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Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic

Derek Armitage [a,*], Fikret Berkes [b], Aaron Dale [a], Erik Kocho-Schellenberg [b], Eva Patton [b]

[a] Wilfrid Laurier University, Canada
[b] University of Manitoba, Canada

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ABSTRACT

Co-management institutional arrangements have an important role in creating conditions for social learning and adaptation in a rapidly changing Arctic environment, although how that works in practice has not been clearly articulated. This paper draws on three co-management cases from the Canadian Arctic to examine the role of knowledge co-production as an institutional trigger or mechanism to enable learning and adapting. Experience with knowledge co-production across the three cases is variable but outcomes illustrate how co-management actors are learning to learn through uncertainty and environmental change, or learning to be adaptive. Policy implications of this analysis are highlighted and include the importance of a long-term commitment to institution building, an enabling policy environment to sustain difficult social processes associated with knowledge co-production, and the value of diverse modes of communication, deliberation and social interaction.

1. Introduction

Institutions have a central role in building the capacity of society to adapt to change, and in addressing inevitable socio-economic and ecological trade-offs among adaptation options (Gupta et al., 2010). Institutions can mediate individual and collective responses to change by providing incentives (or disincentives) to collaborate, facilitate the delivery of resources, and influence the vulnerability of different groups of social actors (Agrawal, 2008). Less clearly articulated in the climate and environmental change literature is the important role of institutions and institutional processes in conferring adaptiveness by creating the conditions for social learning, defined here as the iterative action, reflection, and deliberation of individuals and groups engaged in sharing experiences and ideas to resolve complex challenges collaboratively (Diduck et al., 2005; Keen et al., 2005).

Pelling et al. (2008: 868) suggest that "Little research has investigated the relationship between individual learning and the underlying communication pathways and institutional constraints through which adaptive capacity and action are negotiated within and between organisations". There is a growing body of literature on co-management institutions and institutional arrangements in the Canadian Arctic that is promising in this regard. The co-management literature examines collaboration among actors and organizations at different levels, and shared learning through change, or adaptive co-management (Olsson et al., 2004; Armitage et al., 2009). Evidence suggests the process and linkage functions of co-management build adaptive capacity at multiple levels by fostering shared understanding and sense-making, increasing dialogue and interaction (e.g., among harvesters and decision makers in government agencies), distributing control and shared responsibility for actions, and improving conditions for individual and group learning (Berkes, 2009; Plummer, 2009).

In the Canadian Arctic, co-management institutional arrangements are moving beyond specific projects, single resources and individuals. These arrangements provide emerging networks, or horizontal and vertical linkages that give rise to new social practices and stakeholder interactions, and thus a greater ability to cope with variability and build longer-term adaptive responses to minimize risk and uncertainty. As Pelling et al. (2008) argue, "Seeing adaptation in terms of learning highlights both material adaptation and institutional modification as valid adaptive strategies. If learning itself is considered a kind of adaptive behaviour, then this opens up questions surrounding the process through which actors can learn to learn (or learn to be adaptive)".

This paper analyses the role of co-management institutional arrangements in efforts to adapt to environmental change in the Canadian Arctic. In particular, we examine the processes or

* Corresponding author. Tel.: +1 519 884 0710x2653.
E-mail address: darmitag@wlu.ca (D. Armitage).

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mechanisms that help bring together local and traditional knowledge with scientific knowledge to enable learning. First, we outline the linkages among knowledge, learning and adaptation in a co-management context. We draw next on three case studies of co-management in which learning processes have emerged over time to show how knowledge co-production acts as a trigger or mechanism for learning. Insights from these cases contribute to co-management and learning theory and are relevant for policy and institutional design. We conclude the paper with reflections on learning as adaptation, and indicate how experiences with knowledge co-production in Canada's Arctic may provide lessons for other contexts.

2. Knowledge co-production for learning and adaptation

Adaptive capacity is the ability of an individual or group (i.e., community) to cope with, prepare for, and/or adapt to disturbance and uncertain social-ecological conditions. The importance of learning through change and ability to experiment is implicit in this definition but has not been fully examined (Diduck, 2010). Adaptations are specific manifestations of adaptive capacity (Smit and Wandel, 2006; Fazey et al., 2010), and are defined in the climate change literature as the "...adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2007: 869). Nelson et al. (2007: 398) provide a definition of adaptation in the context of environmental change as "an adjustment in ecological, social, or economic systems in response to observed or expected changes in environmental stimuli and their effects and impacts in order to alleviate adverse impacts of change".

How social groups respond through institutional practices (decision-making, resource transfer, information sharing) is an important dimension of adaptive capacity and adaptation (Lemos et al., 2007). Tschakert and Dietrich (2010), for example, emphasize how current research and practice must better recognize that adaptation is a process, and that it involves the ability to consider consequences of different adaptation options (i.e., avoiding maladaptation), evaluating and negotiating trade-offs, and communication among diverse groups. These insights point to the role of learning as central to effective adaptation, with social learning processes themselves increasingly recognized as a key type of adaptation (Pelling et al., 2008; Tschakert and Dietrich, 2010). However, what this means in practice is not always clear because learning theories are diverse and learning goals in adaptation cases may not be well articulated (Diduck, 2010).

Some theories emphasize individual learning and others emphasize group learning. Fazey et al. (2005) highlight the importance of both individual and group (social or institutional) learning. For instance, learning may take place at the individual level, but a focus only on the individual neglects the social and institutional context in which individual learning occurs. Reed et al. (2010) suggest that social learning must involve a "...change in understanding that goes beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks". This is consistent with our focus given the emergence of group-based or social learning within the climate and environmental change literature (Collins and Ison, 2009). Following Argyis and Schon (1978), social learning theorists often draw attention to learning loops (Keen et al., 2005; Diduck, 2010) as a way to reflect changes in understanding. Single-loop learning involves fixing errors from routines (modifying harvest strategies), double-loop learning involves correcting errors by rethinking management goals, adjusting values and policies, and triple-loop learning involves more fundamental changes in governance norms and protocols.

Linkages between social learning, adaptation and institutions have been a focus of analysis (Pelling and High, 2005; Collins and Ison, 2009), and social learning is increasingly emphasized as an emerging policy issue for climate change adaptation. Muro and Jeffrey (2008: 330), for example, suggest that, "...despite the lack of a coherent theoretical foundation and a clear definition...the core of [social learning] models is a process of collective and communicative learning, which may lead to a number of social outcomes, new skills and knowledge". Yet, there remains a need to better understand the institutional processes or mechanisms that link learning and adaptation outcomes (Pahl-Wostl, 2009; Tschakert and Dietrich, 2010).

In many Arctic co-management contexts, factors that constrain learning have been identified and include changing motivations of individuals and communities in a globalizing economy, the often formalized nature of interactions among harvesters and officials which add to already significant barriers to trust building, and historic power inequities inevitably embedded in co-management (Armitage, 2005). Diduck et al. (2005) have also examined key factors that influence learning and the capacity for adaptation in an Arctic context, including: (1) the extent to which co-management actors are willing to experiment and be open to some degree of risk; (2) the strategies and tools (e.g., DVD, CD-ROM, maps) used to share and communicate information in a culturally appropriate manner to different groups (Bonny and Berkes, 2008); and (3) the role of the comprehensive land claims as a legislative catalyst for greater collaboration and participation of Arctic communities in decision making.

One arena in this collaboration is the effort to combine science with local and traditional knowledge to solve problems in which neither science nor local knowledge is sufficient by itself (Berkes and Jolly, 2001; Davidson-Hunt and O'Flaherty, 2007; Pohl et al., 2010). Experience in the Arctic has been important in this regard and has highlighted the institutional, epistemological and policy challenges of integration (Huntington, 2000; Krupnik and Jolly, 2002; Laidler, 2006). Raymond et al. (2010) argue for a shift from the development of knowledge integration 'products' to problem focused knowledge integration processes that are reflexive, systematic and multi-method. This perspective leads into the realm of knowledge co-production, which we define as the collaborative process of bringing a plurality of knowledge sources and types together to address a defined problem and build an integrated or systems-oriented understanding of that problem. The focus here is to examine the role of knowledge co-production as the institutional trigger or mechanism that actually enables learning within co-management settings in the Canadian Arctic, and to highlight the implications for institutional arrangements that build the capacity to adapt to change.

With reference to the role of researchers in sustainability research projects, Pohl et al. (2010) outline two modes of knowledge co-production, both of which are relevant in a co-management context. The first mode involves the role of boundary or bridging organizations that exist at the intersection of science and politics. The second mode relates to the interactive and dynamic endeavour of multiple actors where conventional epistemological realms and roles of different actors are blurred (Pohl et al., 2010). Guston (2001: 401) describes these activities as the 'simultaneous production of knowledge and social order', thus drawing attention to the constant re-working of understandings, norms, beliefs and practices, and the openness to uncertainty and messiness of knowledge co-production that can serve as sources of learning (see also Lemos and Morehouse, 2005). This view is consistent with the characterization of knowledge by Davidson-Hunt and O'Flaherty (2007: 293) as a dynamic process "...contingent upon being formed, validated and adapted to changing circumstances". The exercise of power in its different

Table 1
Challenges of knowledge co-production, participant roles and implications for co-management.

Challenges	Requirement of participants	Implications
Role of power	Willingness to recognize and accept existence of different systems of understanding and practices	Addressing power relationships among multi-level actors in co-management process
Shared understanding	Willingness to interrelate different systems of thought and perspectives in complex and uncertain decision contexts	Ensuring that common understanding emerges (e.g., regarding stocks, solutions to management problem)
Normative context	Shared desire to use knowledge co-production to achieve mutually agreed outcomes (resource use, conservation)	A knowledge co-production process that serves a shared normative goal (sustainability)

Adapted from Pohl et al. (2010).

forms (structural, agent-based, coercive, etc.; see Raik et al., 2008) and historic power inequities in co-management can be a barrier to the knowledge co-production process (Pohl et al., 2010). A rich body of scholarship on 'knowledge/power' elucidates this challenge, and includes critiques of co-management arrangements (Nadasdy, 2003; White, 2006). However, the emphasis here is on examining the specific mechanisms of knowledge co-production in three cases and the policy implications for learning and adapting to environmental change that emerge from this analysis (Table 1).

3. Learning to adapt in three co-management cases in Canada's Arctic

Indigenous groups in Canada's Arctic (Inuit and Inuvialuit) have already experienced difficult socio-cultural, political, economic, and demographic changes in recent decades. Polar regions, including Canada's Arctic, are now also projected to experience significant temperature increases with implications for food security, transportation and human settlements (ACIA, 2005; IPCC, 2007). A seasonally ice-free Arctic is expected to catalyze additional resource development and further social and economic impacts, with unknown consequences for people and ecosystems. Learning at the level of social groups is key to addressing this uncertainty.

Historically, the Inuit and Inuvialuit (the Western Arctic Inuit) of the Canadian Arctic have evolved cultural adaptations (e.g., group mobility, resource sharing) to deal with the variability of the Arctic environment (Pearce et al., 2011). It also appears that Arctic communities are also developing short-term adjustments (or coping strategies) in response to change, such as changing when, where or how hunting and fishing takes place (Berkes and Jolly, 2001; Berkes and Armitage, 2010; Ford et al., 2010), and minimizing risk from travel on sea ice (Ford et al., 2006). However, in view of continuing rapid change, additional adaptive responses may also be needed. These may become available through emerging institutional practices related to co-management (Berkes and Armitage, 2010; Ford et al., 2010). We propose here that social learning processes catalyzed by knowledge co-production in flexible co-management arrangements can transform how different actors (communities, managers) deal with change and uncertainty.

The context for these cases involves the co-management institutions of three Arctic land claims agreements: (1) the *Nunavut Land Claims Agreement* of 1993 in which the main co-management body is the Nunavut Wildlife Management Board (NWMB) (technically referred to as an Institution of Public Government); (2) the *Inuvialuit Final Agreement* of 1984 in the western Arctic in which the main co-management body is the Fisheries Joint Management Committee (FJMC); and (3) the *Gwich'in Comprehensive Land Claim Agreement* of 1992 and its main co-management body, the Gwich'in Renewable Resources Board. These bodies are legally constituted, have formal mandates, consist of representatives of various organisations from the community to the federal government level, meet periodically, and have a centrally located secretariat that follows up on decisions and sustains the regular functions of the agency. Importantly, these bodies are connected to local organizations (Hunters and Trappers Organizations or local Renewable Resource Committees) through which specific management actions are taken (enforcement, monitoring, some decisions on harvest quotas, etc.). Final authority often rests with territorial governments or the relevant federal minister, but claims-based co-management institutions have significant scope to regulate resource access, to approve plans and designations, and to set policy (White, 2006).

A multi-method and comparative case study approach was utilized in the context of a team project, "Adaptation in a Changing Arctic: Ecosystem Services, Communities and Policy". The core objective of this project was to identify the relevant institutions, linkages, networks, and policies from local to national that facilitate or constrain adaptation. We chose three specific co-management cases to illustrate how knowledge co-production serves as a trigger or mechanism for learning in these co-management institutions and the implications for adapting to environmental change (Fig. 1): (1) narwhal co-management in Nunavut; (2); co-management arrangements to address Beluga entrapment in the Husky Lakes, Northwest Territories; and (3) Dolly Varden Char co-management in the Western Arctic.

The case studies were chosen to highlight different resource contexts with each situated in a similar cultural and institutional context (i.e., an Arctic land claim). Case specific research questions and data collection were tailored for each site but addressed core issues of knowledge, experiences with collaboration and learning, and implications for adaptive capacity. Data collection included key informant interviews with representative groups (e.g., elders, hunters, board members and government staff) selected through peer recommendation; a questionnaire (in the beluga case); participation in focus groups, workshops and meetings; literature and document review; and field observation (Table 2). The research builds on findings and data from previous studies in case study communities and the specific co-management arrangements (e.g., Armitage, 2005; Ayles et al., 2007; Hovelsrud and Smit, 2010). We provide a brief summary of the cases below, each of which offers a different lens on the structure and process dimensions of knowledge co-production. We synthesize the lessons from these case studies in the final section of the paper.

3.1. Narwhal co-management in Arctic Bay, Nunavut

In 1999, the Nunavut Wildlife Management Board (NWMB) and Fisheries and Oceans Canada (DFO) initiated an experimental narwhal (*Monoceros monodon*) co-management program in five communities, one of which is Arctic Bay (population 690). Narwhal are of cultural and economic importance to a number of communities in Nunavut, and the decision to implement a co-management approach was catalyzed by stock uncertainty and pressure from local resource-users seeking greater management influence as provided for in the 1993 Nunavut Final Agreement. There has been significant ambiguity (and serious conflict in some communities) among local, regional and national actors about

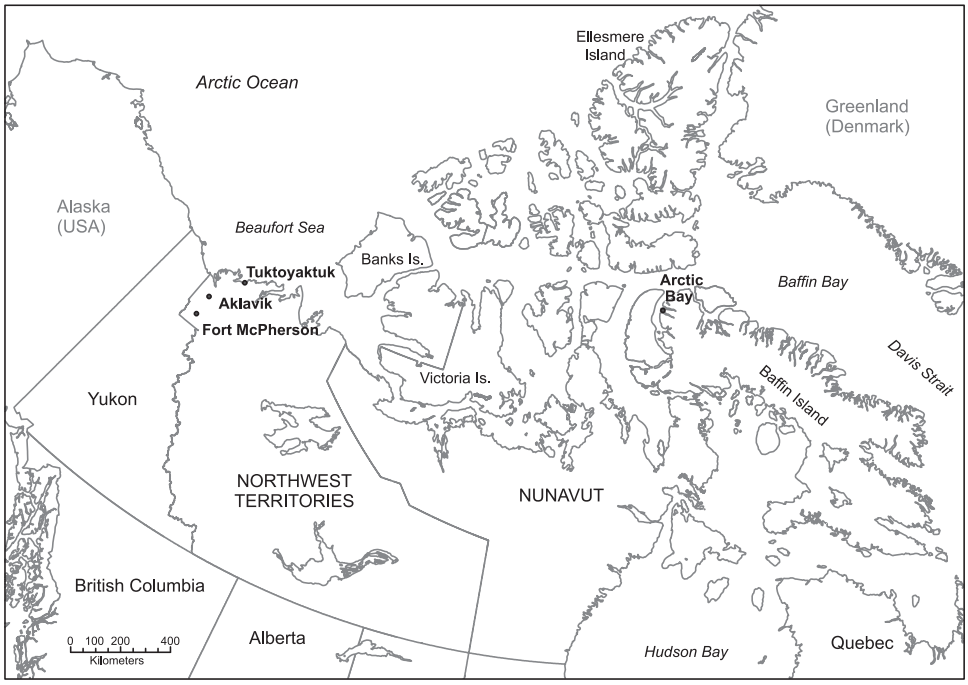

Fig. 1. Case study sites.

roles and mandates within the narwhal co-management process (Armitage, 2005). For instance, to participate, local Hunters' and Trappers' Organizations (HTOs) in each of the communities were required to develop, with support from the NWMB, by-laws to regulate hunting of narwhal, and to increase the role of HTO members in monitoring and enforcement. Learning about narwhal stocks and how to better manage those stocks has been an implicit objective of the program (see Armitage, 2005; Diduck et al., 2005), and has included a commitment on the part of the NWMB and DFO to better 'integrate' Inuit knowledge and western scientific knowledge. The narwhal case thus illustrates important linkages among a changing management context, knowledge claims about stock health, and opportunities for shared learning and capacity for adaptation given uncertain sea-ice conditions and the implications for narwhal stocks.

Knowledge is a precondition for learning through change, yet in many co-management processes the drive to "integrate" indigenous and western science knowledge has simplified the complexity of the knowledge-learning connection. Historically unequal power arrangements disadvantage indigenous knowledge holders. Institutional practices often require their knowledge to fit within a scientific management system even though the knowledge of indigenous people can be fundamentally different from that held by scientists (i.e., oral vs. written, compartmentalized vs. holistic). A fuller account of the role of knowledge in narwhal co-management (see Dale and Armitage, 2011) reveals the complexity of the issue and illustrates how knowledge practices within co-management institutions are one of the critical mechanisms or processes that enable or constrain opportunities for learning.

In a rapidly changing Arctic environment, knowledge about system conditions (e.g., sea ice), narwhal stocks (location, number, trends), and the utility of current practices (e.g., harvest allocation) is uncertain (Laidre and Heide-Jorgensen, 2005; Laidre et al., 2008). In Arctic Bay (as elsewhere) how different forms and types of knowledge have been institutionalized through the practices, rules and roles of narwhal co-management participants has thus emerged as an important mechanism for learning. Five interrelated knowledge practices in the narwhal context are identified: (1) knowledge gathering, (2) knowledge sharing, (3) knowledge integration, (4) knowledge interpretation, and (5) knowledge application (Table 3).

Table 2
Summary of data collection.

Case	Description of methods	Timeframe
Narwhal	39 semi-structured interviews with hunters, co-management board members and government officials Participant observation of two narwhal hunts in Arctic Bay and general meeting of the Nunavut Wildlife Management Board (Iqaluit) Review of policy/legislation and government documents; peer-reviewed literature	2007–2008; 2010
Beluga	37 semi-structured interviews with Elders' committee, HTC/past HTC members, co-management board members, and government From the above, 32 structured interviews for data used for network analysis Review of past HTC, FJMC, DFO records to fill in gaps in early co-management networks Participant observation in the field	2009–2010
Dolly Varden char	40 semi-structured and 12 informal interviews with fishers, community members, co-management board members and government Participant observation at family fish camps and char monitor program; attendance at nine (9) local and regional co-management meetings Review of policy/legislation; government documents; co-management, fisheries and TK reports	2009–2010

Table 3
Dimensions of knowledge co-production in narwhal management.

Dimension	Key elements, opportunities and constraints
Knowledge gathering	Knowledge gathering accomplished through harvest surveys (social survey) or wildlife surveys (biological assessments)
	Despite involvement of Inuit in wildlife surveys, the methodology captures only conclusions but not reason or logic of those conclusions
	Inuit involved in knowledge gathering activities are often younger, more active members of community, but are not necessarily those with most knowledge
	Inuit participation in knowledge gathering can legitimize (unintentionally) research and/or management
	Some knowledge gathering activities are considered disrespectful of animals (tagging, handling)
Knowledge sharing	Knowledge sharing is determined in large part by how knowledge is 'documented' and language issues
	Documented knowledge is privileged in management contexts which can be intimidating in an orally based culture
	When information is not challenged because of cultural reasons, there may be an illusion of consensus
	Knowledge is embedded in language making translation processes difficult and incomplete, undermining opportunities for shared learning
Knowledge integration	Integration is only one dimension of knowledge-learning praxis
	Inuit knowledge is often described as including values, practices and beliefs, in contrast to western scientific knowledge which seeks to separate knowledge from values
	In management context, western trained scientists expect to hear about 'knowledge' of stocks and environment, but often hear about values which can create tension and/or a disconnect
	Knowledge (Inuit, western scientific) is premised on different time scales; qualitative knowledge of relative abundance of narwhal stocks spanning multiple decades is not easily linked with quantitative stock projection based on observations over a few decades
Knowledge interpretation	Informational knowledge must be interpreted bringing into play different worldviews
	Even where data gathering is collaborative, analysis/interpretation may not be
	Even where there are generally shared goals, there may be different assumptions – observations may converge, interpretations diverge
	Where western science and Inuit knowledge lead to observation of wildlife declines, the interpretation of the decline may vary (it may be seen as cyclical pattern or discrete and verifiable decline)
	The merits of differing interpretations is less important for learning than the consequences of have interpretations summarily dismissed using western science criteria
Knowledge application	Application is not an endpoint, but leads to ongoing process of knowledge co-production
	How to apply contested knowledge is key challenge and often involves conflict; Inuit may perceive conflict as risky to society and to animals (taboos on conflict)
	Conflict avoidance in co-management will limit Inuit willingness to engage, and undermine quality of decisions
	Western actors may be overly cautious as well about how they react to Inuit knowledge, also constraining effective dialogue

The summary of knowledge-learning relationships in Table 3 masks a great deal of complexity associated with changes in understanding. For example, one local actor highlighted how Inuit participation in narwhal management does not equal the inclusion of Inuit knowledge, pointing out how knowledge gathering is only one dimension of a complex knowledge-learning process:

> Government hires Inuit as staff now, to work in the field with research groups – in their report the scientists say that the Inuit were involved in their research, but they only use the Inuit name, the person's name, as saying they are using the Inuit knowledge. It seems that they are abusing that. . .when an Inuit name is being used, they put it in the report and say that they included the Inuit knowledge, but it's not really that because the Inuit employees are only following the guidelines or policies of the Department, or whoever is doing the study, so it's not really [Inuit knowledge], because they are only using the person's name to say that Inuit were involved. (Interviewee, Pers. Comm., 2007)

Similarly, another community actor summarized the role of language in *knowledge sharing*, with significant implications for learning about human–narwhal interactions and stock conditions in uncertain and increasingly variable conditions:

> I can speak Inuktitut, and I know the traditional knowledge, but I have to use a translator to get that information across to you. If there was a direct communication link, you would have a better chance of having your questions answered, and I would have more opportunity to tell you about [Inuit knowledge]. I try to only say what can be understood, but if I were talking to you directly I would say a lot more. (Interviewee, Pers. Comm., 2007)

Gathering, sharing, integration, interpretation and application of knowledge all have a role in facilitating or constraining single and double-loop learning. Rather than a simple focus on knowledge integration, experience in the narwhal case points to the critical role of knowledge co-production. Yet, many of these dimensions of knowledge co-production remain under-explored. As co-management institutions continue to evolve, these dimensions of knowledge co-production serve to enable or constrain how actors learn and modify practices. A knowledge co-production perspective also provides a tangible illustration of the relational processes that link individual learning and underlying communication pathways (formal and informal) (*sensu* Pelling et al., 2008) as they emerge within narwhal co-management institutions.

Lastly, recognition of the influence of knowledge practices within narwhal co-management institutions draws attention to the relatively slow temporal context in which knowledge and learning about the narwhal system emerge, and what this means for adaptive capacity in the management process as conditions (e.g., sea ice) become increasingly uncertain. As a participant in narwhal management explained about progress:

> It will take a long time, because we're kind of playing around with things right now, and we'll be doing that possibly for the next 50 years. Things will definitely be better 50 years from now, but there's no magic wand available to make things right right now, we just have to fiddle around with both sides to see what's working, what's not working. I guess what we're doing right now is that we're somewhere in the centre here, Inuit on one side of the system, *qadlunat* [non-Inuit] on the other, and those of us who are working are trying to pick out a little bit from each side to come up with something that we think will work, and sometimes were not even right, because like I said, we're playing around with things to see if they will work – it's a learning process and it will take a long time. (Interviewee, Pers. Comm., 2007)

3.2. Co-management of beluga entrapment, Husky Lakes, Northwest Territories

Husky Lakes is a system of brackish water lakes that lies south of the Tuktoyaktuk peninsula in the Northwest Territories. Every year, pods of beluga whales (*Delphinapterus leucas*) enter into Liverpool Bay, which connects the Husky Lakes with the Beaufort

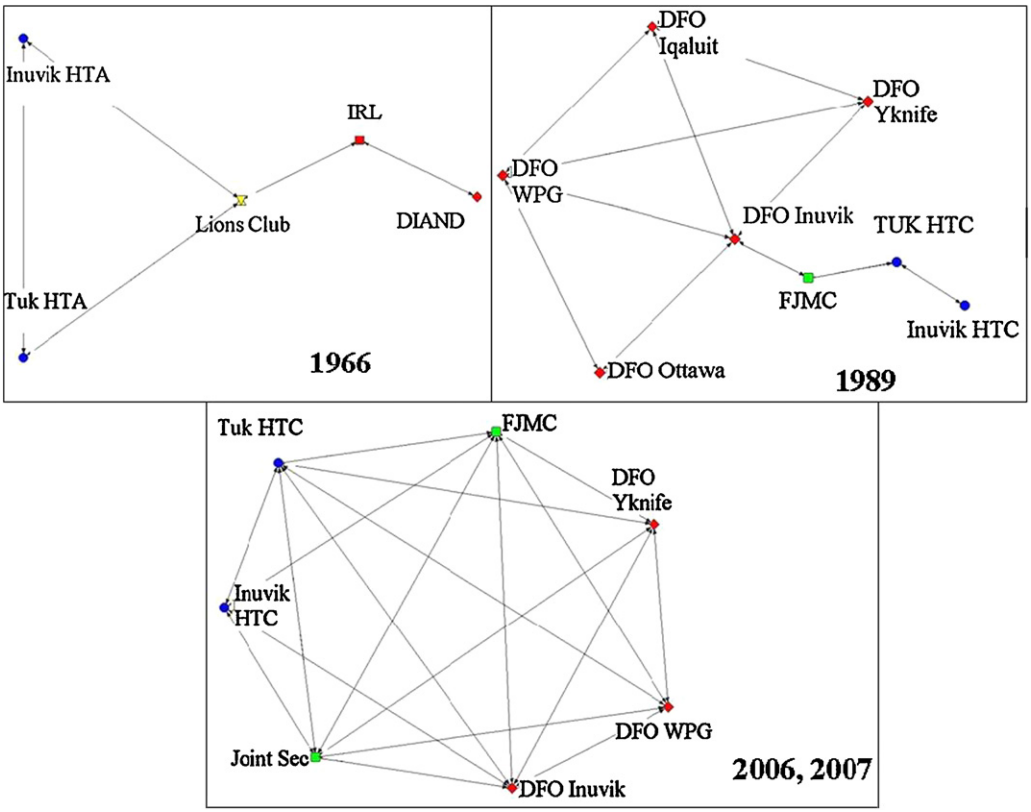

Fig. 2. Networks of organizations involved in beluga entrapment management in 1966 (a), 1989 (b), and 2006/2007 (c).

Sea. For as far back as the Inuvialuit can remember, groups of beluga have occasionally become trapped during freeze-up in *savssats* (crowded breathing holes in the ice) (Porsild, 1918). Inuvialuit have customarily taken advantage of the *savssats* for hunting and have even purposefully trapped beluga. However, beginning in the 1960s the Canadian Government became involved in the management of these sporadic entrapments to address public concerns (largely of southerners) about animal welfare and about the sustainability of beluga stocks. The Inuvialuit have experienced varying degrees of involvement in the decisions about managing these entrapments.

The beluga case illustrates important differences in terms of knowledge, learning and decision-making prior to and after the establishment of the relevant co-management institutional arrangements. Under the Inuvialuit Final Agreement (IFA), the relevant co-management institution is the Fisheries Joint Management Committee (FJMC). Thus, the beluga case provides valuable insights about changes in the composition and efficacy of the co-management network formed by the FJMC, the DFO, and the Tuktoyaktuk Hunter and Trapper Committee, and the implications for knowledge co-production and learning. By examining the organizations that have been involved and how their interactions have changed over time, this case illustrates how co-management can develop into a working partnership to co-produce knowledge and lead to institutional learning. In this context, we compare the co-management institutional network for beluga entrapment in 1966, 1989, and 2006/2007 (Fig. 2).

In 1966, the parties directly involved in response to the discovery of the entrapment were the Inuvik Research Laboratory (IRL) (under the Department of Indian Affairs and Northern Development) and the Inuvik Lions, a local service club representing resident non-native people rather than Inuvialuit hunters (Fig. 2a). According to Inuvialuit who hunted at that time, there was no direct consultation or communication between the IRL and the Tuktoyaktuk Hunter and Trapper Association (HTA) (Hill, 1967). Rather than seeking to understand the situation or obtain advice from local hunters, the Lions Club actively attempted to rescue and feed the whales, with limited success. To this day, many Inuvialuit from Tuktoyaktuk are displeased with the way the entrapment was handled and their lack of involvement. This experience is illustrative of many decision-making processes in Canada's North during this time period.

Another entrapment occurred in 1989, just five years after the signing of the IFA. The FJMC had been officially established in 1986, and a DFO district office had been formed in Inuvik. After the entrapment came to the attention of the authorities, a meeting of high-level DFO officials discussed strategies on how to manage the issue, and decided that a community-led slaughter of the trapped whales would be a good option. The idea was brought forth to the Tuktoyaktuk HTC, which suggested instead using boats to herd the whales into open water. The alternative was deemed unrealistic by the DFO, and the slaughter was carried out and funded as a harvesting/sampling project which involved Inuvialuit hunters as well as scientists. While the co-management institution had been in existence at the time, and this did lead to more community involvement than in the 1966 entrapment (Fig. 2b), there were clear barriers to communication and limits in knowledge-sharing and social learning. Inuvialuit were seen as participants to implement decisions largely developed by government officials.

James Pokiak, the chair of Tuktoyaktuk HTC has commented on the interactions between the government and the Inuvialuit in the 1989 entrapment, as compared to the subsequent ones: "In 1989 a lot of it [interaction; Inuvialuit participation] was lacking. The department Fisheries and Oceans Canada] didn't listen to the local people. . .[However] now with all these different organizations set up, not only do they have to listen to the people, but they have to come to a solution to try to solve the problem" (personal communication to Kocho-Schellenberg).

Back-to-back entrapments occurred in 2006 and 2007. By this time, 22 years after the signing of the Agreement, the co-management institution (FJMC) was well established, networks were in place, and communication processes had become routine (Fig. 2c). Perhaps most importantly, the Tuktoyaktuk HTC and the FJMC worked directly with the DFO Inuvik office right from the start of the entrapment management process. As soon as the entrapment was identified, conferences involving all organizations were held to share knowledge and understanding, and to determine an appropriate course of action. In 2006, the Tuktoyaktuk HTC decided that a harvesting/sampling project would prevent undue suffering of the whales and provide traditional food to other Inuvialuit communities. The harvest as well as the distribution of food was facilitated financially and logistically by the DFO. In 2007, the HTC decided to leave the whales and let nature take its course. Back to back entrapments had never been observed, and it was thought that this phenomenon should be monitored. The DFO agreed with this decision, and aided by writing detailed communication plans to handle inquiries regarding the management of the entrapment.

After the back to back entrapments of 2006 and 2007, the issue went to the top of the priority list for the Tuktoyaktuk HTC. During a meeting between the Tuktoyaktuk and Inuvik HTCs in 2007, it was agreed that a plan for dealing with future entrapments was needed. In response to this, the FJMC supported a community workshop to collaboratively produce an action plan, drawing on the knowledge and different perspectives of co-management participants. The DFO Inuvik manager agreed to partially fund and take the lead in the workshop, while the Tuktoyaktuk HTC agreed that representation from all six Inuvialuit communities would be valuable. The Beluga Entrapment Action Plan produced from this collaborative workshop included a monitoring and whale deterrence camp with a traditional knowledge education component.

The processes that have characterized changes in the management of beluga entrapments from 1966 to 2007 show learning in the face of change. The institutional networks that have formed through time reflect, and are reflective of, a growing commitment to knowledge co-production, and the capacity for more adaptive management as future entrapment situations emerge. Fig. 2 graphically illustrates the increasing complexity of communication networks over time and increasing participation of the local Inuvialuit people in management. By 2006/2007, the Inuvialuit were basically in control of the management process, and beginning to take proactive measures about future beluga entrapments in which knowledge co-production is the critical mechanism.

While the focus here is on the beluga entrapment issue, these same institutional networks serve a wider range of resource and wildlife management challenges, and they are important for the Inuvialuit to assert their knowledge, rights and cultural traditions. The specific knowledge co-production and social learning that emerged through experience with beluga entrapment has contributed to the development of adaptive capacity necessary to deal with a wide range of social and ecological uncertainties associated with a rapidly changing Arctic. The plan that has been developed since the 2007 entrapment, involved all parties and provided a forum in which knowledge was shared and co-produced. The workshop brought together scientists, Inuvialuit hunters and leaders from all six Inuvialuit communities, and government managers to discuss a wide range of issues related to beluga entrapment. These included the use of sophisticated whale deterrence technology and the role of traditional knowledge about whale behaviour and the environment of Husky Lakes in responding to future concerns. Lastly, the plan has had a positive impact on traditional knowledge education and cultural preservation through the distribution of culturally important food and stimulating inter-community sharing.

3.3. Dolly Varden char co-management in the Western Arctic

Dolly Varden char (*Salvelinus malma malma*) co-management in the Canadian Western Arctic (Yukon North Slope and Northwest Territories) provide another example of knowledge co-production, improved decision making, and learning. Efforts to address declining Dolly Varden char stocks and to understand impacts of habitat changes occurring in some of the key fish bearing rivers west of the Mackenzie River has led to collaborative long-term working relationships among the Inuvialuit of Aklavik, the Gwich'in of Aklavik and Fort McPherson, the Fisheries Joint Management Committee (FJMC), the Gwich'in Renewable Resources Board (GRRB), Parks Canada and the DFO. The potential for a 'Species at Risk' designation has heightened creative conservation efforts to protect the Dolly Varden char populations, while allowing future harvest opportunities for Inuvialuit and Gwich'in communities. The engagement in locally driven research and management was critical to the communities given the role of Dolly Varden char as a culturally important subsistence food species. As with the narwhal case, a knowledge and learning relationship has emerged out of co-management efforts.

What is the evidence for actual knowledge co-production, improved decision making, and learning to adapt? We approach this question by comparing decision-making processes between the 1986 closure in the Big Fish River and the 2006 closure in the Rat/Peel River. The 1986 case represents the pre co-management situation and the Rat/Peel River case represents an evolution of the learning and adapting process. Both rivers are important char fishing areas within the Inuvialuit and Gwich'in regions. The resulting regulatory moratorium in the early case was the only management tool available at the time and although both DFO and the community worked together to protect the overwintering fish, the population never rebounded. Subsequent acknowledgement of local observations that habitat change was a likely driver of the decline initiated the crafting of new co-management approaches, revealing a double-loop learning process whereby local indigenous knowledge was validated and sustaining cultural practices on the land recognized as a policy priority. Table 4 characterizes the two cases.

Comparing early co-management and recent co-management, as characterized by the two cases in Table 4, three points can be made about knowledge co-production as a trigger or mechanism for learning. First, formal and informal knowledge sharing occurs through the legislated co-management structure established under the Inuvialuit and Gwich'in land claims agreements. Local and traditional knowledge is contributed through frequent consultations with community members or the expert input of elders and fishers who serve on these co-management boards. The co-management deliberation process developed by the GRRB and the FJMC involves regular cycles of regional meetings throughout the year and engages fisheries scientists from DFO and local experts from community Hunter Trapper Committees (HTC), and Renewable Resource Councils (RRC). Formal management plans receive repeated opportunity for community feedback. Studies are often solicited and funded by the GRRB and FJMC, utilizing both traditional knowledge and scientific research methods (Ayles et al., 2007). DFO has also directed on-going monitoring programs, which include local hire of fishers from the community as a key component of the success (Harwood, 2001). Regional management plans such as the Dolly Varden Char Integrated Fisheries Management Plan are considered "living documents" developed as a working guide for all partners involved; designed to be revisited annually to incorporate new knowledge, observations, or new community concerns that arise.

Table 4
Contrast in the decision making process and use of knowledge between an early co-management case with Big Fish River and the recent Rat/Peel River case.

Big Fish River Char closure – 1986	Rat/Peel River Char closure – 2006
Final decision to close fishery made by DFO	Final decision to close fishery made by community of Aklavik and Fort McPherson
Closure is a formal legal mandate	Closure is voluntary and monitored by community
Closure is scheduled to be re-evaluated every 5 years	Closure is scheduled to be re-evaluated annually
Re-opening of fishery required formal change in mandate	Re-opening fishery jointly decided between co-management groups, with allowance for flexible options
No options available for community to adapt to closure of fishery	Management plan includes options for use of selective size mesh nets, fishing healthy stocks, subsidy options
Research priorities initially determined by DFO	Research priorities determined by community and supported by GRRB, FJMC, and DFO
Primarily local observation of fish declines contributed to the initial management process	Formal TK studies on char, and char river habit and cultural importance. Local knowledge included in every step of decision-making. Cooperative research and monitoring programs established with DFO/RRCs and HTC
Cause of decline initially assumed by DFO to be over-harvesting but may have been due in large part to change of habitat caused by drop in water table on the Big Fish River (DFO, 2003)	Cause of decline recognized by local management and DFO: driven in part by loss of critical over-wintering habitat due to low water levels on the Rat River (Sandstrom et al., 2001)

Second, representatives of each of the co-management partners involved in char conservation planning meet annually to share knowledge and information through two non-formal working groups which meet annually: the Rat River Char Working Group for the upriver Gwich'in area, and the West Side Working Group for the Inuvialuit area on the lower river and coast. These working groups provide a forum for discussion of relevant knowledge from the community, environmental monitoring, and ongoing scientific research from federal biologists. Many of the Working Group members have been engaged in a collaborative problem solving process by bringing traditional knowledge and science together for over 10 years. These long-term informal working relationships have fostered an atmosphere of open communication and have facilitated cross-cultural understanding and respect.

Third, information is shared and documented within the community via monthly HTC and RRC meetings, the membership of which involves local Inuvialuit or Gwich'in selected for their knowledge of the land. All community members may attend these meetings to contribute observations, concerns, or ask questions. Both the GRRB and FJMC also host annual "community tour" meetings which are designed as opportunities to formally present current fisheries research information, propose management actions, and receive feedback directly from the community. These forums facilitate a face-to-face dialogue often including DFO biologists from the regional Inuvik office. The information presented verbally and in writing by co-management leaders is intended to be understandable by all, and language is kept simple, without scientific jargon. Management plans are worked back and forth in this manner until agreement is arrived at by all affected communities.

As compared to the formal regulatory closure in 1986, the 2006 closure works very differently. In the latter case, the fishing restriction is voluntary, and communities support the plan as a non-binding/non-legal management agreement that would be implemented by the local HTC and RRC using multiple types of knowledge. This plan is flexible, designed to revisit the fishing moratorium annually to see how it was working. The plan is "adaptive" in the sense that it would be changed if proven ineffective through new knowledge. It is not "regulatory" in that people who truly needed to could still fish. Monitoring and the pressure to adhere to the moratorium come largely from within the community. A common interest in seeing the char population rebound to sustain the subsistence fishery provides incentives to collaborate. The support of the community resulted in a high degree of compliance and in this case the fishery did rebound enough after three years to allow for conservative harvest again in 2009.

The 2006 case clearly shows a number of differences from the 1986 case, all in the direction of greater local participation, built-in flexibility, increased local decision-making, and use of indigenous knowledge. Dolly Varden char feed and migrate through the coastal and lower river of the Inuvialuit homeland, but spawn and overwinter in the upper watershed of the Gwich'in homeland. The local traditional knowledge of subsistence fishers in the two land claims areas, combined with biological science from the DFO, has allowed for a more comprehensive understanding of this complex fishery, leading to greatly nuanced and precise management options. The combination of complementary indigenous knowledge from the Gwich'in and the Inuvialuit with biological science has resulted in a revised view of char declines, highlighting the importance of habitat changes on the two river systems, and bringing recognition to the impact of low water levels on important char over-wintering areas. Such co-production of knowledge and the resulting learning are viewed by many in the community as a key adaptive measure and the means to maintain options for the future.

4. Discussion and conclusion

Understanding how Arctic co-management institutions create the conditions for learning and build adaptive capacity for environmental change remains incomplete. This paper helps to address that gap and highlights how knowledge co-production in co-management institutional arrangements can serve as a trigger or mechanism for learning and adaptation (Table 5). Social learning catalyzed by increasingly meaningful knowledge co-production thus emerges as a key type of adaptation. In each of the cases, there is evidence of double-loop (and even triple-loop) learning (e.g., altering how beluga entrapments are understood and managed, reframing Dolly Varden char declines). Important changes in understanding about system conditions (*sensu* Reed et al., 2010) has occurred that go beyond individual learning and are situated within wider social networks. The co-management cases assessed here thus reflect multi-level and adaptive governance arrangements linked to specific problems, but increasingly suited to deal with rapid change and complexity of the Arctic environment and to build system resilience over time (Galaz et al., 2010).

Learning through co-management is only a small part of the solution of a very large adaptation problem. Co-management institutions are no panacea for rapid environmental change in the Arctic or elsewhere. As well, we have not sought to systematically examine in this analysis the underlying power dynamics associated with knowledge co-production and learning. Moreover, it remains unclear the extent to which co-management institu-

Table 5
Summary of policy-relevant insights on knowledge co-production and learning from three cases.

Policy implication	Case example
Commitment to a long-term view on institutional arrangements and a recognition among actors that there is no 'end point' to co-management	Char Integrated Fisheries Management Plan as 'living document'
Recognition that co-management institutional arrangements require continuous cultivation. As the cases reveal, these arrangements are slow to develop but trust and communication pathways can be easily lost	Trust building in the char and beluga cases; perception among Inuit of superficial participation in narwhal case
Promotion of multi-layered institutional arrangements, including clear value and roles of bridging organizations that link local actors with government officials and serve as clearing houses for information and conflict	All three cases to varying degrees through the FJMC, NWMB, GRRB
Use of a variety of modes of communication, deliberation and group interaction (meetings, workshops, study tours and visits) that encourage formal and informal relationships important for knowledge co-production	Regular cycles of regional workshops, community tour meetings in char case; community workshops in beluga case
Existence of an enabling policy environment with commitment from higher-order institutions to foster knowledge co-production and learning. In the Canadian Arctic the land claims agreements provide this critical policy context	Evident in narwhal, beluga and char cases; longer-term experience and strength of practice evident in beluga and char cases
Commitment to dual focus on single-loop or instrumental learning to improve management decisions, as well as double- or triple-loop learning in which participants in the cases have revised their assumptions, worldviews and governance practices	Emerging in narwhal case in context of stock uncertainty; role of knowledge in ongoing learning-by-doing in beluga and char cases reveal fundamental shifts in practice
Sensitivity to power dynamics and historical relationships that constrain trust building	Commitment to deliberative practice within FJMC; long-term informal working relationships in beluga and char cases
Fostering 'collective ownership' of problem through greater collaboration	Removal of formal regulatory approach in char case created policy window for knowledge co-production, shared understanding and learning
Recognizing crises as windows of opportunity to rethink knowledge and learning processes for adaptation	Crises in stock situation (char) helped catalyze new approaches and openness to competing knowledge claims; crisis in management in narwhal case posed a challenge to learning, knowledge co-production

tional arrangements are sufficiently stable while also suitably flexible to allow actors to modify practices quickly (e.g., quotas, seasonal no-take periods, adjustments in population estimates using traditional knowledge). The experience with land claims agreements is mixed in this regard (Bankes, 2005), but it seems unlikely the gains made in terms of knowledge co-production and social learning over the past two decades would have progressed to this point in the absence of this enabling policy context.

Each case examined here provides an example of evolving institutional networks and linkages (vertically and horizontally) through which understandings are negotiated and values made explicit. What is evident is the long time horizons involved in building these institutional arrangements and knowledge co-production processes. This is a particular concern in a rapidly changing Arctic, and it remains unclear whether knowledge co-production involving communities and hunters, scientists and managers can respond quickly enough to emergent system changes, including rapid sea ice loss, accompanying perturbations to wildlife stocks and biodiversity, and loss of cultural practices and knowledge gained from everyday interactions with the land.

Also evident is that knowledge co-production as a mechanism for learning has advanced farther in the Dolly Varden char and beluga cases than in the narwhal case. This is partly a reflection of the earlier (1984) establishment of the land claims and co-management institutions in the Inuvialuit region, as opposed to 1993 in Nunavut. The experience of a management 'crisis' around beluga (entrapment) and Dolly Varden char (population declines) has also served to crystallize the role of knowledge co-production and instigated double and triple-loop learning. This has not happened to the same degree in the narwhal case although knowledge co-production is ongoing.

In conclusion, the narwhal, beluga and Dolly Varden char cases examined here help to illustrate the institutional mechanisms through which co-management actors can learn to learn, or learn to be adaptive (Pelling et al., 2008). Establishing clear performance or outcome measures to empirically validate this proposition is difficult because of the wide range of contextual factors and because co-management institutions are not static. However, Fig. 2 graphically shows how co-management interactions have been elaborated over time. There remain many constraints on learning and adaptation in an Arctic context. Despite the high transaction costs, however, the knowledge co-production processes that have evolved over time in the co-management institutional arrangements examined here are triggering positive social and ecological outcomes in the face of environmental change.

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References

ACIA, 2005. Arctic Climate Impact Assessment. Cambridge University Press, Cambridge, UK.

Agrawal, A., 2008. The role of local institutions in adaptation to climate change. In: Paper Prepared for the Social Dimensions of Climate Change, Social Development Department, The World Bank, Washington, DC, March 5–6, 2008.

Argyis, C., Schon, D.A., 1978. Organizational Learning: A Theory of Action Perspective. Addison Wesley, Reading, MA.

Armitage, D., 2005. Community-based Narwhal Management in Nunavut, Canada: change uncertainty and adaptation. Society and Natural Resources 18 (8), 715–731.

Armitage, D., Plummer, R., Berkes, F., Arthur, R., Charles, A., Davidson-Hunt, I., Diduck, A., Doubleday, N., Johnson, D., Marschke, M., McConney, P., Pinkerton, E.L., Wollenberg, 2009. Adaptive co-management for social-ecological complexity. Frontiers in Ecology and the Environment 7 (2), 95–102.

Ayles, B., Bell, R., Hoyt, A., 2007. Adaptive fisheries co-management in the Western Canadian Arctic. In: Armitage, D., Berkes, F., Doubleday, N. (Eds.), Adaptive Co-management: Collaboration, Learning, and Multi-level Governance. UBC Press, Vancouver, pp. 125–150.

Bankes, N., 2005. Exploring the roles of law and hierarchy in ideas of resilience. In: Berkes, R., Huebert, H., Fast, M., Manseau, A., Diduck, (Eds.), Breaking Ice: Renewable Resource and Ocean Management in the Canadian North. Arctic Institute of North America and University of Calgary Press, Calgary, pp. 291–315.

Berkes, F., 2009. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. Journal of Environmental Management 90, 1692–1702.

Berkes, F., Jolly, D., 2001. Adapting to climate change: social-ecological resilience in a Canadian western Arctic community. Conservation Ecology 5 (2), 18 online at: http://www.consecol.org/vol5/iss2/art18/

Berkes, F., Armitage, D., 2010. Co-management institutions knowledge and learning: adapting to change in the Arctic. Etudes/Inuit/Studies 34 (1), 109–131.
Bonny, E., Berkes, F., 2008. Communicating traditional environmental knowledge: addressing the diversity of knowledge, audiences and media types. Polar Record 44, 243–253.
Collins, K., Ison, R., 2009. Living with environmental change: Adaptation as social learning. Environmental Policy and Governance 19, 351–357.
Dale, A., Armitage, D., 2011. Marine mammal co-management in Canada's Arctic: knowledge co-production for learning and adaptive capacity. Marine Policy 35 (4), 440–449.
Davidson-Hunt, I.J., O'Flaherty, R.M., 2007. Researchers, indigenous peoples and place-based learning communities. Society and Natural Resources 20, 291–305.
DFO, 2003. Big Fish River Dolly Varden. DFO Science Stock Status Report. D5-60 2002.
Diduck, A., 2010. The learning dimension of adaptive capacity: untangling the multi-level connections. In: Armitage, D., Plummer, R. (Eds.), Adaptive Capacity and Environmental Governance. Springer-Verlag, Heidelberg, Berlin, pp. 199–222.
Diduck, A., Bankes, N., Clark, D., Armitage, D., 2005. Unpacking social learning in social-ecological systems: case studies of polar bears and narwhal management in northern Canada. In: Berkes, F., Huebert, R., Fast, H., Manseau, M., Diduck, A. (Eds.), Breaking Ice: Renewable Resource and Ocean Management. University of Calgary Press, Calgary, pp. 269–291.
Fazey, I., Fazey, J.A., Fazey, D.M.A., 2005. Learning more effectively from experience. Ecology and Society 10 (2), 4.
Fazey, I., Gamarra, J., Fischer, J., Reed, M., Stringer, L., Christie, M., 2010. Adaptation strategies for reducing vulnerability to future environmental change. Frontiers in Ecology and the Environment 8 (8), 414–422.
Ford, J., Smit, B., Wandel, J., 2006. Vulnerability to climate change in the Arctic: A case study from Arctic Bay, Canada. Global Environmental Change 16 (3), 282–292.
Ford, J., Pearce, T., Duerden, F., Furgal, C., Smit, B., 2010. Climate change policy responses for Canada's Inuit population: the importance of and opportunities for adaptation. Global Environmental Change 20, 177–191.
Galaz, V., Duit, A., Eckerberg, K., Ebbesson, J., 2010. Governance complexity and resilience. Global Environmental Change 20 (3), 363–546.
Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., van de Brink, M., Jong, P., Nooteboom, S., Bergsma, E., 2010. The adaptive capacity wheel: a method to assess the inherent characteristics of institutions to enable the adaptive capacity of society. Environmental Science and Policy 13, 459–471.
Guston, D.H., 2001. Boundary organizations in environmental policy and science: an introduction. Science, Technology and Human Values 26 (4), 399–408.
Harwood, L.A., 2001. Rat River Dolly Varden DFO Stock Status Report D5-61.
Hill, R.M., 1967. Observations on Beluga Whales Trapped by Ice in Eskimo Lakes, Winter 1966/67. Inuvik Research Laboratory Report (typescript).
Hovelsrud, G., Smit, B. (Eds.), 2010. Community Adaptation and Vulnerability in Arctic Regions. Springer, Berlin–Heidelberg.
Huntington, H., 2000. Using traditional knowledge in science: methods and applications. Ecological Applications 10 (5), 1270–1274.
IPCC (Intergovernmental Panel on Climate Change), 2007. Intergovernmental Panel on Climate Change, Climate Change 2007, Synthesis Report. Cambridge University Press, Cambridge.
Keen, M., Brown, V.A., Dyball, R. (Eds.), 2005. Social Learning in Environmental Management. Earthscan, London.
Krupnik, I., Jolly, D. (Eds.), 2002. The Earth is Faster Now: Indigenous Observations of Arctic Environmental Change. Arctic Research Consortium of the United States. Fairbanks, Alaska.
Laidler, G.J., 2006. Inuit and scientific perspectives on the relationships between sea ice and climate change: the ideal compliment? Climate Change 78, 407–444.
Laidre, K.L., Sterling, I., Lowry, L.F., Wiig, Ø., Heide-Jørgensen, M.P., Ferguson, S.H., 2008. Quantifying the sensitivity of arctic marine mammals to climate-induced habitat change. Ecological Applications 18 (2), 97–125.
Laidre, K.L., Heide-Jorgensen, M.P., 2005. Arctic sea ice trends and narwhal vulnerability. Biological Conservation 21 (4), 509–517.
Lemos, M.C., Morehouse, B.J., 2005. The co-production of science and policy in integrated assessments. Global Environmental Change 15, 57–68.
Lemos, M.C., Boyd, E., Tompkins, E.L., Osbahr, H., Liverman, D., 2007. Developing adaptation and adapting development. Ecology and Society 12 (2), 26 [online] URL: http://www.ecologyandsociety.org/vol12/iss2/art26/
Muro, M., Jeffrey, P., 2008. A critical review of the theory and application of social learning in participatory natural resource management processes. Journal of Environmental Planning and Management 51 (3), 325–344.
Nadasdy, P., 2003. Reevaluating the co-management success story. Arctic 56 (4), 367–380.
Nelson, D.R., Adger, W.N., Brown, K., 2007. Adaptation to environmental change: contributions of a resilience framework. Annual Review in Environment and Natural Resources 32, 395–419.
Olsson, P., Folke, C., Berkes, F., 2004. Adaptive co-management for building resilience in social-ecological systems. Environmental Management 34 (1), 75–90.
Pahl-Wostl, C., 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Global Environmental Change 19 (3), 354–365.
Pearce, T., Ford, J., Duerden, F., Smit, B., Andrachuk, M., Berrang-Ford, L., Smith, T., 2011. Advancing adaptation planning for climate change in the Inuvialuit Settlement Region (ISR): a review and critique. Regional Environmental Change 11, 1–17.
Pelling, M., High, C., 2005. Understanding adaptation: what can social capital offer assessments of adaptive capacity? Global Environmental Change 15, 308–319.
Pelling, M., High, C., Dearing, D., Smith, D., 2008. Shadow spaces for social learning: a relational understanding of adaptive capacity to climate change within organisations. Environment and Planning A 40 (4), 867–884.
Pohl, C., Rist, S., Zimmermann, A., Fry, P., Gurung, G., Schneider, F., Speranza, C.I., Kiteme, B., Boillat, S., Serrano, E., Hadorn, G.H., Wiesmann, U., 2010. Researcher's roles in knowledge co-production: experience from sustainability research in Kenya, Switzerland, Bolivia and Nepal. Science and Public Policy 37 (4), 267–281.
Porsild, M.P., 1918. On "Savssats": a crowding of Arctic Animals at Holes in the Sea Ice. Geographical Review 6, 215–228.
Plummer, R., 2009. The adaptive co-management process: an initial synthesis of representative models and influential variables. Ecology and Society 14 (2), 24 [online] URL: http://www.ecologyandsociety.org/vol14/iss2/art24/
Raik, D., Wilson, A., Decker, D., 2008. Power in natural resources management: an application of theory. Society and Natural Resources 21 (8), 729–739.
Raymond, C., Fazey, I., Reed, M., Stringer, L., Robinson, G., Evely, A., 2010. Integrating local and scientific knowledge for environmental management. Journal of Environmental Management 91 (8), 1766–1777.
Reed, M.S., Evely, A.C., Cundill, G., Fazey, I., Glass, J., Laing, A., Newig, J., Parrish, B., Prell, C., Raymond, C., Stringer, L.C., 2010. What is social learning? Ecology and Society 15 (4) [online] URL: http://www.ecologyandsociety.org/vol15/iss4/resp1/
Sandstrom, S.J., Harwood, L.A., Chetkiewicz, C.B., 2001. Over-wintering habitat of the juvenile Dolly Varden Charr (*Salvelinus malma*) in the Rat River NT as determined by radio telemetry. Can. Tech. Rep. Fish. Aquat. Sci..
Smit, B., Wandel, J., 2006. Adaptation, adaptive capacity and vulnerability. Global Environmental Change 16, 282–292.
Tschakert, P., Dietrich, K.A., 2010. Anticipatory learning for climate change adaptation and resilience. Ecology and Society 15 (2), 11 [online] URL: http://www.ecologyandsociety.org/vol15/iss2/art11/
White, G., 2006. Cultures in collision: traditional knowledge and Euro-Canadian governance processes in northern land-claim boards. Arctic 59 (4), 401–419.