directly on the resource stock with potential effects on the harvest pressure (Figure 1; left). For example commercial exploitation by non-residents and habitat change by e.g. expanding extractive industries, are drivers that might reduce the state of the resource and thereby increase its vulnerability to local utilization. Similarly, climate change is expected to reduce or shift the abundance of traditional resources, making them more vulnerable to local harvest. Finally, large natural fluctuation in the resource stock might increase the frequency and duration of periods when the resource is vulnerable to local harvest. Equally important and probably more complex, are the exogenous drivers that work on the resource users (Figure 1; right). For example, the adoption of new technology and equipment for hunting and fishing, as well as more efficient means of transportation and storage, will enhance the hunters’ ability to increase the harvest pressure. However, new technology and fuel are costly, and whether an increased efficiency is realized depends on the resource demand as well as a sufficient cash income to buy the equipment and fuel needed. Population increase and opportunities to sell country food are among the drivers that may increase the resource demand, and encourage investments in technologies that enable hunting levels above the subsistence need. On the other hand, urbanization might offer alternative livelihoods, wage labor and increased importation of food, thus reducing the demand for the traditional resources. Finally, the traditional subsistence culture and practices might be influenced by globalization through the diffusion of ideas, meaning and values. As a result, the younger generations' interest in traditional harvests might weaken, reducing the demand for the traditional fish and wildlife resources.

If the exogenous drivers increase the harvest efficiency, the resource demand and/or the resource scarcity, then the resulting increase in harvest pressure might trigger a transition from a provisioning action situation to an appropriation action situation (Figure 1). The new situation would shift the collective action challenge from one of securing the subsistence in the local group of resource users to one of avoiding over-harvest at the scale of the resource stock. It is important to note that this model (Figure 1) is dynamic, i.e.; depending on whether the pressure from an exogenous driver increase or decrease, the change can either inhibit or activate a transition. Furthermore, if the system is in an appropriation action situation a "reversed" transition to a provisioning action situation could also be envisaged through a reduced resource demand, an increased resource stock and/or a reduced harvest efficiency.

The long-term outcome of a broad scale transition to an appropriation action situation is dependent on the institutions, i.e. the formal rules and informal norms that structure social interactions, which constrain or enable adaptations to the new governance challenges. Albeit not the main focus in this paper, our conceptual

Figure 1: A dynamic conceptual model of how exogenous drivers could impact the dynamics of a social-ecological system (SES) which, in this case activates a transition from a provisioning action situation to an appropriation action situation. The pressure from a driver can increase or decrease, and thus either inhibit or activate a transition. The colors of the arrows indicate the relationship between the driver and the response; blue for positive effect and red for negative effect. Under the provisioning action situation the resource users are limited by the fluctuations in a large and uncontrollable renewable resource. A number of exogenous drivers working on the resource might have negative consequences for the state of the resource (left side). Similarly, drivers working on the resource users might enhance the harvest efficiency and the resource demand (right side). Note that the list of exogenous drivers is not exhaustive. Increased harvest pressure could be a result of 1) increased harvest efficiency and increased resource demand, and/or 2) increased harvest efficiency and reduced state of the resource. The result of an increased harvest pressure could be a transition of the SES from a donor controlled system where the collective challenge is to secure the subsistence on a local scale, to a common-pool resource system where the collective challenge is to avoid overuse on the scale of the resource system. Once an appropriation action situation has been introduced several pathways for the SES transition is possible, e.g. resource collapse, self-organizing of resource users to avoid over-harvest or governmental top-down regulations.

model also illustrates that the new governance challenges could result in multiple pathways of SES transitions. At least three possible outcomes could be envisioned: First, if the resource users do not respond to the challenge, unsustainable harvests may collapse the resource system. Second, resource users might organize at the scale of the resource system and adapt to the new collective challenges, for example through cross-scale arrangements. Third, governments might implement



top-down regulations to protect the resource from local harvests. All of these outcomes could have profound impacts on the resource system, the resource users and/or their interactions. Thus, the emergence of this new appropriation action situation would trigger a transition of the SES along different pathways ending in different alternate configurations.

3. Data synthesis

In the following data synthesis we seek to answer our research questions by comparative analyses of subsistence systems in the Western Arctic. The cross-national comparison allows us to examine the influence of large scale exogenous drivers of SES transitions to a greater extent than would be feasible through singular case studies (Popay et al. 2006; Young et al. 2006b). Our approach is a narrative synthesis (Popay et al. 2006) using multiple lines of evidence to examine how the observed system dynamics conform to the conceptual model (Figure 1) by a step-by-step analysis. First, in Section 3.1 we investigate whether the properties of the most important fish and wildlife resources in our study system are congruent to the expectations from a donor-controlled system (i.e. large resource systems with migrating and fluctuating resources; Figure 1, top). In Section 3.2, we synthesize the literature on adaptations and governance challenges associated with donor-controlled systems, and ask whether the traditional SESs conform to a provisioning action situation (Figure 1, upper box). In Sections 3.3 and 3.4 we investigate the major exogenous drivers affecting harvest efficiency and resource demand (Figure 1, right). In Section 3.5, we analyze recent trends in subsistence harvest using available data. Finally, in Section 3.6, we investigate cases were appropriation challenges have arisen due to resource scarcity. We ask what drivers have been involved and what management actions have been taken. We conclude by pointing to the major drivers behind recent transitions to appropriation action situations, and discuss future challenges given the current trends in exogenous drivers.

3.1. Fish and wildlife harvest in the Western Arctic

This section introduces subsistence communities in the Western Arctic, and asks whether the properties of the most important fish and wildlife resources are congruent to the expectations from a donor-controlled system (Figure 1, top).

On a pan-Arctic scale, about 550 communities with a total population of less than one million inhabitants live within or close to the Arctic tundra biome; i.e. communities that harvest from the Arctic fish and wildlife resource systems (Figure 2). This study focuses on the Western Arctic, including 244 tundra communities in Alaska, Canada and Greenland. Fishing and hunting has been the principal livelihood for these predominantly small and remote communities that harvest sea mammals from the Arctic Ocean, fish from the rivers, lakes and the sea, and mammals, birds and plants from the Arctic tundra (Huntington 2013). The area is mainly populated by Inuit, Iñupiat and Yup’ik, however, some of the

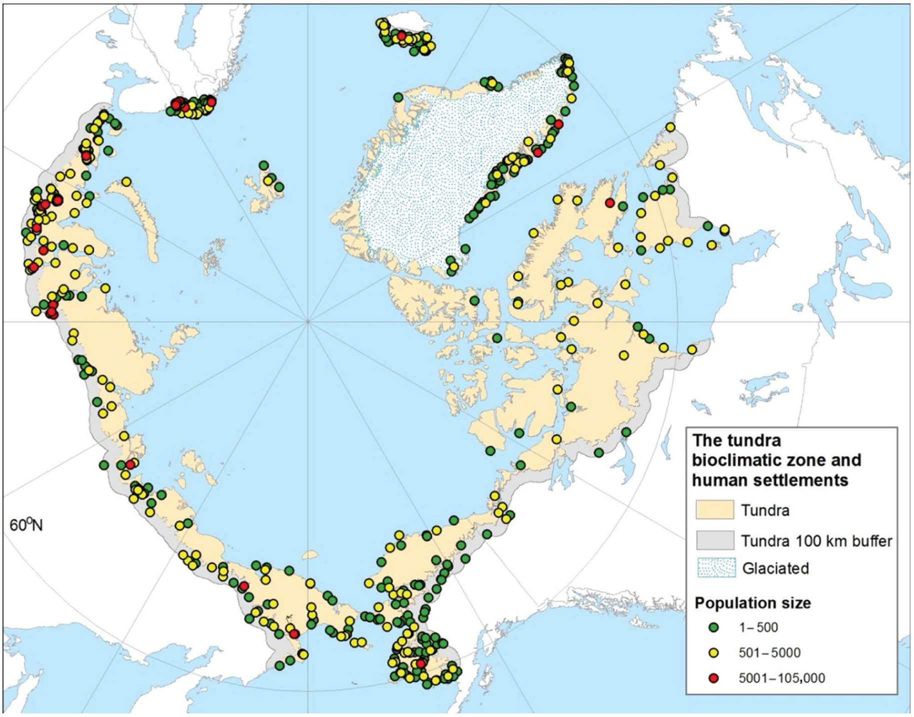


Figure 2: Human settlements within or close to the circumpolar Arctic tundra biome (Walker et al. 2005) including a 100 km buffer zone to the south. Population data are from the most recent official statistics in Alaska, Canada, Greenland, Iceland, Norway and Russia. See Appendix 1 for data sources.

resources are shared with interior communities further south including Dene, Gwich'in and Métis peoples.

Based on community-based subsistence surveys in Alaska and Canada in the period 1964–2007 and catch statistics from Greenland in the period 1996–2013 (see Appendix 1), we calculated the relative importance of the different resources in terms of biomass (Table 1). According to these data, the harvest has been dominated by relatively few types of resources. In Alaska, the harvest was dominated by pacific salmon, moose and migratory caribou. In Canada, the harvest was dominated by migratory caribou and ringed seal, while harp seal and ringed seal dominated the harvest in Greenland (Table 1).

In donor-controlled systems resource users do not control the resources by harvest, but adapt to their fluctuating availability. There are at least four resource system characteristics that are likely to keep the SES donor-controlled and in a situation where the main governance challenge is to secure resource needs rather than to prevent overharvest: 1) extensive seasonal migration, 2) large inseparable resource stocks, 3) seasonal superabundant concentrations of the resources, and

4) low predictability in resource availability. By reviewing management reports and the scientific literature, we classified the most important Arctic wildlife resources according to these four characteristics (Appendix 2, Table 1). For example, several of the most important marine wildlife resources have strong affinity to sea ice i.e.; the "ice seals" (harp seal *Pagophilus groenlandicus*, ringed seal *Pusa hispida*, spotted seal *Poca largha* and bearded seal *Erignathus barbatus*), narwhal *Monodon monoceros*, bowhead whale *Balaena mysticetus* and polar bear *Ursus maritimus*. These species follow the seasonal advance and retreat of the sea ice, making extensive seasonal migrations during their annual cycle. The stocks are large both in terms of number and habitat area, and one stock is normally shared by several distant communities (see e.g. Allen and Angliss 2013). In general, we found that the main food resources in the Western Arctic largely exhibit donor-controlled characteristics (Appendix 2, Table 1). The resources that deviated from this pattern were all terrestrial herbivores including stationary populations of caribou, muskox (*Ovibos moschatus*) and moose (*Alces alces*).

3.2. Provisioning actions

This section investigates whether the traditional subsistence SES conforms to a provisioning action situation (Figure 1, upper box).

Our analysis on resource characteristics (Section 3.1), suggested that large, migrating and fluctuating resources dominate the subsistence harvests in the Arctic SES, making donor-controlled systems more likely. First, these characteristics make it difficult and costly to control resource-access of potential users, but they also make it difficult or even irrelevant to engineer the resource system to enhance productivity by means of traditional management measures such as selective harvesting to optimize the sex and age-ratio of the stock, habitat alternation to maximize productivity, or culling of competitors such as wolves. Instead, provisioning actions in the Arctic typically depends on a number of strategies that mitigate the seasonal, annual, decadal and possibly centennial fluctuations in the availability of the resources (Robards and Alessa 2004; Tejsner 2013). Flexibility with respect to hunting location, hunting technique, seasonal migration and the targeted species would be important adaptation to a variable resource situation. Subsistence surveys in Alaska show that the resource users in a community might utilize as many as 69 different animal species (Magdanz et al. 2002) and the substitution of a declining resource with alternative hunting targets has been suggested to be an important strategy to cope with changed resource availability (Robards and Alessa 2004; Brinkman et al. 2007; Wenzel 2009). However, Hansen et al. (2013) found little evidence for switching between major subsistence resources in a study of 19 communities in Alaska. They suggested that resource switching might be precluded by the recent transition of the communities into a more market-based economy in which the resource users supplement declining subsistence resources with store-bought foods instead of switching their hunting target (see also Loring and Gerlach 2009).

Table 1: Relative importance and characteristics of different wildlife resources in Arctic Alaska, Canada and Greenland. The percentage of harvest is the resource-specific biomass harvested as percentage of the total harvested biomass. A dominant resource characteristic is indicated with black cell. Grey shading indicates that the feature might be present to some extent. White cells indicate that this is not a typical feature of the resource. A detailed specification of the rationale behind the classifications are given in Appendix 2.

Resource	Percentage of harvest (biomass)			Resource system characteristics			
	Alaska	Canada	Greenland	Extensive seasonal migration	Large inseparable stock shared by more than one community	Seasonal superabundant concentrations	Unpredictable availability
Pacific salmon	55	1	0	black	black	black	
Atlantic salmon	0	0	NA*	black	black	grey	
Seabirds, ducks and geese	3	4	2	black	grey	black	
Bowhead whale	2	0	0	black	black	grey	grey
Beluga whale	3	5	1	black		grey	grey
Narwhal	0	0	2	black		grey	grey
Moose	14	0	0				
Migratory tundra caribou**	13	41	0	black	black	black	black
West Greenland caribou***	0	0	6				grey
Peary caribou****	0	1	0				grey
Muskox	0	6	4				grey
Polar bear	0	2	0		black		
Walrus	2	3	1	black	black	black	
Hooded seal	0	0	2	black	black	black	black
Bearded seal	4	8	2	black	black		black
Harp seal	0	1	59	black	black	black	black
Spotted seal	1	0	0	black	black		black
Ringed seal	2	28	21	black	black		black

*Not applicable, data from Greenland did not include fish.
**Tundra populations of *Rangifer tarandus caribou, R.t. groenlandicus* and *R. t. granti* in Canada and Alaska.
***_R. t. groenlandicus_ populations in West Greenland.
****_R.t. pearyi_ populations in the Canadian Arctic Archipelago.

Many aspects of the hunter-wildlife relationships embedded in Inuit culture mirror the characteristics of a donor-controlled resource system. For example, traditionally Inuit do not view wildlife as passive subtractable resources, but perceive the animals as active, sentient partners in the harvest (Schmidt and Dowsley 2010). The traditions and knowledge emphasize proper relationships with animals through respectful hunting behavior and distribution of hunt products within the community (Thorpe 2004). According to the beliefs, these habits will persuade animals to return to be harvested in the future, ensuring the flow of food and other hunting products to the community (Fienup-Riordan 1990; Stairs and Wenzel 1992; Kendrick 2000). Thus, the provisioning actions go beyond the hunters decisions of where, how and what to hunt and fish, to include the accumulation and transmission of traditional ecological knowledge on a wide array of targeted wildlife and fish species (Berkes and Jolly 2001; Thorpe 2004; Ford et al. 2006; Berkes 2012), and one governance challenge is, for example, to maintain and transfer the knowledge of subsistence hunting and fishing to the younger generations in the community (Pearce et al. 2015).

Provisioning actions are also enabled by the organization of households into networks engaged in cooperative subsistence activities and sharing of hunting equipment and country food (Magdanz et al. 2002; Collings 2011; Harder and Wenzel 2012). This characteristic and well-documented organization of collective provisioning actions among Inuit in the Arctic is the basis for the mixed subsistence-cash economy (Wolfe 1984; Langdon 1991; Marquardt and Caulfield 1996; Usher et al. 2003), and is also important in terms of buffering subsistence disparities between lower- and higher-income households (Dombrowski et al. 2013; BurnSilver et al. 2016). Fuel, supplies and hunting equipment are costly, and access to such resources either by cash income or through sharing networks is a collective challenge of the resource users (Pearce et al. 2015). Subsistence harvest is accordingly combined with wage labor and transfer payment so that cash income is invested in e.g. store-bought food in times of hardship or hunting equipment in times of prosperity (Tyrrell 2009). Recent studies show that sharing networks remain persistent despite higher engagement in cash economy at the household and community levels (Dombrowski et al. 2013; BurnSilver et al. 2016). Similar analyses of sharing networks have not been undertaken in Greenland, but case studies suggest that networks and food markets depend on whether you are a professional commercial hunter or a non-professional hunter that mainly distribute fish-and wildlife resources locally (e.g. Sejersen 2001; Tejsner 2014; Ford et al. 2016).

3.3. Harvest efficiency and local resource demand

This section investigates exogenous drivers affecting harvest efficiency and resource demand (Figure 1, right).

Because the yield in a donor-controlled system is constrained by demanding resource characteristics, an improved harvest efficiency might be a prerequisite to increase the harvest pressure, and eventually transform the system from a provisioning to an appropriation action situation. Harvest technologies have changed considerably since the rifles and steel traps were first introduced in the 19th century, and since then, outboard motors, modern boats, manufactured fishing nets, snowmobiles, freezers, ATVs, two-way radio communications and GPS have all become common technologies used in the subsistence activities (see e.g. Thorpe 2004; Wenzel 2009; Pearce et al. 2015). The increased hunting and fishing efficiency has been assumed by some scholars to disrupt the balance between the subsistence users and the fish and game populations, possibly leading to excessive harvest and declining resources (Hansen and Worrall 2002; Gunn et al. 2011). However, evidence that the use of new technology among subsistence users in the Arctic has resulted in increased or unsustainable harvest pressure is equivocal (Collings 1997). High costs of fuel, hunting equipment, and poor markets might prevent an increased harvest pressure although improved technologies are available (e.g. Fazzino and Loring 2009; Kofinas et al. 2010). For example, Brinkman et al. (2014) found that more than 80% of 178 subsistence users in Alaska reduced the number of trips and the distance travelled, most likely because of higher fuel prices. In other words, while motorized transport potentially could increase harvest efficiency, the resource users depend on cash income to fully access the resources (Wenzel 2009). The governmental programs for settling Inuit in larger sedentary villages in the 20th century often increased the travel distances to the traditional hunting grounds. However, the introduction of snowmobiles allowed people to get further away from the community, and back to their original hunting grounds (Wenzel 2009). Thus, in order to understand how increased harvest efficiency potentially could result in an appropriation action situation, harvest technology and transport need to be coupled to other trends, such as participation in labour markets, the cost of imported goods, changes in demography and settlement pattern.

The Western Arctic is sparsely populated, however in our study area the population has increased several fold during the 20th century (Figure 3, see Appendix 1 for data sources). At the beginning of the century the Arctic part of Alaska, NWT/Nunavut and Greenland each held approximately 10,000 inhabitants. This number had increased to 34,000 for Arctic Alaska, 77,000 for NWT/Nunavut, and 57,000 for Greenland by 2012 (Figure 3). Assuming a proportional increase in the consumption of resources, one could accordingly expect a 3 to 8-fold increase in the harvest of fish and wildlife in the same period. There are however several factors that might have prevented such an increase. First, the shift from the use of dog-teams to the use of snowmobiles and ATVs for transportation reduced the need for dog feed and thereby the harvest of typical "dog feed species" of fish and seals (Collings 1997). Second, according to the analyzes of Rasmussen (2011), most of the population growth in the Arctic since the 1960s has occurred in urban centers, often linked to industrial activities, social services and public administration (see also Magdanz et al. 2002). This development is accompanied by increased wage labor and importation of

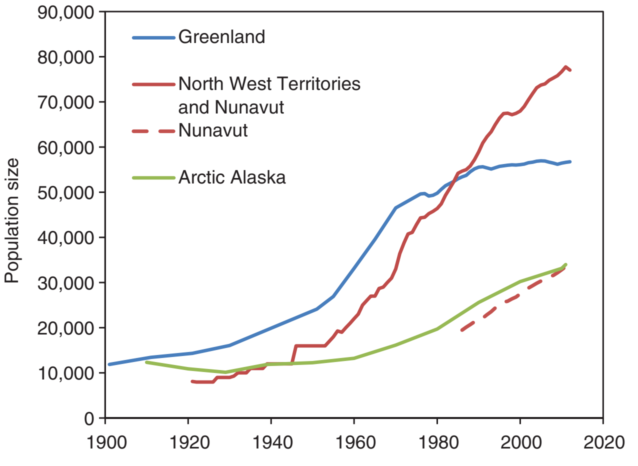


Figure 3: Population development in Greenland, Northwest Territories, Nunavut and Arctic Alaska from the beginning of the 20th century. Arctic Alaska includes Nome Census Area, North Slope Borough, Northwest Arctic Borough and Wade Hampton Census Area. Note that the southern part of Northwest Territories is not within the Arctic definition of Figure 2. Data from Nunavut, which is entirely within the Arctic definition, was available from 1986 to 2012. See Appendix 1 for data sources.

goods, while the importance of traditional harvesting for subsistence is, according to Rasmussen (2011) declining. The increase in consumption of imported food on the expense of local food has been referred to as a nutritional transition, and is particularly evident among the younger generations and in centers with good access to store-bought food (Council of Canadian Academies 2014). Thus, while an increase in harvest pressure could be expected due to a combination of increased harvest efficiency, increased access to cash income to buy equipment and fuel and increased population size, a stable or decreasing harvest pressure is also possible due to urbanization combined with increased wage labour and consumption of imported food.

3.4. Commercialization of resources

This section addresses how commercialization affects resource demand (Figure 1, right).

Commercialization is an important factor that could both increase the resource demand and provide cash income to buy fuel and expensive hunting equipment. User-rights are often linked to a particular utilization of the resource, and in our study system the legislative authorities' prioritization of commercial vs. subsistence use has been the source of a long-standing debate (Wenzel 1991; Marquardt and Caulfield 1996; McGee 2010). Commercial use of wildlife and fish resources might provide important monetary income for rural communities (Armitage 2005; Dowsley 2010), and introducing the resource to a larger market might increase the immediate economic value of the resource and thereby the incentives for hunting and fishing. Interestingly, the commercialization of country food differs considerable among the three study regions. Greenland has a long history of selling fish and wildlife resources on local as well as international markets, while on the other side, the Alaskan legislature put strict restrictions on the commercial utilization of fish and wildlife resources among Alaskan subsistence users. In between we find northern Canada where local food markets have developed at a smaller scale than in Greenland.

In Greenland all residents with a hunting permit (non-professional or professional) are eligible to harvest. However, professional hunters (hunters with more than 50% of the income from hunting and fishing) are prioritized by larger quotas, longer hunting seasons and larger bag limits compared to non-professionals (Marquardt and Caulfield 1996; Sejersen 2003). Harvest not used for one's own consumption or sharing, is sold unprocessed on the local market, privately to institutions or to other households, or for a fixed price to governmental owned companies (i.e.; Royal Greenland A/S) (Caulfield 1993, 1997). Greenland stands in stark contrast to Alaska, where federal and state laws prioritize subsistence use over commercial use and sport hunting (Behnke 1996; McGee 2010). According to the principle of subsistence priority, the subsistence needs must be fulfilled before commercial or other types of uses are allowed. Marine mammals are protected by the 1972 Marine Mammal Protection Act, and commercial use of marine mammals is not allowed. An exemption was made for Alaska Natives living in coastal communities to allow them to hunt for subsistence and make handicrafts provided that the hunts were not conducted in a wasteful manner. Commercial offshore fisheries are not authorized outside Arctic Alaska (i.e. the Chukchi and Beaufort Seas). Inshore commercial fisheries are however allowed (e.g. salmon, king crab and herring), but are often limited by poor infrastructure and low market interest e.g. (Bavilla et al. 2010; Estensen et al. 2012). Subsistence priority is also adopted as a principle by the Land Claim Agreements in the Canadian Arctic, but selling wildlife and fish products to other subsistence users is allowed. The regulations on how Inuit harvesters could sell local food varies according to the specific Land Claim Agreement (Gombay 2005). In Nunavik, commercial tag and quality standards are needed to sell local foods. In Northwest Territories and Nunavut sponsored programs have supported commercial sale of muskoxen and caribou products, but much of the local food is exported to the south (Council of Canadian Academies 2014). The commercial use of marine mammals is not prohibited, and the commoditization of the traditional harvest of polar bear, narwhal and pinnipeds has caused heated conflicts with respect to management and protection (Wenzel 1991; Armitage 2005; Dowsley 2010). The local food market is still small in northern Canada as harvest is mostly sold locally to the Hunter and Trapping Organization, local restaurants or processing plants, but a recent study by Ford et al. (2016) also reports concerns among resource users of the emerging markets for local food on Facebook.

3.5. Trends in local resource use

This section investigates trends in resource use as a response to changes in resource demand (Figure 1, right).

We used the subsistence data from Canada and North America (Appendix 1) to assess the recent temporal trends in harvest and the relationship to community size (number of inhabitants). Descriptive statistics of the dataset is given in Appendix 1: Table A1. The subsistence surveys have been conducted in different communities in different years, and there are no extensive time series from one single community. To address the temporal trends, we therefore fitted the data to a statistical model controlling for community size and community within region. Specifically, the log-transformed harvest values were fitted to a generalized additive mixed model (GAMM) using the *nlme* library (Pinheiro et al. 2009) and the *mgcv* library (Wood 2006) in R, ver. 3.2.0 (R Development Core Team 2015). Year and the log-transformed population size of the community were used as fixed factors and community nested within regions were included as random factors. To account for possible non-linear relationships, harvest was modeled with smooth functions using a thin plate regression spline as basis.

The GAMM model (Figure 4) revealed that the total amount of fish and wildlife harvested per year and person (log-transformed) decreased significantly with year (edf=1.0, $P<0.0001$) and community size (log-transformed average number of inhabitants; edf=2.7, $P<0.0001$). For a community size of 386 inhabitants (the median community size), the model indicated that harvest rate per person decreased from 362 kg per person (95% C.I. 285–459) in 1970 to 172 kg per person (95% C.I. 138–215) in 2007 (Figure 4A). Keeping year constant and equal to 2007, the predicted harvest per person was 192 kg (95% C.I. 147–251) in a community with 100 inhabitants, while this figure decreased to 42 kg (95% C.I. 26–69) for a community with 4000 inhabitants (Figure 4B).

To investigate whether the trend differed between large and small communities (i.e.; an interaction term between community size and year), we performed the model for communities larger and less than 386 inhabitants (median community size) separately. In both models, the total amount of fish and wildlife harvested per year and person (log-transformed) decreased significantly with year (#inhabitants<386: edf=1.0, $P=0.0002$ and #inhabitants>386: edf=1.7, $P<0.0001$). The predicted trends for the median community sizes is shown in Figure 5. There was a tendency for a slightly more rapid decrease in harvest in large communities compared to small communities, however this difference was small, and due to low sample size it was possibly masked by a large uncertainty for the large communities in the early years (Figure 6).

The catch statistics from Greenland show different trends for different resources (Figure 6). Declining populations of seabirds were followed by stricter regulations in the beginning of the 2000s, and harvests of these species have decreased dramatically since 1996. The same situation is found for beluga

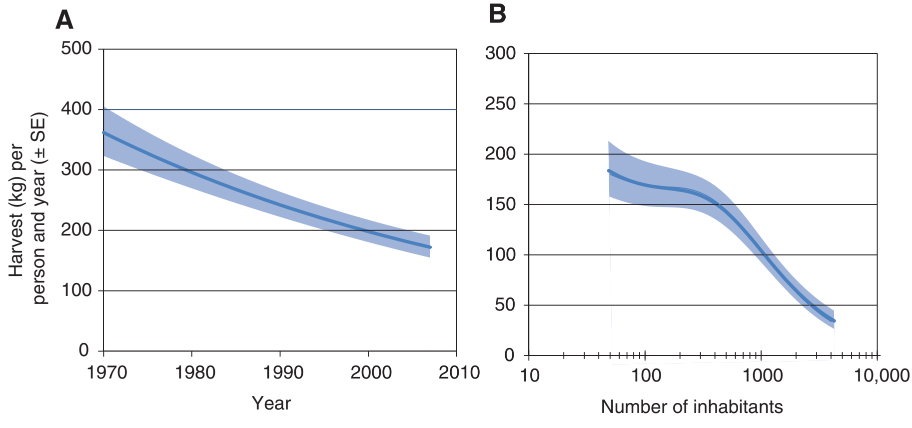


Figure 4: Harvest of wildlife and fish resources with respect to (A) year and (B) community size in Canada and Alaska combined. The figures show the predicted values (±standard error) from a Generalized Additive Mixed Model with total harvest rate as a dependent variable and year and log community size as independent variables. In (A) community size is held constant and equal to 386 (the median community size). In (B) year is held constant and equal to 2007 (the last year with data). Random components were community (st.dev.=0.20) within region (st.dev.=0.09). Residual st.dev.=0.13. R^2*(adj) of the model was 0.44, N=326 (community, years).*

whale, walrus (*Odobenus rosmarus*) and narwhal (*Monodon monoceros*). The populations of harp seals and ringed seals (*Pusa hispida*) are considered to be in good conditions (Appendix 2) and harvests of these species have decreased only slightly. Increasing populations of muskox and reindeer were followed by relaxed hunting regulations and increased catches (e.g. Cuyler 2007). The number of professional hunters and commercial use has decreased (Figure 7); however, the number of non-professional hunters increased temporally, following changes in opportunities for reindeer hunting in the late 1990s and early 2000s (Rasmussen 2005).

In sum, the harvest and subsistence survey data suggest that the use of local wildlife and fish resources in Arctic Alaska, Canada and Greenland is decreasing, supporting the "nutritional transition hypothesis" (see Section 3.3). The subsistence data from Alaska and Canada also suggest that the harvest per person decreased for increasing community size, indicating that the ongoing urbanization might be important. However, the trend is also evident in small communities (Figure 5), suggesting that this is a general negative trend that is likely to be exacerbated by the urbanization trend. It is important to note that the data from Alaska and Canada represent the biomass harvested per person, thus given the increase in population size (Figure 4), the trend in harvest pressure will be closer to constant. On the contrary, in Greenland the data represent the total harvest,

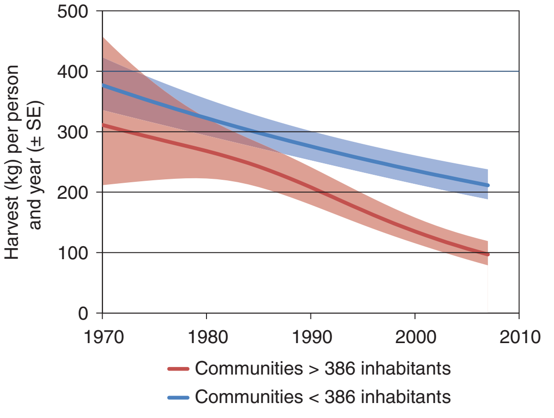


Figure 5: Trends in the harvest of wildlife and fish resources for large and small communities separately. Median community size (386 inhabitants) was used as cut-off. Model formulation was the same as for Figure 4. Figures show the predicted values (± standard error) for the median large and median small community (789 and 154 inhabitants). Effect of year was significant in both models (P<0.001).

and the trends suggest that the harvest of vulnerable (i.e. red-listed) species has decreased substantially, while the harvest of abundant species has been constant or variable (Figure 6).

3.6. Appropriation challenges

This section investigates how exogenous drivers impact resource status (Figure 1, left), the importance of local harvest in causing resource scarcity (Figure 1, harvest pressure), and the emergence of appropriation challenges (Figure 1, lower box).

To investigate cases were appropriation challenges have emerged, we reviewed management reports and the scientific literature to assess the current status and trend of important fish and wildlife resources, the most important drivers of change and possible management responses (Appendix 2). Specifically, we searched for: i) the status of the resource stocks; ii) the current trend in the resource stocks; iii) the major drivers behind current stock dynamics; and iv) implementations of management regulations of local harvest. Based on the reports, we divided the drivers into five major groups: i) local harvest; ii) rebounding from historical industrial/commercial exploitation; iii) climate warming; iv) natural population cycles; and v) unknown. A detailed description of each resource is provided in Appendix 2. A summary of the results is given below, and a resource specific overview is given in Table 2.

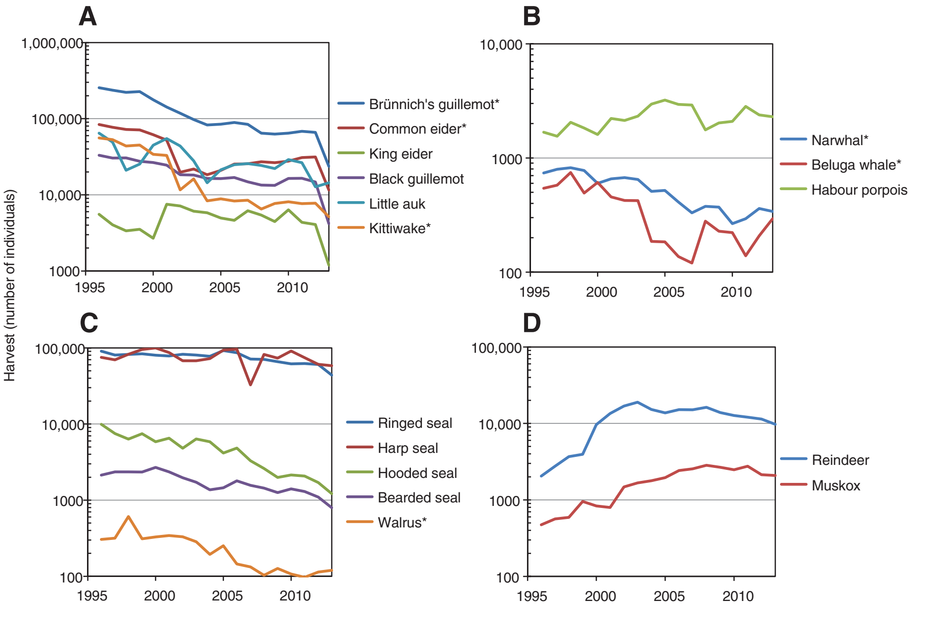


*Figure 6: Harvests of wildlife in Greenland; (A) seabirds, (B) cetaceans, (C) pinnipeds and (D) reindeer and muskox. * indicates national red-listed species.*

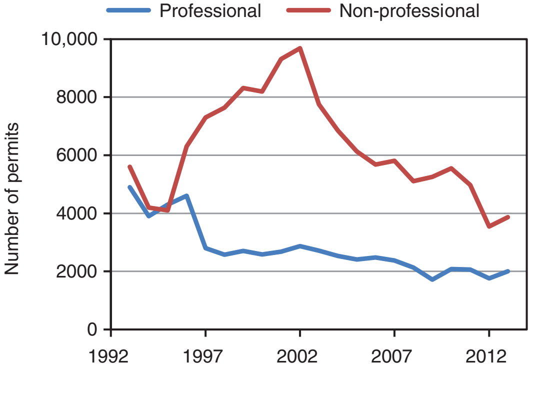


Figure 7: Hunting permits (professional and non-professional) issued in Greenland.

Climate change, historical over-exploitation and natural fluctuations were common explanations for the observed dynamics of resources in the literature, and we found several examples were these drivers were the ultimate reason for implementing harvest restrictions on local hunters and fishers (Appendix 2).

Commercial sealing, whaling and hunting during the 19th and 20th centuries decimated many important Arctic wildlife resources, and several slow-growing species are still at low levels. Although many resources have recovered or are recovering, low population size due to previous overexploitation is, together with climate change, a major rationale for current restrictions on local harvest of polar bear, beluga whale, bowhead whale, walrus and narwhal in the three Arctic regions (Appendix 2, Table 2). However, climate warming has become an increasingly important driver in Arctic ecosystems, and in particular the reduction in sea ice is currently severely threatening endemic Arctic species associated with the ice habitat (Kovacs et al. 2011; Michel 2013). This is the major argument behind the recent ESA listing of polar bear and ringed seal (FR 2008, 2012), and it is possible that the effect of climate warming will be an increasingly important argument for the implementation of regulations of the local harvest of Arctic marine mammals. Caribou is the most important terrestrial wildlife resource in the Western Arctic and many of the caribou populations undergo more or less cyclic changes with a period of 60 to 90 years (Ferguson et al. 1998; Zalatan et al. 2006; Gunn et al. 2011). The impact of local harvest when the populations are cyclic low has been heavily debated, especially in the Canadian management system, and recently the Nunavut Government banned hunting of the Baffin Island caribou due to historically low numbers (Nunavut Government 2014).

In all the above mentioned examples the harvest regulations were implemented by governments, and the rationale has been that local harvest represented an additional impact on an already threatened population, indicating that an appropriation action situation has arisen due to exogenous drivers working on the resource (see Figure 1). However, such arguments are often heavily contested by local harvest organizations who frequently question the management authorities' assessment of the stock and/or the impact from local harvest (Collings 1997; Armitage 2005; Clark et al. 2008; Dowsley and Wenzel 2008; Kendrick 2013). In other words, while governments claim that low resource levels has resulted in an appropriation action situation necessitating harvest regulations, local people often claim that the situation is still provisioning. Thus the conflict is rooted in two different action situations, addressing different governance challenges, scales and levels of organization and knowledge systems. For example, in the caribou hunting systems in Canada and Alaska, hunters use Traditional Ecological Knowledge (TEK) to guide effective, non-wasteful and respectful local hunting practices (Kendrick 2000; Parlee et al. 2005; Kendrick and Manseau 2008). However, to address collective action problems in the case of appropriation challenges, there might be a need for delineating the caribou herds, identify the respective resource users, and implement a monitoring regime that can give unbiased and trustworthy estimates of the harvests and stock size. Currently, this knowledge is mainly collected by management authorities using western scientific methodology, and it is accordingly a considerable challenge

Table 2: Status, trend, major drivers and management regulations of Arctic wildlife and fish stocks.

Resource	Alaska			Canada			Greenland		
	Status & trend	Major drivers	Regulation of local harvest	Status & trend	Major drivers	Regulation of local harvest	Status & trend	Major drivers	Regulation of local harvest
Pacific salmon	↘ (red)	Unk	Yes						
Atlantic salmon							↘ (red)	His/Unk	Yes
Seabirds and ducks	→ (yellow)	His/Nat	Few	→ (yellow)	His/Nat	Few	↘ (red)	His/Loc	Yes
Geese	↗ (green)	His/Nat	Few	↗ (green)	His/Nat	Few	↗ (green)	His/Nat	Yes
Bowhead whale	↗ (yellow)	His	Yes	↗ (red)	His	Yes	↗ (red)	His	Yes
Beluga whale	→ (yellow)	His	Few	→ (red)	His/Loc	Yes	→ (red)	His/Loc	Yes
Narwhal				→ (yellow)	Cli/Loc	Yes	→ (yellow)	Cli/Loc	Yes
Moose	↘↗ (red)	Nat	Yes						
Migratory caribou	↘ (green)	Nat	Few	↘ (red)	Nat	Few[1]			
Greenland caribou							↘ (green)	Nat	Yes
Peary caribou				↘↗ (red)	Nat	Few			
Muskox	↘↗ (yellow)	His/Nat	Yes	↘↗ (yellow)	His/Nat	Yes	↘↗ (yellow)	His/Nat	Yes
Polar bear	↘ (yellow)	His/Cli	Few	→ (yellow)	His/Cli	Yes	↘ (yellow)	His/Cli	Yes
Walrus	↘ (green)	His/Cli	Few	→ (red)	His/Loc	Few	→ (red)	His/Loc	Yes
Hooded seal				↗ (yellow)	His	Few	↗ (yellow)	His	Few
Bearded seal	→ (yellow)	Cli	Few	→ (yellow)	Cli	Few	→ (yellow)	Cli	Few
Harp seal				→ (green)	His	Few	→ (green)	His	Few
Spotted seal	→ (yellow)	Cli	Few						
Ringed seal	→ (yellow)	Cli	Few	→ (yellow)	Cli	Few	→ (yellow)	Cli	Few

"Status & trend" refers to the status (color) and trend (arrow) assessed from management reports. "Regulation of local harvest" refers to governmental regulations of local native, mostly subsistence hunting and fishing in the study area. Detailed regulations are indicated with "yes", largely unregulated harvests or wide hunting/ fishing limits are indicated with "few". "Major drivers" refers to the major drivers acting on the current stock dynamics: Cli is climate warming; His is rebounding from historical industrial or commercial over-harvest; Loc is local harvests; Nat is natural fluctuations; Unk is unknown. A detailed specification of the rationale behind the classifications are given in Appendix 2.

[1]Native harvest is mostly unregulated except on Baffin and Southampton Islands.

(red) *Resource scarcity and/or stock is reduced compared to historical levels.*
(yellow) *No resource scarcity reported.*
(green) *Resource is abundant compared to historical levels.*
↘ *Resource stock is declining.*
→ *Resource stock is stable or no trend reported.*
↘↗ *Resource stock is fluctuating.*
↗ *Resource stock is increasing.*

to combine TEK with western science in the herd specific management boards that have been established to specifically tackle collective action problems (Kofinas 1998; Kruse et al. 1998; Kendrick 2000; Urquhart 2012). Despite these challenges, the implementation of TEK or IQ (*Inuit Qaujimajatuqangit*) in the Canadian co-management system has empowered the local resource users and has been instrumental for turning the management focus from a one-sided focus on appropriation challenges towards local provisioning challenges (see e.g. Thorpe 2004; BQCMB 2014).

The impact from and regulations of local harvest followed a regional pattern with less impact and regulations in Alaska, more incidences of impact and regulations in Canada and relatively widespread recent impact and detailed regulations in Greenland (Appendix 2, Table 2). In other words, the effects of local harvest followed the pattern in commoditization of the resources (see Section 3.4), suggesting that commercialization might spur an increased demand and eventually an increased harvest pressure. In Arctic Alaska, where commercialization of fish and wildlife is largely suppressed by national and state legislation and poor infrastructure (Section 3.4), we found relatively few local regulations of subsistence hunting (Table 2, see Appendix 2 for details). In the cases where regulations have been issued resource scarcity was, according to the management reports, mainly due to exogenous drivers such as natural fluctuations, historical overharvest from non-locals or climate change. We found no cases where local harvesting was mentioned as a major driver of population dynamics, and subsistence harvest was neither considered to be a threat to any of the three Arctic species listed under the Endangered Species Act (ESA).

In Arctic Canada, restrictions on local hunting have been implemented to protect declining or vulnerable populations of bowhead and beluga whales, narwhal, polar bear, caribou and muskoxen. The dominant explanations for decreasing resources have been natural fluctuations, historical overharvest from non-locals or climate change. However, local harvest of migratory caribou, beluga whale, narwhal and polar bear have according to the management reports contributed to resource decline in several cases (Appendix 2, Table 2). In general, there has been an increased need for cash in the mixed household subsistence economy, and in Canada were selling resources have been enabled to some extent (see Section 3.4), there are several examples in which commoditization of wildlife products has spurred conflicts among management authorities and local resource users (Wenzel 1991; Armitage 2005; Clark et al. 2008; Dowsley and Wenzel 2008).

In contrast to Canada and Alaska, Greenland has long traditions of commercial utilization of natural resources (Section 3.4), and local over-harvest and dwindling resources were the main causes behind the enforcement of new and stricter hunting regulations on walrus, beluga whale, narwhal, polar bear and several bird species in the early 2000s (Appendix 2, Table 2). For example, of the 115 species/populations considered in the Greenland red-listing process, 36 were listed within one of the six IUCN criteria and hunting was considered to be a serious threat to half (18) of the listed species/populations (Boertmann 2007). Subsequent to the implementation of stricter hunting regulations, the pressures on the threatened species have decreased considerably (cf. Figure 6). The situation for some seabird populations has improved following the reduction in harvest pressures (Merkel 2010); however, populations of thick-billed murre (*Uria lomvia*) have continued to decrease (Merkel and Labansen 2013). Thus, despite being largely top-down oriented with little legitimacy locally (Nielsen and Meilby 2013), the hunting statistics suggest that the management actions have been successful in terms of reducing harvest pressures on the threatened populations. This has, however come at a cultural and democratic cost (Nielsen and Meilby 2013).

4. Conclusion

Our synthesis of the characteristics of the fish and wildlife resources and the corresponding provisioning challenges in the Western Arctic, suggests that the resource users traditionally do not control the resource level but rather adapt to the fluctuating availability of fish and wildlife. The collective challenge facing the resource users is therefore to maintain and secure the subsistence in the community rather than to prevent overexploitation. The traditional subsistence SESs are accordingly mainly donor controlled and conforming to a provisioning action situation. Given the potential increase in harvest efficiency during the last century by the introduction of new technology, a transition from a provisioning to an appropriation action situation might arise due to exogenous drivers working to 1) increase the cash income to buy necessary equipment and fuel, 2) increase the resource demand, and 3) reduce the standing stock of the resource. Our synthesis show complex interactions among multiple exogenous drivers which have either activated or inhibited transitions. Thus, the results do not indicate a broad scale transition throughout the Western Arctic. However, the data indicate that appropriation challenges have emerged to a varying degree, and mainly through two lines of development. First, exogenous drivers such as climate change and previous industrial overharvest have resulted in several cases of resource scarcity. Although the arguments often have been contested by the resource users themselves, management authorities have as a consequence implemented harvest restrictions on local subsistence users. Secondly, commercialization of fish and wildlife resources have, most notably in Greenland, provided cash income and incentives to increase the harvest. In Greenland and in a few cases in Canada, this has resulted in excess harvest and appropriation action challenges. As a response, the government in Greenland has implemented harvest restrictions which presumably have reduced the pressure on vulnerable wildlife species. A third line of development has worked in the opposite direction to decrease the demand for fish and wildlife. A combination of urbanization, increased wage labor and importation of food has reduced the demand for local country food throughout the study area. Thus despite increasing populations, the resource use has not increased, possibly preventing appropriation challenges. Presently, Arctic warming is threatening many important Arctic wildlife resources, and this exogenous driver is likely to result in more cases of resource scarcity and associated governance interventions in the name of preventing additional impacts from local hunters and fishers. The transition to an appropriation action situation involves a change in the objectives and scale for collective actions. The governance challenges may not be perceived equally among all participants and stakeholders, and conflicts have been a frequent outcome in the arenas where these re-framings are negotiated (Kofinas et al. 2013). Such changes are particularly demanding in the Arctic where the fish and wildlife resources typically are large, fluctuating and migrating and where the collective actions traditionally have been directed towards solving local provisioning challenges.

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Appendix 1

1. Population data

Population statistics were collected from official web-sites. We were able to construct three time series of population size from the beginning of the 20th century to the present from the arctic regions of Alaska, Canada and Greenland. Data from Alaska was retrieved from State of Alaska, Census and Geographic Information (http://labor.alaska.gov/research/census/). The data included the inhabitants in the 2nd Judicial District from 1910 to 2011. This division was the census division from 1910 to 1950 encompassing Nome Census Area, North Slope Borough, Northwest Arctic Borough and Wade Hampton Census Area. Population estimates from Arctic Canada was retrieved from Statistics Canada, CANSIM (http://www5.statcan.gc.ca/cansim/a01?lang=eng&p2=1). The longest time series from an arctic area covered the Northwest Territories (NWT) and Nunavut from 1921 to 2012. Thus, the data also covers the southern part of NWT, which is slightly south of the tundra region. Data from Nunavut, which is entirely within the arctic definition, was available from 1986 to 2012. Population estimates from Greenland was retrieved from Statistics Greenland, Stat Bank (http://bank.stat.gl/pxweb/en/Greenland/?rxid=79ffe66b-c8c4-434a-bfd5-9e24cb0fe685). Greenland is entirely within the defined tundra region, and data goes back to 1901.

2. Harvest data

We used data from subsistence surveys in Arctic Alaska and Canada and official statistics on harvest in Greenland to investigate the recent development of wildlife and fish harvest in the study area. The importance of the different fish and wildlife resources utilized by the Arctic communities in Canada and Alaska has been mapped by subsistence surveys conducted by the management authorities since the 1960s. Data for Alaska and Canadian Arctic has been compiled by the Arctic Observatory Network AON database (Kruse 2011). Data from this database was downloaded from (http://www.iser.uaa.alaska.edu/Projects/SEARCH-HD/aonsub.htm). In addition, the Canada data was supplemented with data from the Inuvialuit Harvest Study (IHS 2003). We did only include complete surveys where data from all resources had been collected. In total, the resulting dataset comprised 326 entries of community/year harvest. Harvest was expressed as the weight (kg) of a resource harvested per person per year. In cases were data were expressed as the number of harvested items, the data were converted to weight in kilograms using the average conversion factors given by Subsistence Division, Alaska Department of Fish and Game (http://www.adfg.alaska.gov/sb/CSIS/index.cfm?ADFG=main.conversionFactorSelRes). Communities outside the defined study area (see main article Figure 2) were excluded from the dataset. The final dataset spanned 116 communities from the time period 1964 to 2007. Descriptive statistics of the dataset is given in Table A1.

Table A1: Descriptive statistics of subsistence harvest data from Canada and Alaska.

N (community and year)	326
Average (kg)	235.4
Median (kg)	192.0
Min (kg)	13.6
Max (kg)	1060.2
StDev (kg)	157.3
CV	105.1

Data are entries of complete community and year records expressed as the total weight (kg) of all harvested resources per person in the community.

In Greenland, it is mandatory to report the harvest of mammals and birds to the management authorities. Annual catch statistics of harvested species (number of individuals harvested) in the period 1996–2013 were retrieved from Statistics Greenland, Statistical Yearbook (http://www.stat.gl/dialog/topmain.asp?lang=da&subject=Statistical%20Yearbook&sc=SA). The data were converted to weight in kilograms, using the average conversion factors given by Subsistence Division, Alaska Department of Fish and Game (http://www.adfg.alaska.gov/sb/CSIS/index.cfm?ADFG=main.conversionFactorSelRes). Note that fish is not included in the statistics from Greenland.

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Appendix 2

1. Materials and methods

1.1. Data sources

Data on resource characteristics, resource status and management actions were collected from official reports and web sites issued by the international and national institutions providing advice to the governmental management institutions. To guide the management, these bodies provide detailed reports based on scientific and traditional ecological knowledge (TEK), including *Inuit Qaujimajatuqangit*. The national institutions are responsible for collecting the primary data of the resource use system, both through survey activities and by collecting TEK. These data are compiled and synthesized in comprehensive reports edited by leading experts in the field and issued by the respective national and international institutions. We used reports and official web-pages issued by: Alaska Department of Fish and Game (ADFG), Committee on the Status of Endangered Wildlife in Canada (COSEWIC), Government of Nunavut Department of Environment, Department of Fisheries and Oceans Canada (DFO), Environment Canada, Greenland Institute for Nature Research (GINR), International Union for Conservation of Nature (IUCN), International Whaling Commission (IWC), The North Atlantic Marine Mammal Commission (NAMMCO), National Oceanographic and Atmospheric Administration (NOAA) and US Fish and Wildlife Service (USFWS). In addition, we consulted reports and management plans issued by local co-management boards as well as the scientific literature.

In this synthesis, we concentrate on the most important wildlife resources harvested by local indigenous people in Arctic Alaska, Canada and Greenland (see main article).

1.2. Resource characteristics

Arctic wildlife resources were classified according to four characteristics considered important for diagnosing the social-ecological system:

1. The presence and degree of seasonal stock migration.
2. Size and extent of the stocks, and whether the resource is shared by multiple communities.
3. The presence of seasonal superabundant concentration of the resource.
4. The predictability of resource availability.

For each wildlife resource, we give a short description with arguments for the classification followed by a conclusion.

1.3. Resource status and regulation of subsistence harvest

To address evolving resource subtractability and possible drivers behind resource scarcity, we searched for:

1. Status of the resource stocks with emphasis on scarcity with respect to the subsistence users' need.
2. Current trend in the resource stocks.
3. Major drivers of current stock dynamics.
4. Implementation of regulations of local subsistence harvests.

For each wildlife resource, we give a short description with arguments for the classification followed by a conclusion. It should be noted that the procedure for national red-listing differ between the countries, however the red-listing provide important documentation pertaining to the causes of declines and important threats.

2. Results

2.1. Pacific salmon (*Oncorynchus spp.*)

2.1.1. Resource characteristics

Pacific salmon harvested by local subsistence users in the Arctic Alaska and Canada belong to five different species spawning in rivers discharging into the Bering and Chukchi Seas. They use the Bering Sea and North Pacific for growth until they return to their home river to spawn. The salmon stocks are easily identified by the rivers where they spawn, however during the sea phase salmon from different stocks mix over large ocean areas. Fishing takes place in rivers and near-shore coastal areas where maturing salmon is caught during the spawning migration. The migration of spawning salmon is predictable, and the maturing fishes might occur in super-abundant concentrations. The salmon run does however show some inter-annual variation. In large river systems such as the Kuskokwim and Yukon drainage systems, the salmon stocks are particularly large and shared by several communities, and salmon spawning in the Yukon river system might also be shared by communities on both side of the US-Canada border.

Conclusion: Pacific salmon conduct extensive migrations between spawning and feeding areas. Stocks are defined by river systems. In the large river systems in Alaska, the stocks are large and shared by many communities. The resource is predictable and does commonly occur in super-abundant concentrations.

2.1.2. Resource status and fishing restrictions

Pacific salmon is particularly important in the Arctic-Yukon-Kuskokwim region. Salmon returning to this region has been in decline for several decades and restrictions on commercial and subsistence fisheries have been implemented. The reason behind the decline is complex and uncertain.

Conclusion: Salmon in the Arctic-Yukon-Kuskokwim region has been declining, resulting in resource scarcity and fishing restrictions. The reason for the declining resources is unknown.

2.1.3. Sources

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2.2. Atlantic salmon (*Salmo salar*)

2.2.1. Resource characteristics

In the Arctic, Atlantic salmon is mainly fished along the coast of West Greenland. Greenland has only one isolated spawning population of salmon, and the salmon fished along the coast is fish spawning in North American and European rivers using the coastal areas outside West Greenland as feeding areas. The resource do therefore belong to the larger North Atlantic stock.

Conclusion: Atlantic salmon fished along the western coast of Greenland, conduct extensive migrations to the spawning rivers in Europe and North America. The resource belong to a large inseparable stock utilized by many users. The resource is relatively predictable.

2.2.2. Resource status and fishing restrictions

Intensive commercial fisheries for Atlantic salmon in the marine feeding areas in West Greenland, North Norwegian Sea and Faroe Island peaked in the1970s and early 1980s. The fisheries ended in the early 1990s after dwindling resources and international agreements resulting in stricter regulations. For unknown reasons, the decline in the population of Atlantic salmon has continued after the commercial fishing has ended. At present, salmon fishery is strictly regulated in Greenland limited to a subsistence fishery allowing for a restricted local sale.

Conclusion: Previous commercial fisheries in the mid-1900 contributed to declining salmon populations. The reason behind the more recent decline is unknown. As a consequence of resource scarcity, salmon fisheries in in Greenland is strictly regulated.

2.2.3. Sources

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2.3. Seabirds, ducks and geese

2.3.1. Resource characteristics

Seabirds, duck and geese are harvested by local people throughout the circumpolar Arctic. In total, more than 40 different species of geese, ducks and seabirds are harvested, however harvest is often concentrated around a few abundant groups such as murres (*Uria* spp.), eiders (*Somateria* spp.), snow goose (*Chen caerulescens*), brent goose (*Branta bernicla*) and cackling (Canada) goose (*Branta hutchinsii*).

Eggs, adults and chicks are harvested in remote breeding colonies. Adults and juveniles are in addition hunted outside the breeding season in places where they concentrate, e.g. feeding areas at sea, roosting places, places where they molt, and migratory fly ways. When congregating in breeding colonies, during molting, migration or on feeding grounds, seabirds duck and geese may form a highly concentrated, superabundant and more or less predictable resource. The distance and access to large breeding colonies is important for the harvests of seabirds, and a colony close to a settlement might form a predictable and clearly delineated resource. However, due to seasonal migration, other distant settlements might hunt the same resource during e.g. spring migration or on winter feeding grounds. Moreover, birds in an aggregation outside the breeding season do often belong to several different breeding colonies, further complicating the delineation of the resource. Therefore, hunting of birds outside the breeding season increase the number of potential resource users and complicate the delineation of the resource.

Conclusion: Seabirds, ducks and geese conduct extensive seasonal migrations. Breeding colonies do often form predictable, superabundant and clearly delineated resources. However, species that are also hunted outside the breeding season form large and inseparable resources shared by many groups of resource users.

2.3.2. Resource status and hunting restrictions

By the end of the 19th and beginning of the 20th century, an industrialized harvest of eggs and birds had a detrimental effect on many large seabird colonies in the Arctic. During the 20th century, regulations in Alaska and Canada were implemented to end the commercial harvest and regulate the sports hunting. Exemptions were made for traditional, native, subsistence users, and this harvest has continued more or less unregulated to date. The harvests are however minimal and within sustainable limits. More intense harvests of seabird colonies have however continued in Greenland. This activity has threatened several populations of ducks and seabirds, which consequently were listed on the Greenland red-list. Stricter regulations were implemented during the early 2000s, including bag limits and restricted hunting seasons. Since then, the harvests in Greenland has declined. The populations of geese have generally increased in the western Arctic with expanding breeding ranges. The increase is mainly due to improved forage conditions in the winter habitats and reduced hunting pressure during migration. In several cases, increased hunting has been encouraged by management authorities to stabilize the populations. In contrast, several sea duck species (e.g. common eider *Somateria molissima*, Steller's eider *Polysticta stelleri*, long-tailed duck *Clangula hyemalis*, velvet scoter *Melanitta fusca*) have shown population declines. In Greenland and Canada, hunting has been argued to be a reason for the decline, and stricter hunting regulations have, in some cases been successful with respect to change the negative trends.

Conclusion: There are few harvest restrictions on the native subsistence use in Alaska and Canada. Local overharvest has been an important explanation for declining seabird and eider populations in Greenland where harvest restrictions have been implemented and several species are red-listed. The populations of geese are generally high and increasing across the study area. Several seabird and duck populations in Greenland are low and declining. The status and trends for seabirds and ducks are probably more mixed in Canada and Alaska.

2.3.3. Sources

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2.4. Bowhead whale (*Balaena mysticetus*)

2.4.1. Resource characteristics

Commercial whaling, ending in the beginning of the 20th century, heavily decimated this large, slow, circumpolar, Arctic baleen whale and the populations are still slowly recovering. The global population is divided into four subpopulations: 1. Okhotsk Sea, 2. Bering-Chukchi-Beaufort seas (BCB population), 3. Eastern Canada – West Greenland (EC-WG population), 4. Svalbard/Barents Sea. The bowhead whale stay in Arctic waters throughout the year, however the BCB and EC-WG populations conduct extensive seasonal migrations, following the changing feeding opportunities and the expansion and retreat of the sea ice. The BCB population summers in the eastern Beaufort Sea and Amundsen Gulf and winters in the central and eastern Bering Sea. The EC-WG population summers in the Canadian High Arctic, Foxe Basin, and northwestern Hudson Bay and winters in northern Hudson Bay, Hudson Strait, and along the ice edge in Davis Strait and off West Greenland. They are social animals that commonly form large loose groups along the ice edge or where ocean conditions concentrate prey. Possibly due to shifting environmental conditions, there is considerable inter annual variation in the geographic locations where bowhead whales are observed during migration and summer.

Conclusion: Bowhead whales occur in large inseparable stocks shared by more than one community. They conduct extensive seasonal migrations, they commonly occur in groups, and the availability is variable depending on environmental condition and migration pattern.

2.4.2. Resource status and hunting restrictions

IWC regulate the harvest, and a limited number of Bowhead whales are allowed harvested by subsistence hunters in Alaska, Canada and Greenland. The BCB population has presumably recovered more quickly from the period of industrial whaling than the Atlantic stocks, and the population is now close to the pre-industrial level, counting about 10,000 individuals. Currently 64 animals are allowed harvested annually from this stock by indigenous subsistence hunters in Alaska. There exists large uncertainty regarding the size of the EC-WG population, however the population is currently increasing and estimated to about 6000 individuals. Canadian and Greenland hunters are allowed to take a few animals from this stock. Due to the historical depletion of the populations, bowhead whale is classified as "Endangered" under ESA, the EC-WG population is listed as "Near Threatened" in the Greenland red list.

Conclusion: Current resource scarcity is related to historical overexploitation and a slow recovery rate. The stock in Alaska is probably close to pre-historic levels, while the stocks in the Atlantic probably still are at relatively low levels. Native hunting is regulated through strict quotas, and the current harvest is wihin a sustainable range.

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2.5. Beluga whale (*Delphinapterus leucas*)

2.5.1. Resource characteristics

Beluga whale is, together with narwhal, one of the two members of the family Monodontidae, and is found in seasonally ice-covered waters in the circumpolar north. They conduct extensive seasonal migrations, often covering several thousand kilometers between offshore waters associated with pack ice during winter, and coastal estuaries, bays, glacier fronts and rivers during summer where they molt and calve. Belugas are gregarious animals and are generally found in aggregations counting tens to several hundred individuals. Occasionally, when entering river estuaries during summer, the aggregations may number several thousand individuals. In the Northwest Atlantic, summer aggregation sites are found in coastal Canadian arctic and subarctic areas. Belugas are generally not summering along the Greenland coast, but two important wintering areas are found in the waters off West Greenland. In Alaska, coastal summer areas are found from Cook Inlet to Beaufort Sea. Bering Sea is the major wintering area. The discontinuous summer distribution is used to delineate the stocks, and currently five stocks are recognized in Alaska waters while seven stocks are recognized in Canada (one stock, the Beaufort stock, is overlapping). Stock sizes ranges from less than thousand to tens of thousands individuals. The world population of Belugas counts more than 150,000 individuals.

Conclusion: Beluga whale conduct extensive seasonal migrations between summer and winter habitats. During summer, they belong to separable stocks utilized by a defined group of resource users. The stocks are poorly defined during the winter season. They might be found in relatively dense aggregations, however the availability might be variable and stochastic due to variable ice conditions and migrations.

2.5.2. Resource status and hunting restrictions

Belugas are hunted for food by Native people in Alaska, Canada and Greenland. Commercial exploitation during the 19th and 20th century greatly affected several populations of belugas. The strong philopatry of belugas, which causes them to return to the same estuaries year after year, makes them vulnerable to overexploitation, and this trait is an important factor that has led to the extirpation of belugas from some parts of their range by a combination of commercial and subsistence hunting. Hunting for human consumption is still the biggest known threat to belugas across certain portions of their range, and the most immediate concerns relate to continuing harvests from small and depleted subpopulations. For this reason belugas were listed as "Near Threatened" by IUCN, several subpopulations are listed as threatened by COSEWIC, but none of the northern populations are currently legally listed under SARA. Finally, belugas are listed as "Critically Endangered" in the Greenland red-list. In Alaska, the four arctic populations are not threatened or depleted, and they have increasing, stable or unknown trends. The subsistence take is small and generally considered to be within sustainable limits. Several populations in Arctic Canada and West Greenland are still severely depleted by earlier commercial and subsistence harvests. In the early 2000s, the Native harvest in eastern Canada was suggested to threaten several subpopulations, and the harvest in Greenland was considered unsustainable. Management plans were implemented in Canada and more strict hunting regulations were introduced in Greenland. Subsequently the catches have decreased, most notably in Greenland, and recent surveys suggest that several populations have stabilized or are increasing. At present the catches in Greenland and Canada are considered to be sustainable.

Conclusion: Resource scarcity is related to a combination of historical commercial harvest and continued subsistence harvest. Stocks in Alaska are not depleted and trends are stable, increasing or unknown. In Greenland and Canada several stocks are still severely depleted. Restriction on native harvest has been implemented in Greenland and Canada. As a result, the harvests have declined and is currently within a sustainable range.

2.5.3. Sources

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2.6. Narwhal (*Monodon monoceros*)

2.6.1. Resource characteristics

Narwhal is a medium-sized toothed whale found in Arctic waters in the North Atlantic and the adjacent Arctic Ocean. Closely associated with sea-ice, they conduct extensive seasonal migrations, generally returning to the same summering and wintering areas year after year. The summer habitats are found in coastal areas and fjords where they are hunted, and the stocks have been identified by these summer aggregations. Currently, five stocks in Canada, two stocks in West Greenland and one in East Greenland have been defined. Stock assessments indicate that the abundance of animals might vary considerably from year to year and also within seasons. Ranges of stock sizes varies from a few thousand to tens of thousands individuals. In sum, the world population of narwhal counts about 85,000 individuals. During winter, the stocks from the different summer areas mixes in offshore winter habitats such as the pack ice in Davis Strait/Baffin Bay.

Conclusion: Narwhal conduct extensive seasonal migrations between summer and winter habitats. During summer, they belong to distinct separable stocks utilized by a defined group of resource users. The stocks are however poorly defined during winter. They might be found in relatively dense aggregations. The availability might be variable and stochastic due to variable ice conditions and migrations.

2.6.2. Resource status and hunting restrictions

Narwhal is harvested by Native hunters in Canada and Greenland. They were not a major target for the large-scale commercial hunting of Cetaceans in the Arctic, however narwhals have been hunted by Inuit for centuries. The mattak (skin and adhering blubber) is highly prized as food, and until recently the ivory tusk was an important commercial commodity. In the 1990s and early 2000s large catches, an unknown proportion of struck and lost animals, and surveys indicating declining populations in West Greenland, raised the concern for possible overharvest. As a consequence, narwhal was listed as "Near Threatened" by IUCN, it was designated a "Special Concern" by COSEWIC but was not given a formal SARA status, and it was listed as "Critically Endagered" on the Greenland red list. In the last ten years the harvest has declined, most notably in Greenland, the harvest has been within the proposed quotas set by NAMMCO, and recent surveys of the populations suggest that the current harvests are sustainable. Because narwhal is a high-arctic species closely associated with sea-ice, the direct and indirect effects of climate warming is likely to have negative impact on this species in the future.

Conclusion: Resource scarcity has been related to native harvests. Currently, climate warming is considered to be the most important threat to this high-arctic species. The species is red-listed by IUCN and in Greenland. High harvest rates of narwhal in Canada and Greenland, partly related to the commercialization of narwhal tusk, was considered unsustainable by the management authorities by the early 2000s. More strict quotas were implemented, and harvest rates have decreased to sustainable levels, most notably in Greenland.

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2.7. Moose (*Alces alces*)

2.7.1. Resource characteristics

Moose is a large herbivore with a circumpolar distribution. It inhabits northern forests and is normally relatively rare in the northern areas bordering the Arctic tundra. During the 20th century moose expanded west and northwards in Alaska, and has become an important resource for many arctic communities. In these areas, moose is mainly found in riparian habitats. They are relatively evenly distributed in the preferred habitat, and normally make small seasonal movements to calving, rutting, and wintering areas.

Conclusion: Moose do not conduct extensive seasonal migrations. The resource is evenly distributed and can be delineated into relatively small units.

2.7.2. Resource status and hunting restrictions

Moose started to colonize the western and northern parts of Alaska in the 1930s and 1940s. The moose populations in these areas grew rapidly and became an important resource for local subsistence hunters. The populations peaked in the 1980s, and due to a series of harsh winters combined with increased predation from brown bear and diseases, the populations declined and are presently fluctuating at relatively low levels. Bag limits and hunting seasons have been introduced to reduce the additional impact from hunting on the declining populations.

Conclusion: Natural fluctuations generate resource scarcity and hunting restrictions have been implemented. Currently the resource stock is fluctuating at low levels.

2.7.3. Source

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2.8. Migratory tundra caribou (*Rangifer tarandus caribou, R. t. groenlandicus and R. t. granti*)

2.8.1. Resource characteristics

The migratory barren-ground caribou populations inhabiting the tundra in North America consist of three sub-species belonging to more than 20 more or less well-separated herds covering the tundra region from Labrador in east to Seward Peninsula in west. Current herd sizes ranges between a few thousand animals up to more than 350,000 animals. The herds are delineated and counted in summer when the herds congregate on their specific calving grounds on the Arctic tundra, often on the coastal plains close to the Arctic Ocean. In general, the herds migrate south to the boreal forest during winter, and during an annual cycle the herds might cover an area of tens of thousands to several hundred thousand square kilometers. While the calving grounds are relatively fixed, the winter areas might change considerably depending on density and forage availability. The populations show cyclic population changes with a period of ~60 years. Large population changes combined with congregated and migratory behavior make the availability of caribou variable and stochastic.

Conclusion: Migratory tundra caribou conduct extensive seasonal migrations, they belong to large, often inseparable herds each shared by more than one community, they occur in seasonal superabundant concentrations especially during migration and calving, and the availability is variable and stochastic.

2.8.2. Resource status and hunting restrictions

Large natural population cycles, likely driven by climate interacting with forage availability, predation, and pathogens, will inevitably induce periods of resource scarcity. Several herds in the Arctic Canada have declined substantially since the 1980s and management authorities have expressed concern for the additional negative impact from subsistence harvest. Partly as a response to this challenge, co-management boards have been established for several herds. However, with some exceptions (see next paragraph), few hunting restrictions with respect to the local aboriginal hunting has been enforced in Canada. In Alaska, the herds have been increasing during the 1980s and 1990s and are currently at high levels, although several of the herds are currently decreasing. The local subsistence harvests of the Arctic herds are regulated through hunting seasons and bag limits. The regulations varies between management areas and herds; however, the regulations are relatively liberal, i.e., multiple bag limits (2–10 caribou) and closed seasons mainly during calving.

Most likely, because of natural population cycles, the Baffin Island population has been declining since the 1980s, and the Nunavut Government introduced a hunting moratorium in January 2015. In August 2015, the government opened up for a limited hunt after advice from the Nunavut Wildlife Management Board. The Southampton Island caribou in Hudson Bay was extirpated, partly by overhunting by 1952. Caribou where re-introduced in 1967, and a rapid increase in the population allowed a commercial exploitation of the stock. A disease affecting reproduction (*Brucellosis suis*), icing event on pastures and possibly deteriorating pastures and over-harvest has resulted in a decrease from 30,000 animals in 1997 to about 7000 in 2014, and as consequence, harvest quotas have been implemented. In the 1920s the Dolphin-Union herd on Victoria Island went almost extinct as a consequence of a combination of over-harvest and icing events on the pastures. Since then the population has increased to a quarter of the original size. Climate warming and increased shipping make the seasonal migration between Victoria Island and the mainland more dangerous, and this population has been listed as “Special concern” by SARA (Species At Risk Act) in Canada. Restrictions on local hunting has however not been implemented on this population.

Conclusion: Although overharvest might have been important for some isolated stocks, most of the current episodes of resource scarcity has been driven by natural population cycles. When stocks are cycling low, management actions to mitigate additional effects of local subsistence harvest have been implemented in some cases. Herds in Alaska are currently at a relatively high level but several are decreasing. In Canada, a majority of herds are decreasing and are currently at a low level.

2.8.3. Sources

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2.9. West Greenland caribou (*Rangifer tarandus groenlandicus*)

2.9.1. Resource characteristics

The caribou populations inhabiting West Greenland consist mainly of the original sub-species *R. t. groenlandicus* but also introduced semi-domesticated reindeer from Norway (*R. t. tarandus*). Fjords, mountains and glaciers restrict the ranges, and the caribou are divided into 12 more or less isolated populations counting from a few hundred to almost 100,000 animals. Seasonal migration is limited, and the animals occur in relatively small groups. They lack natural predators, and the populations show large cyclic fluctuations.

Conclusion: West Greenland Caribou do not conduct extensive seasonal migrations. The herds are relatively stationary and evenly distributed. Due to large population fluctuations, the availability of the resource might be highly variable on a decadal scale.

2.9.2. Resource status and hunting restrictions

Hunting of caribou in Greenland is regulated by quotas and limited hunting season. Due to high fertility and population growth under favorable forage conditions, the number of caribou in West Greenland has increased substantially the last decades. High densities increase the risk of overgrazing, resulting in poor body condition and potential population collapses, especially under severe winter conditions. Surveys in 2001 suggested that caribou populations in West Greenland were overabundant with densities up to four animals per km^2. Quotas were consequently increased and eventually an open harvest was implemented in 2003. Moreover, the hunting season was pro-longed from one to five and a half months. The populations are currently stable or decreasing, and low calf recruitment suggests that the pastures are overloaded.

Conclusion: Natural population fluctuations generate periods of resource scarcity and overabundance. Hunting restrictions have recently been relieved to reduce overabundance and the accompanying risk of population collapse. The herds show currently a declining trend.

2.9.3. Sources

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2.10. Peary caribou (*Rangifer tarandus pearyi*)

2.10.1. Resource characteristics

The Peary caribou inhabits the northern part of the Canadian Arctic Archipelago. They show little seasonal migration however, especially during severe winters, they may migrate to explore new pastures. They are usually found in relatively small groups or loose aggregations. The populations show large fluctuations with more or less frequent crashes following severe winters with icing events on the pastures.

Conclusion: Peary caribou do not conduct extensive seasonal migrations. The herds are relatively stationary, and evenly distributed. Due to large population fluctuations, the availability of the resource might be highly variable on a decadal scale.

2.10.2. Resource status and hunting restrictions

The populations of Peary caribou have declined by about 70% over the last three generations. This is mostly because of catastrophic die-offs related to severe icing episodes. Such fluctuations might be exacerbated by climate warming. Management authorities have not implemented local hunting restrictions, however voluntary restrictions by local people are in place. This has not stopped population declines, and because of the expected changes in long-term weather patterns due to climate warming, Peary caribou is at risk of extinction and has been listed as endangered by the SARA listing.

Conclusion: Resource scarcity is mainly due to natural population fluctuations. Local people have in some places, implemented voluntary hunting restrictions. Populations are at low levels and several populations are probably still decreasing.

2.10.3. Source

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2.11. Muskox (*Ovibos moschatus*)

2.11.1. Resource characteristics

This large, generalist herbivore is relatively stationary, utilizing slightly different seasonal pastures. They are found in small herds on the tundra distributed through Arctic Canada and Northeast Greenland, and has been introduced or re-introduced to Alaska and western Greenland. The global population is between 150,000 and 200,000 animals. About 75% (113,000 animals) are found in Arctic Canada with about 80,000 animals on the large mid-Arctic Islands; Banks and Victoria Islands.

Conclusion: Muskoxen do not conduct extensive seasonal migrations. They have small home ranges and are evenly distributed. The availability of the resource varies on a decadal scale due to large population fluctuations.

2.11.2. Resource status and hunting restrictions

Unregulated commercial harvesting caused the disappearance of muskoxen from large areas of their continental ranges in North America by the late 19th century. At the same time, ice storms probably reduced muskox numbers on Banks and Western Victoria islands. During the early 20th century muskoxen were reintroduced in several places in Alaska and West Greenland. Hunting was first suspended and later strictly regulated, and as a response, muskoxen began to recover, expanding their range by recolonizing historic ranges in North America. At present, a combination of density-dependent food limitation, harsh winter conditions and diseases has caused large fluctuations in the populations in West Greenland

and on Banks and Victoria Islands. Hunting by locals is regulated by quotas and hunting seasons.

Conclusion: Previous commercial overharvest decimated the populations and the subsequent management actions included re-introduction and hunting restrictions. Hunting regulations are still in place and populations have recovered in many places. Currently, the populations show large natural fluctuations.

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2.12. Polar bear (*Ursus maritimus*)

2.12.1. Resource characteristics

Polar bear is a circumpolar marine top predator, found in Arctic waters covered by seasonal or permanent ice. The major food source is ice-dependent seals, most importantly ringed seals, which the bears hunt in ice-filled waters. The distribution of polar bears is therefore closely associated with sea ice. Except when environmental conditions concentrate individual bears, polar bears are mostly solitary animals, travelling large distances over the ice in search for food. The global population is about 20–25,000 individuals and is divided in 19 more or less distinct sub populations across the Arctic.

Conclusion: Due to long travel distances and large individual home ranges, the polar bear "stocks" are relatively large and inseparable. They are in general evenly distributed, but might occasionally occur in aggregations. The availability of bears varies according to environmental conditions.

2.12.2. Resource status and hunting restrictions

Unsustainable commercial and sport hunting threatened polar bears by the mid-1900. By the signing of the 1973 Agreement on the Conservation of Polar bears and the subsequent implementation of regulations and conservation measures in the Arctic countries, overharvests were mostly ended and the population was allowed to grow in several areas. The traditional hunting by native people has however continued in Alaska, Canada and Greenland. Quotas have been implemented in Canada and Greenland. Trophy hunting and the sale of hides has been important sources of income in some communities. Although greatly reduced, periodic overharvests are still a concern in some places. In the last 15 years, climate change and reduced ice cover has taken over as the main threat to polar bear.

This is because reduced ice-cover is likely to reduce the preferred habitat as well as the abundance and availability of the main prey. For this reason polar bear is listed as "Vulnerable" by IUCN, "Threatened" by ESA, "Special Concern" by SARA and "Vulnerable" by the Greenland red list. One sub-population in Alaska is decreasing and is assessed to be reduced in a 25 years perspective. Six of the sub-populations in Canada are stable, one is increasing and two are declining. Two sub-populations are assessed to be reduced while four are not reduced. In Greenland, two sub-populations are declining while one is stable.

Conclusion: Historic overharvest has been an important reason for resource scarcity, and native harvests are regulated by quotas in Greenland and Canada. Currently, climate change is the most important threat and the main reason for the present red-listing in all three countries. The sub-populations show no marked pattern with respect to status and trend. There is however a tendency of a negative trend in some sub-populations in Alaska and Greenland.

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2.13. Walrus (*Odobenus rosmarus*)

2.13.1. Resource characteristics

This large Pinniped species is found in Arctic ice-filled waters and has a circumpolar distribution. The species is divided into a Pacific (*O. rosmarus divergens*), an Atlantic sub-species (*O. rosmarus rosmarus*) and a Leptev Sea sub-species (*O. rosmarus laptevi*). Walruses are bottom feeders, and during spring, summer and fall, walrus occupy coastal areas with access to shallow water. They might conduct extensive seasonal migrations, and the Atlantic subspecies generally winters amongst pack ice, in leads and polynyas often deep into the ice. Pacific walruses conduct seasonal migrations between winter areas in the central and south Bering Sea and the summer areas in the Chukchi Sea. Walrus are found in dense, relatively predictable aggregations at haul-out sites. In the Atlantic, the walrus is subdivided into several stocks with stock sizes ranging from less than a thousand to about ten thousand individuals. The size of the larger Pacific stock is in the range of 100,000–250,000 individuals.

Conclusion: Walrus do in general conduct extensive seasonal migrations between summer and winter habitats. The Pacific population consist of one large stock, while the Atlantic populations are subdivided into more geographically confined stocks. They are found in super-abundant concentrations on haul-out sites. These sites are relatively predictable although variation might occur depending on ice conditions and migration pattern.

2.13.2. Resource status and hunting restrictions

The historical exploitation of this species by European whalers and sealers in the 19th and 20th centuries was very high, restricting its present distribution and abundance. For centuries, walrus has been an important resource for native people, and it is still hunted in Alaska, Canada and Greenland. In Alaska, large-scale commercial harvests are believed to have reduced the population to 50,000–100,000 animals in the mid-1950s. After implementing strict harvest regulations, the population increased rapidly, and presumably reached a top, counting about 250,000 during the 1980s. There are some evidence that the population has shown a weak decline in recent years. The present subsistence catch in Alaska is minimal and considered to be within a sustainable range. However, the habitat, and especially the winter ranges in the Bering Sea is threatened by reduced ice cover due to climate warming, and the Pacific subspecies was therefore listed as “Endangered or Threatened” in the ESA in 2011. Similar to the Pacific sub-species, the populations of the Atlantic sub-species was decimated by commercial harvests that ended in the mid 20th century. However, the populations are still at relatively low levels. The trends for these populations are largely unknown. Currently the subsistence catch in eastern Canada is above what is considered sustainable for two subpopulations. Harvest is regulated by quotas, and a management plan is under development. Serious concern has been raised towards unsustainable hunting of walrus in Greenland, and the different populations were listed as “Near Threatened”, “Endangered” and “Critically Endangered” respectively in the Greenland red-list in 2007. At the same time, quotas were implemented and at present, the local harvest is considered to be within a sustainable range.

Conclusion: Resource scarcity is related to overexploitation. Currently, the Pacific subspecies is abundant, but is threatened by reduced sea ice cover and probably show a weak negative trend. Subsistence catch is minimal and within sustainable limits. In eastern Canada and Greenland the native harvests have until recently been above a sustainable level for several subpopulations. Harvest restrictions have been implemented in Greenland, and the catch has declined substantially in recent years. The populations are still at low levels due to local harvests and historical commercial exploitation. Population trends are largely unknown.

2.13.3. Sources

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2.14. Hooded seal (*Cystophora cristata*)

2.14.1. Resource characteristics

Hooded seal are found in the northernmost Atlantic Ocean and the adjacent Arctic Ocean. They congregate in large aggregations in the pack ice during breeding and moulting in late winter. Based on these aggregations, they are separated in four different herds: Gulf of St Lawrence (40,000 individuals); off the coast of Newfoundland and Labrador (540,000 individuals); Davis Strait (20,000 individuals); and the West Ice (80,000 individuals) located off East Greenland near Jan Mayen. There is however considerable interchange of seals among the three western herds. After moulting the seals conduct an extensive seasonal feeding migration covering large areas of open waters. The western herds have a main distribution covering the Baffin Bay, Davis Strait, Labrador Sea, Irminger Sea and Denmark Strait.

Conclusion: Hooded seals conduct extensive seasonal migrations, they belong to large inseparable stocks each shared by more than one community, they occur in seasonal superabundant concentrations during breeding and moulting, and the availability is variable and to a certain extent stochastic.

2.14.2. Resource status and hunting restrictions

Hooded Seals were subject to intense commercial hunting in the 19th and 20th centuries, which presumably had a strong negative impact on the populations. The western stocks have shown a moderate increase the last 30 years. However, in the same period, the eastern stock has shown a substantial decline. Hooded seal is therefore listed as "Vulnerable" in the IUCN Red list. Local hunters from Arctic Canada and Greenland utilize the western stocks. This population is not listed in

SARA (Canada) and listed as "Least Concern" in the Greenland red list. No harvest restrictions are enforced on the eligible local hunters.

Conclusion: No current resource scarcity in the study area. No harvest restrictions on local hunters in Arctic Canada and Greenland.

2.14.3. Sources

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2.15. Bearded seal (*Erignathus barbatus*)

2.15.1. Resource characteristics

This large circumpolar species inhabits the seasonally ice-covered seas where it breeds and molts on the ice in the spring and early summer. The bearded seals are closely associated with ice, they are benthic feeders and are mostly found in shallow waters, i.e.; in waters overlaying the continental shelves. They are mostly solitary animals, and some individuals may conduct extensive migrations. Although some bearded seals winter in areas with heavy ice cover, most will stay close to the ice edge following the expansion and retreat of the seasonal ice cover. Bearded seals are divided into a Pacific (*nauticus*) and an Atlantic (*barbatus*) sub-species. The stocks are not delineated and the population sizes are largely unknown. However, the two sub-species may count some hundred thousand individuals respectively.

Conclusion: Bearded seals generally conduct extensive seasonal migrations following the ice edge. They belong to large inseparable populations shared by more than one community. They are generally solitary and are not found in superabundant aggregations. The availability might be variable and stochastic due to variable ice conditions and migrations.

2.15.2. Resource status and hunting restrictions

Bearded seal is hunted by native subsistence users in Arctic Alaska, Canada and Greenland. The size and trend of this resource is largely unknown. It is likely that the population will be affected by changes in the sea-ice habitat due to climate warming. The subsistence harvests are considered to be sustainable, and the native subsistence hunt is not currently restricted.

Conclusion: Status and trend of population is largely unknown and no restrictions have been implemented on Native subsistence use.

2.15.3. Sources

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2.16. Harp seal (*Pagophilus groenlandicus*)

2.16.1. Resource characteristics

Harp seals are found in the northernmost Atlantic Ocean and the adjacent Arctic Ocean. Based on their specific breeding locations, the harp seal is divided into three separate herds; the Northwest Atlantic (7.2 mill individuals) located off eastern Canada; the West Ice (627,000 individuals) located off East Greenland near Jan Mayen; and the East Ice (1.4 mill individuals) located in the White Sea in Russia. Breeding and whelping occurs synchronously in large herds in the pack ice during late February to April. Harp seals are social and highly migratory, and after breeding they follow the sea ice as it retreats to the north. The Northwest Atlantic stock follows the pack ice northeast and spread into a large area covering the northern Hudson Bay, Foxe Basin, Hudson Strait, Davis Strait, Baffin Bay and the coast south of Greenland. During autumn and winter they return south towards the breeding grounds. The migration is dependent on ice cover and food availability.

Conclusion: Harp seals conduct extensive seasonal migrations, they belong to large inseparable stocks each shared by more than one community, they occur in seasonal superabundant concentrations during breeding and moulting, and the availability of this resource is variable and to a certain extent stochastic.

2.16.2. Resource status and hunting restrictions

Following previous commercial overexploitation, the population has grown substantially since the 1970s. The population growth has leveled off in recent years. Harp seals are hunted by local subsistence users in Canada and Greenland. It is not listed in SARA (Canada) and listed as "Least Concern" in the Greenland red list. No harvest restrictions are enforced on eligible local hunters.

Conclusion: No current resource scarcity. No harvest restrictions on local hunters in Arctic Canada and Greenland.

2.16.3. Sources

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2.17. Spotted seal (*Phoca largha*)

2.17.1. Resource characteristics

Spotted seals are found in the Bering, Chukchi, and Beaufort seas, and the Sea of Okhotsk. Although the population structure is unresolved, the seals inhabiting the Bering, Chukchi, and Beaufort seas are considered as one Distinct Population Segment (DPS): the Bering DPS. Population size is not known, but as an order of magnitude, the Bering DPS count about hundred thousand individuals. Seals in the Chukchi and Beaufort Sea migrate through the Bering Strait in early winter, they over-winter along the ice edge in the Bering Sea where they make east-west movement along the ice edge. In late summer and fall, spotted seals move into coastal areas, including river mouths. They might range north into the Arctic Ocean to about the edge of the continental shelf. They are generally associated with the sea ice habitat.

Conclusion: Spotted seals conduct extensive seasonal migrations and they belong to large inseparable populations shared by more than one community. They are not found in superabundant aggregations, but the availability might be variable and stochastic due to variable ice conditions and migrations.

2.17.2. Resource status and hunting restrictions

Spotted seal is hunted by native subsistence hunters in Alaska. The size and trend of this resource is largely unknown. It is likely that the population will be affected by changes in the sea-ice habitat due to climate warming. The subsistence harvests are considered to be sustainable, and the native subsistence hunt is not currently restricted.

Conclusion: Status and trend of population is largely unknown and no restrictions have been implemented on Native subsistence use.

2.17.3. Sources

Allen, B. M. and R. P. Angliss. 2013. *Alaska Marine Mammal Stock Assessments, 2012*. NOAA Technical Memorandum NMFS-AFSC-245. U.S. Department of Commerce.

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2.18. Ringed seal (*Pusa hispida hispida*)

2.18.1. Resource characteristics

Ringed seal is a small seal species, closely associated with the sea-ice habitat throughout its circumpolar range. The Arctic subspecies has a very broad distribution covering all permanently and seasonally ice-filled waters. It consist probably of several more or less separated populations, however the population structure is still unresolved. In total, the Arctic subspecies counts several million individuals. The broad distribution ensures that a large number of seals, at any time, are inaccessible to hunters. The ringed seals follow the advance and retreat of the sea ice as well as the availability of food, and it will accordingly travel long distances during the annual cycle. The availability to hunters varies accordingly; largely depending on local and regional ice conditions.

Conclusion: Ringed seals conduct extensive seasonal migrations, and they belong to large inseparable populations shared by more than one community. They are relatively evenly distributed throughout their range, however the availability is variable and stochastic.

2.18.2. Resource status and hunting restrictions

Ringed seal is an important wildlife resource for local native subsistence users in coastal communities throughout the Arctic. The size and trend of this resource is largely unknown, however they are the most abundant high arctic seal and although no accurate global estimate is available, the species is thought to number at least a few million animals. Due to the dependence on sea-ice, the species are most likely threatened by changes in the ice habitat stemming from climate change. For this reason the Arctic sub-species was listed as "Threatened" under the Endangered Species Act (ESA) in 2012. The subsistence harvests are considered to be sustainable, and the native subsistence hunt was not affected by the ESA listing. There are currently no harvest restrictions applying to the local, native hunters in Alaska, Canada and Greenland.

Conclusion: Ringed seal is threatened by climate warming, however the local harvests in the Arctic is sustainable and hunting restrictions have not yet been implemented.

2.19. Sources

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