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Bridging knowledge systems to enhance governance of the environmental commons: A typology of settings

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Abstract: We offer a typology of settings to bridge scientific and indigenous knowledge systems and to enhance governance of the environmental commons in contexts of change. We contribute to a need for further clarity on how to incorporate diverse knowledge systems and in ways that contribute to planning, management, monitoring and assessment from local to global levels. We ask, *what settings are discussed in the resource and environmental governance literature to support efforts to bridge indigenous and scientific knowledge systems?* The objectives are: 1) to offer a typology that organizes various settings to bridge knowledge systems; and 2) to elaborate on how these settings function independently and in concert, using examples from a diverse literature in addition to field research experience. Our focus is on indigenous and scientific knowledge, but the typology offers lessons to bridge diverse knowledge systems more generally, and in ways that are sensitive to a moral, political and process-based approach. The typology includes specific methods and processes, brokering strategies, governance and institutional contexts, and the arena of epistemology. We describe each setting in the typology, and provide examples to reflect on the function and potential outcomes of different settings. Insights from our synthesis can inform policy and participatory action.

Keywords: Arctic, Environmental governance, indigenous knowledge, knowledge systems, multi-level governance, traditional knowledge

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1. Introduction

Navigating environmental change and sustaining environmental commons (e.g. the climate system, wildlife, freshwater) will depend, in a large part, on coordinated action across levels (local, regional, global) and knowledge systems (Reid et al. 2006; Armitage 2008; Berkes 2012). While knowledge systems are themselves a kind of 'commons' (Hess and Ostrom 2006), our emphasis in this paper is on environmental commons and the ways of knowing (or knowledge systems) associated with them. Different environmental commons are shared by diverse social actors with unique (although not independent) forms and types of knowledge (e.g. indigenous and western knowledge). Identifying opportunities to bridge different knowledge systems has been a key theme in commons governance for some time (Ostrom et al. 2002; Reid et al. 2006), although getting clarity on the appropriate settings in which to do so remains a challenge.

Diverse types and sources of knowledge can make important contributions towards understanding and governance of environmental commons (Tuhiwai Smith 1999; Wilson 2008; Bohensky and Maru 2011). Despite the potential of individuals with different knowledge systems to contribute experiential and tacit knowledge about their environments (Fairhead and Leach 1995; Batterbury et al. 1997; Forsyth 2003; Dryzek 2005; Njaya et al. 2012; Robbins 2012), scientific knowledge has emerged as a dominant lens through which humanity makes sense of, and decisions about, environmental change (Ellis 2005; Smith and Sharp 2012; Partidario and Sheate 2013). However, major international research initiatives to understand and govern environmental change (e.g. the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES); Arctic Resilience Interim Report) are seeking new ways to incorporate diverse knowledge systems. Clarifying how different settings can facilitate knowledge system bridging, and how these opportunities to bridge knowledge systems act in synergy across multiple levels, requires more research (Weiss et al. 2013; Fleischman et al. 2014). Effective governance responses to multi-scale challenges must align action with values of social justice and democracy, and

must validate the legitimacy of diverse knowledge systems in both sense making about environmental change and the strategies used to navigate impacts of environmental changes (Mitchell et al. 2006; Armitage 2008; Henry and Dietz 2011). We contribute to this growing need and emphasize the moral/political and practical motivations to connect diverse knowledge systems at the indigenous and scientific knowledge interface.

We use a meta-synthesis procedure and ask, *What settings are discussed in the resource and environmental governance literature to support efforts to bridge indigenous and scientific knowledge systems?* A meta-synthesis approach (discussed below) helps to develop a typology of settings for bridging knowledge systems. We elaborate on how these settings function independently and in concert. The typology of opportunities includes specific methods and processes, brokering strategies, governance and institutional contexts, and the arena of epistemology. We describe each setting and provide selected empirical examples to reflect on the function and potential outcomes of different opportunities. Outcomes from our synthesis can inform policy and participatory action, as well as identify areas for future research in efforts to bridge knowledge systems in a wide-range of contexts. In doing so, we contribute to the growing need for clarity on how diverse knowledge systems contribute to environmental planning, management, monitoring and assessment, from local to global levels.

We conceptualize the interface of indigenous and scientific knowledge systems as *bridging* (Reid et al. 2006). We define bridging knowledge systems as maintaining the integrity of each knowledge system while creating settings for two-way exchange of understanding for mutual learning. This definition acknowledges the role of both a parallel approach to knowledge systems, as well as mutual learning and evolution/innovation of the shared knowledge base. For some knowledge systems, connection to a specific place or landscape is necessary to maintain the integrity of knowledge – learning occurs embedded in places. Throughout our discussion, issues of *power* are always near the surface and warrant careful attention (see Clement 2013). However, having a typology as elaborated in this paper can help those engaged in knowledge bridging processes to be reflective about the role of power via the choice of settings and contexts that are used.

Our geographic scope for this analysis is global, but we have a particular emphasis on the Arctic for several reasons. The Arctic is a "canary in the coal mine" for environmental changes, and considered particularly susceptible to abrupt and unexpected change in environmental conditions and commons resources (i.e. changes in sea ice, impacts on marine mammals) (Lenton 2012; Arctic Council 2013). The Arctic is also a region where traditional knowledge and local observations have been contributing to an understanding of the social-ecological system in significant ways (Krupnik and Jolly 2002; Laidler 2006; Krupnik et al. 2010). Arctic peoples are the first to be affected by changes, and taking their insights about change and their impacts seriously has required a moral, political and process-based approach.

2. Contributions of indigneous knowledge to understanding environmental change

Differences among knowledge systems are sometimes blurry. Use of discrete categories of 'scientific' and 'indigenous' to describe 'types' of knowledge is a simplification. For example, indigenous people can be versed in the scientific method and participate in scientific knowledge development (Weiss et al. 2013). Yet, there are real distinctions in how holders of scientific and indigenous knowledge see the world (Brody 2001; Cruikshank 2012). Neglecting to acknowledge the similarities and differences among types of knowledge and how they each make sense of, and contribute to governance of, changing environmental commons can perpetuate power asymmetries (Wilson 2008). It may also exacerbate superficiality in what participants of different knowledge systems can contribute to understanding and managing the commons (Weiss et al. 2013). Differences in how people from different knowledge systems perceive and address environmental change are sometimes framed as complementary (Riedlinger and Berkes 2001; Laidler 2006). Complementarities, however, can only emerge when diverse knowledge systems are valued and invited into discourse about changing commons.

Contributions of indigenous knowledge in the Arctic, for example, have enhanced overall understandings of changing environmental commons *and* the governance processes used to navigate that change through: (1) cross-scale and/or multi-level perspectives and data for decision making; (2) place-based narratives; (3) expanded forms of expression (e.g. oral history); (4) alternative epistemological traditions; (5) enhanced perceived credibility and legitimacy of 'other' knowledge systems. Each of these contributions is outlined below.

First, scientific data about Arctic sea ice change, assessed using evidence from regional and global levels (e.g. satellite imagery and models), has been complemented with place-based observations and understandings of Inuit who live with sea ice (Riedlinger and Berkes 2001; Laidler 2006). Policy decisions that benefit from multi-level monitoring (Jasanoff and Martello 2004) have the capacity to respond to local nuances of environmental change because local data are available to direct local initiatives. Further, policy that takes into account local expertise is considered more legitimate, increasing local compliance (Mitchell et al. 2006; Sillitoe and Marzano 2009; Reed et al. 2011). For example, hunters in Nunavut are experimenting with Geographical Positioning Systems (GPS) as a way to both navigate and document changing and dangerous sea ice conditions (Laidler et al. 2010). Hunters also speak on community radios to discuss local nuances in ice conditions and implications for local safety (Pers. comm., Pangnirtung elders, August 2013).

Second, local resource users maintain unique, place-based narratives about the environmental changes they experience. These local narratives have been found to challenge dominant narratives (Fairhead and Leach 1995; Batterbury et al. 1997; Adger et al. 2001). In the Canadian Arctic, Inuit elders have observed the increased effect of the refraction occurring in the Arctic. The process of

documentary film making (Kunuk and Mauro 2010) invited elders to reflect on their observations of climate change in their own language and on their own terms. Mauro noted that:

> "By linking different ways of knowing, we discovered that a warming atmosphere is actually changing the refraction index of the sky, which dramatically alters the visual landscape of the Arctic" (SSHRC 2010).

In this context, the optical illusion of a changing position of the sun shed light on how greenhouse gases are altering the perceived angle and intensity of the sun (Isuma TV 2010; Manitoba Eco Network 2011a,b). This is a good example of a complementary process where the holistic nature and place-based perspectives of indigenous knowledge can create novel hypotheses that challenge the causal framing of western science (see also Berkes and Kislalioglu Berkes 2009).

Third, indigenous knowledge is communicated in socially and culturally embedded mediums such as oral history and art (e.g. carving). Legitimizing these means of expression in the global climate change discourse concurrently offers more flexibility to participants in terms of how they choose to use their 'voice'. Indigenous knowledge can occur in a complex narrative format that communicates both content and cultural context, such as information about environmental change *and* how that is connected to culture/worldview (Leduc 2006, 2011; Cunsolo-Willox et al. 2013). Creative forms of expression can often engage human senses more intensively than do 'rational' formulations of science (Anderson 1996). Indigenous perspectives should not be *coerced* to communicate in written English, because this in itself is an act of power (Foucault 1991; Raik et al. 2008).

A fourth and related argument is that openness to multiple epistemologies and different ways of seeing the world prepares communities to navigate change. Having one's current epistemology challenged by attempting to grasp how someone else sees the world confronts the idea that there is only one possible way to experience the world (Miller et al. 2008). Hence, openness to alternative epistemologies creates a space for envisioning a future that is different from the present. Cruikshank (2005, 2012) expresses this sentiment by exploring oral histories about glacial change told by Tlingit elders. Her book, '*Do Glaciers Listen?',* provocatively implies that for some knowledge systems, indeed glaciers listen. The agency, sentience and connection to human spirituality of glaciers communicated by oral histories creates an alternative view of sentient and non-sentient beings, reflects dynamic time/space scales, and engenders more diverse ontological and epistemological framings for how the world works.

Fifth, the process of finding parallels between indigenous and scientific knowledge systems can act to enhance the perceived credibility and legitimacy of both (Moller et al. 2004; Berkes and Davidson-Hunt 2008). Tools used by science to track environmental change (e.g. anomalies) (Hansen et al. 2006) and to anticipate regime shifts (e.g. skewness, variability) (Scheffer et al. 2009; Dakos et al. 2011) may be paralleled in metaphors, observations and narratives connected

to indigenous knowledge of environmental change (Nayak and Berkes 2010). For example, climate change scientists measure changes in global average temperature using the phenomenon of anomalies (i.e. the differential between observed global temperature averages and a baseline of global average temperature, usually from years 1951 to 1980) (Jones and Wigley 2010). Inuit also describe changes in their local environment in the form of anomalies. However, their 'baseline' is orally communicated wisdom about how to predict the weather, and anomalies rest in the extent to which elders cannot predict the weather as they used to (Krupnik and Jolly 2002; Krupnik et al. 2010).

3. Bridging knowledge systems

Diverse literatures have sought to unpack the meaning of 'knowledge systems'. For example, the philosophy of science is concerned with questions such as 'what constitutes knowledge' (Midgley 2000; Godfrey-Smith 2003; Carolan 2005)? Political philosophers have helped us understand the role of power in the construction, maintenance and deconstruction of knowledge, and they are also concerned with questions about 'whose knowledge?' and the political processes by which knowledge is created, confirmed or denied (Burchell et al. 1991; Foucault 1991). Political ecologists build on political philosophy in the specific context of the environment to study the narratives of different knowledge systems about environmental change, examining how dominant knowledge systems reflect the power of dominant groups, potentially subverting the insights of marginalized people (Fairhead and Leach 1995; Batterbury et al. 1997; Forsyth 2003; Dryzek 2005; Njaya et al. 2012; Robbins 2012).

Increasingly, interdisciplinary scholars are investigating how different knowledge systems can be brought together in applied forms to collectively navigate environmental change and contribute to processes of governance (Reed et al. 2011; Fazey et al. 2013, 2014; Gomez-Baggethun et al. 2013). However, incorporating indigenous knowledge into collaborative processes for decision making and maintaining the integrity and agency of the knowledge holders is not easy. Some scholars argue that indigenous knowledge cannot be combined with western science because to do so would displace indigenous knowledge from its context or place-based significance (Cruikshank 2005). In this regard, Nadasdy (2003, 2007) has scrutinized co-management boards in Northern Canada for narrowing management practices in favor of western paradigms. These critiques are helpful because they broaden the discourse and shed light on important epistemological oversights, including for instance, the assumption that numerical data are more valid than narrative data. Yet, the demands of navigating rapid and complex environmental change, such as that occurring with Arctic sea ice, requires accommodating multiple perspectives and openness to hybrid solutions. Further, indigenous people, in this case the Inuit of Northern Canada, are quite capable of adapting their indigenous knowledge to modern circumstances and their capacity to do so should not be overlooked (Berkes and Armitage 2010).

In a shift away from the language of knowledge 'integration', Fazey et al. (2013) have emphasized *knowledge exchange* in the context of environmental management. They examine how knowledge can be exchanged between actors and across scales, and by doing so, implicitly conceptualize knowledge and information together as *something* that can be "moved". Likewise, Reed et al. (2011) highlight the importance of *managing knowledge* to improve land degradation and assessment. These conceptualizations are technical and perhaps apolitical, yet pragmatic in their attempts to help societies navigate environmental change. Other scholars have previously advocated a parallel approach that views indigenous and western/scientific knowledge as parallel. For example, the two-row Wampum concept takes a beaded indigenous belt with a two-row pattern to symbolize indigenous and western knowledge moving in parallel and enriching one another but not interfering with each other (Doubleday 1993; Berkes 2012). In a similar vein, Tengö et al. (2014) have developed the idea of a 'multiple evidence base' where evidence from different knowledge systems are brought beside each other and evaluated in relation to criteria unique to that knowledge system. In another strand of thinking, knowledge co-production describes processes that leverage expertise of different knowledge systems to create novel and hybrid understandings of environmental change and adaptation strategies (Armitage et al. 2011). What is less clear in these various approaches are the specific settings/contexts or opportunities in which exchange, management, co-production and validation of knowledge might occur, and in which bridging of knowledge can be facilitated. Here we map out a typology of settings to do so, and their relationships to each other, by examining the literature and by reflecting on our own experiences.

4. Methods

We developed the typology using a meta-synthesis approach to interpret groups of qualitative empirical research findings, perspective and review articles, and to generate novel insights about phenomena (Walsh and Downe 2005; Carpenter et al. 2009). The goal of a meta-synthetic approach is to strive for a holistic and reflective perspective on a particular issue or problem. Meta-synthesis techniques from health sciences were used to inform our process (Thorne et al. 2004). Meta-synthesis is different from meta-analysis in that the latter uses a largely quantitative approach to understand a body of literature (see Fazey et al. 2014). We sourced literature from:

1. Expert advised reading lists on the three broad themes of (1) knowledge systems; (2) indigenous/traditional knowledge systems; and, (3) resource and environmental governance;
2. Systematic literature review based on keyword search in two Scopus research database: following search protocol: ("indigenous" OR "traditional") AND "knowledge" AND ("integrat*" OR "link*" OR "bridg*" OR "connect*" OR "evaluat*" OR "manage*" OR "exchange") AND "environment*"

We followed an inductive process that involved: 1) reviewing expert advised reading lists on the topic of indigenous knowledge in environmental governance to discover how authors describe and apply bridging knowledge; 2) based on this initial process, we developed the overarching question – *what settings are discussed in the resource and environmental governance literature to support efforts to bridge indigenous and scientific knowledge systems?* This question was used to guide the systematic literature review; and 3) creating the typology to conceptualize how insights from the literature fit together, and to help further refine current thinking on the different ways that knowledge systems can be bridged.

Based on the preliminary literature review of the expert advised reading list, we found that scholars from various disciplines and working in different areas of the world were focusing on different types of knowledge 'bridging' processes (e.g. formal institutions like co-management boards, informal collaborations with NGOs in social networks). However they were doing so without the guidance of a meta-framework to consider how their approach fit or related to other mechanisms, institutional support structures or political philosophies about bridging indigenous and scientific knowledge. Therefore, we identified an opportunity to clarify the diversity of settings in which to bridge indigenous and scientific knowledge systems, reflect on how these settings can be conceptualized as multi-level, and to consider how bridging settings can work in synergy (within and between levels) to create more robust understanding for governance of the commons in the context of change.

Teasing out settings that support bridging of knowledge system is a subjective process. Moreover, we wanted to capture elements from an interdisciplinary literature that inform environmental governance and management. This includes anthropology, political science, environmental management, environmental sciences, organizational science, global change governance, and indigenous studies, to name a few. We felt it important to capture settings that have both structural elements (e.g. network structures, formal governance arrangements) and process elements (e.g. map making, in-situ interactions through trips on the land). We considered it vital to emphasize the epistemological component of bridging knowledge systems. We were also mindful of the multi-scale, multi-level dimensions of our settings. For example, brokerage as a dimension of bridging (see Cash et al. 2006) can occur at multiple levels from local to global.

We started organizing settings based on initial categories: structure, process and epistemology. The subsequent review/synthesis confirmed the validity of these categories, but also drew our attention to additional settings and additional examples of how settings function in isolation, or in concert, to bridge knowledge systems. We therefore modified the initial categories based on results of the keyword database search which included n=30 papers culled from 429 papers. The large size of the initial output resulted from the intentionally broad parameter to account for different nomenclature used for the concept of connecting indigenous and scientific knowledge (i.e. linking, managing, exchange). We

culled the large initial sum by examining the titles and abstracts of the selection. We also used filters to identify articles specific to environmental change and the environmental commons (e.g. climate change). We kept only case examples (empirical papers), grounded reviews and perspective pieces on indigenous and scientific knowledge bridging for learning about and/or management/governance of environmental commons. We subsequently focused our analysis on a small subset of papers (n=30) that dealt explicitly with connecting indigenous (or traditional) knowledge with scientific knowledge in the context of environmental commons, such as Arctic sea ice. This literature was used for cross checking themes, confirming settings and identifying examples to emphasize each setting in the typology.

5. A typology of settings to bridge knowledge systems

Four categories of settings were ultimately determined: a) epistemological arena b) methods and processes; c) brokerage mechanisms; and d) governance/institutional arrangements. In Table 1, we also identify a selection of sub-categories within each setting category. We explain each setting, provide an example, and list a few key literature sources. In the text below, we elaborate on the key aspects of each category, the evidence from the literature demonstrating the capacity of that setting, and the tangible and intangible outcomes that can result from successful engagement with that setting.

5.1. Epistemological arena

Epistemology "deals with questions involving the nature of knowledge, the justification of beliefs, and rationality" (Godfrey-Smith 2003, 235). By epistemological approach we mean the philosophical framings that identify the relationships between knowledge systems, and how to approach knowledge system bridging, philosophically and ethically. An epistemological approach reflects issues of power, legitimacy and saliency in knowledge bridging – elements that may be overlooked if not explicitly addressed (Brugnach and Ingram 2012). Indeed, the epistemological arena that guides knowledge system bridging is perhaps the most important and least discussed setting in the literature. However, actors committed to bridging knowledge systems must attend to the philosophical and epistemological dimensions of knowledge. Epistemology serves as a setting because actors engaged in knowledge systems must step back into the 'setting of epistemology' and reflect critically on their own views, and the extent to which their epistemology is filtering 'valid' from 'invalid' evidence.

In a focused study of bridging indigenous and scientific knowledges in Australia, Weiss and colleagues (2013) identify a major challenge to coastal marine governance as being a lack in the depth of understanding of epistemology, resulting in only superficial interactions between indigenous and scientific knowledge holders. They find that patterns of superficial engagement perpetuate power struggles and can stunt collaborative efforts (Weiss et al. 2013). Increased

Table 1: Settings for bridging knowledge systems.

	Setting	Explanation	Example	How is this setting is helpful for bridging?	Selected Sources
Epistemological Arena	Epistemological Pluralism	To conceptualize and motivate transdisciplinary research by accounting for knowledge pluralism in research process. This means prioritizing different ways of knowing by valuing the epistemological foundations of different participants in processes and discussions	Authors provide examples from urban ecology and Arctic biodiversity demonstrating traps that occur when epistemological framing is not taken seriously. No example of using epistemological pluralism to guide a successful empirical process.	Guides process of social and scientific inquiry wherein a) multiple epistemologies are valued; b) values, aims, and parameters governing the validity of knowledge are continually negotiated in an iterative science cycle.	Miller et al. 2008
	Polycentric global epistemologies	A variety of dialogues with epistemological 'others' to allow sharing, borrowing, learning and collaborative projects; knowledge practice in the service of human well-being. These dialogues will expand the number of epistemologies accommodated in decision-making processes.	No example provided by author, no example of engaging with approach in an empirical example. Therefore the contribution remains theoretical and should be tested for its added value.	"A creative process of aesthetic ordering. Participants function as artists who create new knowledge practices from the ingredients of existing ones" (p. 63). Aesthetic rather than rational. Participants can learn about each others worldview as a precondition to knowledge bridging and decision making.	Maffie 2009
Methods and Processes	Mapping	Practical spatial processes to understand place based perspectives on ecological systems.	Inuit elders map changing ice extent and flow edge patterns – facilitated by Laidler (2006) and her dissertation research on connecting scientific and Inuit sea ice knowledge.	Provides spatially explicit information about ecological features and perception of ecological space. Mapping can be performed collaboratively with scientists and indigenous peoples both participating. Demonstrates local expertise.	Krupnik and Jolly 2002; Laidler 2006, 2007; Turnbull 2007; Krupnik et al. 2010

Table 1: (continued)

	Setting	Explanation	Example	How is this setting is helpful for bridging?	Selected Sources
	Monitoring	Procedures and processes embedded in local management, co-management, adaptive co-management or adaptive governance arrangements to account for ecological attributes and changes.	The Igliniit project (Gearheard et al. 2011) Inuit hunters document life on the trail to map and monitor arctic change.	Monitoring processes can be embarked on collaboratively in the field or participants can monitor while on the land (local, indigenous), or in the lab (scientific), and report to each other.	Armitage 2008; Krupnik et al. 2010; Gearheard et al. 2011
	Artistic processes	Creative collaboration, space for symbol, culture and tradition.	Kunuk and Mauro (2010) collaboratively created the documentary film 'Inuit Knowledge and Climate change'.	Visual or performing arts can allow for culturally embedded knowledge sharing, emergent ideas, simulations and storytelling.	Kunuk and Mauro 2010; Zurba and Berkes 2014
	Scenario Planning	As a tool to collectively envision and navigate change in social-ecological systems.	Engaging with qualitative scenarios helped Wesche and Armitage (2014) identify local perspectives on the impacts of climate change and resource development for community vulnerability and adaptation.	Discourse, imagery, experience and data can all inform scenario planning. Stakeholder groups create plausible storylines about changing social-ecological systems. These efforts direct continued dialogue and potential steering of social-ecological change.	Bennett and Zurek 2006; Peterson 2007; MA 2005; Wesche and Armitage 2014
	'Out on the land' together	As a way of sharing embodied experience.	In her PhD thesis Laidler (2006) describes the importance of her time on the land with Inuit elders for enhanced bridging of scientific and Inuit knowledge on Arctic sea ice change.	Setting where scientists are dependent on Inuk land skills for security, this can help shift power disparity. Inuit are more comfortable explaining environmental knowledge in context and this means spending time 'on the land'.	Brody 2001; Laidler 2006, 2007

Table 1: (continued)

	Setting	Explanation	Example	How is this setting is helpful for bridging?	Selected Sources
Brokerage	Boundary Objects	As a tool for linking communities of practice.	Zurba and Berkes (2014) use participatory art as a boundary object to help communicate indigenous knowledge and values in coastal resource and management.	Objects that are valued on both sides of the boundary and provide a site for cooperation, debate, evaluation, review and accountability e.g. models, forecasts, newsletters, reports (Cash and Moser 2000, 115). The objects then act at the interface of knowledge systems and can help to bridge questions and ideas.	Star and Griesemer 1989; Cash and Moser 2000; Gearheard et al. 2011; Zurba and Berkes 2014
	Boundary Organizations	In the context of sustainability science; organization with specific role of linking science with policy.	The project 'Nilliajut Inuit perspectives on Arctic Security' initiated by the Inuit Knowledge Center branch of Inuit Tapiriit Kanatami, has documented the perspectives of Inuit on the ever-increasing topic of security in the Arctic (Inuit Qaujisarvingat. 2013).	Institutions that straddle and mediate the divide between science and policy. They "serve to mediate between scientists and decision-makers on the one hand, and between these actors at different scales on the other" p. 114.	Cash and Moser 2000; Cash 2001; Cash et al. 2006; Inuit Qaujisarvingat. 2013
	Bridging Organizations	Within governance or management networks bridging organizations create connectivity between groups, locations and worldviews	Rathwell and Peterson (2012) discuss the critical role of bridging organizations for connecting different actor groups to address water quality in polluted Canadian watersheds.	"Facilitates bringing together science and local knowledge and provide an arena for knowledge co-production, trust building, sense making, learning, vertical and horizontal collaboration and conflict resolution" (Berkes 2009, 1695).	Folke et al. 2005; Cash et al. 2006; Berkes 2009; Rathwell and Peterson 2012
	Networks (bridging and bonding ties)	As a structural arrangement between individuals or organizations.	Weiss et al. (2013) examine knowledge exchange and policy influence of a diverse network of actors in a fisheries context.	Structural bridge in social network arrangement	Granovetter 1983; Coleman 1988; Burt 2001; Bodin and Crona 2009; Weiss et al. 2013

Table 1: (continued)

	Setting	Explanation	Example	How is this setting is helpful for bridging?	Selected Sources
Institutional/ Governance	Adaptive co-management	Combination of co-management with adaptive management practices.	Armitage et al. (2011) discuss the process of linking indigenous and scientific knowledge in three cases Arctic marine co-management.	a) Sharing of management power and responsibility through multiple institutional linages that may involve government agencies, NGO's and other communities; and, b) Feedback learning and building of mutual trust among the partners	Olsson et al. 2004; Berkes 2004, 2009; Armitage et al. 2007, 2011
	Adaptive Governance	To govern ecosystems with multiple nested centers of decision making power, connected by polycentric institutional arrangements and capable of adapting to novel circumstances.	Olsson (2007) discuss the importance of adaptive governance to address multi-level and dynamic issues in the context of natural resource management.	Actor groups and organizations involved in governance arrangements interact for iterative sense-making and decision-making.	Folke et al. 2005; Armitage et al. 2007; Olsson 2007; Armitage 2008
	Project driven Environmental Assessment	To assess environmental conditions (e.g. local, regional scales), often in the context of resource development.	Many environmental assessment processes are required (often legally) to include indigenous knowledge and perspectives in understandings of the environment and impacts of local resource development.	Project based environmental assessments are a platform to bridge scientific and indigenous knowledge systems about local environmental conditions. Concerns exist in the literature that environmental assessment is too rigid to respectfully accommodate diverse worldviews.	Stevenson 1996; Usher 2000; Sinclair and Diduck 2001
	Global Environmental Assessment	To synthesize environmental conditions (regional or global scales) and/or social-ecological conditions in changing environments.	The MA (2005) sought input from multiple knowledge systems to assess the state of ecosystems at the global scale. The process required elaborate local, regional and global assessments.	A global perspective of environmental change requires inclusion of many knowledge systems. Global environmental assessments have the added challenge of bridging knowledge systems across many localities to understand ecological change *and* to scale up findings, such that results are compatible amongst regions to create a coherent global picture of environmental conditions.	MA 2005; Tengö et al. 2014; Nakamura 2013

effort to clarify our epistemological starting points remains an important need (Ellis 2005; Fazey et al. 2014) pointing out that "the way knowledge is exchanged is strongly influenced by the way knowledge exchange is conceptualized" (Fazey et al. 2014, 206). We highlight two examples in which philosophical and conceptual settings for bridging knowledge systems are explicitly made.

In the first example Miller et al. (2008), present the idea of epistemological pluralism as a way to consider how each individual may 'hold' multiple epistemologies. Epistemological pluralism as a setting requires commitment to open discourse and negotiation from which might emerge novel insights. Miller et al. (2008) only hypothesize how 'epistemological pluralism' as an arena might improve multidisciplinary work related to environmental commons. They don't provide empirical examples, but the importance of epistemological pluralism as a foundational setting to bridge knowledge systems is clearly articulated.

In a second example, Maffie (2009) proposes the concept of a polycentric global epistemologies' (PGE) philosophical approach to bridge indigenous and scientific knowledges. Respectful conduct between knowledge systems is of utmost importance in this epistemological arena, with "a necessary prerequisite of [PGE] as well as its first and foremost goal…the survival and self-determination of indigenous peoples and their knowledges" (Maffie 2009, 60). Maffie (2009, 63) asserts "PGE promotes greater self-awareness and self-criticism regarding the unstated limitations of participants' philosophical horizons", and clearly acknowledges the political and moral attributes of knowledge system bridging. As with the concept of epistemological pluralism, the rigorous ideals of PGE as an epistemological setting have yet to be fully tested with an empirical case. Engaging with epistemology (and multiple epistemologies) will change how environmental commons are managed. Being aware of the underlying values and beliefs of another culture can clarify why and how particular resources can be managed to build rather than burn bridges between scientific and indigenous cultures.

5.2. Methods and processes

Methods and processes serve as the tangible settings to bridge indigenous and scientific knowledge. Methods and processes that bridge knowledge systems have been directed toward resource management tasks, for example, by monitoring the environment (e.g. sea-ice change) (Nichols et al. 2004; Gearheard et al. 2011), setting quotas for wildlife catch (Armitage et al. 2011; Dale and Armitage 2011), or modeling changing environments (Giordano et al. 2010). Alternatively, processes can be 'soft' and exploratory, grounding participants in local context and epistemology through, for example, anthropological inquiry that includes storytelling (Brody 2001; Cruikshank 2005, 2012), artistic processes (Kunuk and Mauro 2010; Petheram et al. 2011; Zurba and Berkes 2014), role-play (Castella 2009) and participating in local cultural events (Castleden et al. 2012).

As illustrated through the meta-synthesis, research engaged in knowledge system bridging can embrace a bundled approach with regards to methods. Scenario planning is an example of a method that engages with multiple processes such as interviews, monitoring, mapping, workshops and creation of imagery (Peterson et al. 2003; Peterson 2007; Wesche and Armitage 2014). Bundling methods and processes is a robust way to connect knowledge systems. Being part of a hunting party provides insights about how hunters work together in practice over space and how Inuit worldview guides hunting practice (Wenzel 2004). Laidler's (2006) work on Baffin Island to map Arctic sea-ice change provides a good example. Working in collaboration with elders and other community partners, she has undertaken rigorous systematic spatial mapping of the changing ice by drawing on expertise from Inuit hunters to complement scientific understandings (Laidler 2006). Outcomes from this mutual process are maps indicating the extent of sea-ice change. Balancing the scientific approach of map-making with openness to local culture, Laidler (2006) speaks about the importance of being 'out on the land' with the Inuit. A scientist willing to participate in explorative methods to bridge knowledge systems demonstrates respect for the way indigenous peoples have accumulated their expertise (Laidler 2006, 2007; Laidler et al. 2011). Trust and respect between knowledge systems, mutual experience and the sharing of place embedded stories about sea-ice and how it is changing are all fruitful outcomes of collaborative fieldwork as a bridging process. These outcomes have direct impact on how environmental commons are managed. For example, respect and trust emerging from engagement in diverse methods and processes for bridging knowledge systems, will create improved learning and collective compliance regarding governance of environmental commons (Mitchell et al. 2006; Armitage et al. 2011).

Methods and processes are important to bridge indigenous and scientific knowledge in space and time, but these techniques alone remain insufficient. Methods and processes must be embedded within organizational (governance, institutional) structures to support a 'scaling-up' of insights and experience from these processes, to allow bridging to occur beyond the local, and to be sustained over time to allow for learning to occur. Methods and processes are the building blocks of management of environmental commons. Expanding and diversifying the methods and processes used for environmental commons management and understanding that different methods have different capacities for bridging knowledge systems will allow resource managers to better accommodate the multiple knowledge systems sharing environmental commons.

5.3. Brokerage and networks

The structure of organizations, actors/actor groups, and objects interacting with each other about a particular issue can be thought of as a social network (Granovetter 1983; Burt 2001). Formal and informal networks influence the information, connectivity, activities and decision-making power of actor groups

in an environmental change context (Bodin and Crona 2009; Rathwell and Peterson 2012). Thus, one can think structurally about how knowledge systems are connected in social networks and the implications of structural settings for bridging indigenous and scientific knowledge systems.

Particular network configurations impact if and how knowledge systems are connected to each other to govern commons (Bodin and Crona 2009). Robust social networks include both strong and weak connections (ties) between entities (Granovetter 1983; Coleman 1988; Burt 2001). Strong connections (bonding ties) enable trust and shared values, while weak ties (bridging ties) provide sources of new information/insight and can challenge assumptions held by otherwise isolated actors. Both bridging and bonding ties can help facilitate bridging of knowledge systems to make sense of complex environmental change and identify solutions. For example, Inuit actors can hold bonding ties with other hunters to reinforce their local knowledge (often confirming observations through informal networks) and at the same time have weak ties (bridging ties) with scientific parties in the form of co-management boards where results from scientific studies can provide additional insights into environmental change (Nichols et al. 2004).

A structural perspective about how actor groups understand and navigate environmental change points to particular entities, organizations and/or 'objects' embedded within social networks that can facilitate or impede the bridging of knowledge systems (Cash 2001; Rathwell and Peterson 2012). Boundary organizations have been highlighted for their capacity to link science with policy, often across levels (Cash and Moser 2000; Cash 2001; Cash et al. 2006). Inuit Tapiriit Kanatami (ITK), a political advocacy organization, is a boundary organization that seeks to bridge Inuit knowledge and scientific knowledge to direct Canadian policy. For example, the project 'Nilliajut Inuit Perspectives on Arctic Security' initiated by the Inuit Knowledge Center branch of ITK, has documented the perspectives of Inuit on this emerging topic (Inuit Qaujisarvingat 2013). For Inuit, the concept of 'security' involves a focus on food, shelter and a healthy environment. In contrast the southern discourse on security is focused on projecting military strength (Inuit Qaujisarvingat 2013).

Boundary objects connect organizations or actors in social networks by functioning as a mutually beneficial tool for learning and adaptation. Boundary objects act as a mutual reference point for different knowledge systems (Star and Griesemer 1989). Boundary objects themselves can adapt over time. For example, Inuit hunters and geomatics engineering students co-created an integrated GPS/PDA mobile weather station technology that can be utilized by scientists and hunters for observing and monitoring a changing Arctic environment (Gearheard et al. 2011). This technology acts as a boundary object in that both its creation and utilization can bridge knowledge systems. Likewise, Zurba and Berkes (2014) describe a collaborative mural as a means to communicate Australian aboriginal perspectives on how to 'care for country' (i.e. conserve local ecosystems). The artwork's imagery serves as a boundary object to foster discussion of what is important for this indigenous group in regards to ecosystem management.

Engaging with brokerage as a bridging setting means connecting levels – local to global across time. Brokerage impacts governance of environmental commons by connecting knowledge systems across time and space in efforts to enhance collective action across large commons. For example, bridging organizations can connect municipalities with different priorities across two watersheds in efforts for collaborative water management (Rathwell and Peterson 2012).

5.4. Institutional/Governance

Governance refers to "…processes and institutions through which societies make decisions that affect the environment" (Oakerson in Armitage et al. 2012, 246). For the purposes of this paper, we focus on formal governance arrangements as a setting to explicitly facilitate the bridging of both science and indigenous knowledge into learning and decision-making. Adaptive co-management, for example, is a governance approach that has gained some traction due to its emphasis on power sharing and valuing both scientific and indigenous knowledge perspectives on environmental change (see also Nadasdy 2003; 2007 for criticisms; Berkes 2004). Adaptive co-management can provide a setting for social learning where individuals and groups engage in iterative action, reflection, and deliberation to resolve complex challenges collaboratively (Diduck et al. 2005; Armitage et al. 2011).

Some positive outcomes of governance arrangements that facilitate bridging indigenous and scientific knowledge systems are: 1) direct embedding of lessons into formal governance procedures (e.g. setting hunting quotas); 2) representation of both indigenous and scientific perspectives in all stages of governance processes, including problem definition, analysis and implementation; and 3) the development of trust and respect between indigenous and scientific participants of these governance institutions (Berkes 2009, 2012).

Research on narwhal co-management in Arctic Canada illustrates opportunities and challenges for bridging knowledge in co-management settings. Governance structures, such as co-management settings, provide a context where bridging knowledge systems can occur. For example, marine mammal co-management in the Canadian Arctic draws on both Inuit and scientific knowledge for quota setting and enforcement that includes processes such as knowledge gathering, knowledge sharing, knowledge integration, and knowledge application (Dale and Armitage 2011). Embedded within governance and institutional structures are the praxis of participants (e.g. methods and processes, epistemological engagement). Despite settings that seek collaborations (co-management), tensions can emerge during the processes, such as those relating to tagging animals in the Arctic. Tagging is a western resource monitoring practice that is considered by some Inuit to be disrespectful to the animal. Engaging in resource management methods that defy Inuit values, such as tagging marine mammals, burn bridges between knowledge systems because epistemology is disregarded.

Environmental assessment is another setting to bridge knowledge systems. Environmental assessment is a particularly interesting bridging setting because it can be carried out at multiple levels. We have distinguished project based environmental assessment from the global scale assessment initiatives (e.g. IPBES). Opportunities for indigenous participation are considered during each phase of a BHP Diamonds Inc., mine (Stevenson 1996). However, scholars report difficultly in embedding indigenous knowledge contributions into existing environmental assessment protocols (Stevenson 1996; Agrawal 2002). Global scale assessments have the added challenge of synthesizing a myriad of knowledge systems from different parts of the globe into comprehensive patterns, changes and priorities at the global level. The Millennium Ecosystem Assessment (MA 2005) had the intention to draw on indigenous knowledge and it did so, but only to a limited extent. Other emerging global assessments, such as the IPBES, ongoing work within the IPCC, and the Aichi targets of the Convention on Biological Diversity, each seek to better bridge knowledge systems (Thaman et al. 2013; Tengö et al. 2014). Results from this literature point to confusion around how knowledge systems are understood (Stevenson 1996; Usher 2000), and limitations of a discipline-bound analysis (Carpenter et al. 2009) as barriers to effective environmental assessment methods and outcomes.

More accurate and nuanced assessment of changing environmental conditions and human responses can result from environmental assessments that bridge knowledge systems (Riedlinger and Berkes 2001; Laidler 2006; Nichols et al. 2004). Further, assessments that align with the values and priorities of different knowledge systems (e.g. Inuit and scientific) have better chances of improving management of environmental resources because participants feel they were part of a legitimate process (Mitchell et al. 2006).

5.5. Settings act in synergy to bridge knowledge

The various settings, and categories of settings in Table 1, can act in synergy. For example, map-making of sea ice change can be complemented with ‘out on the land’ trips as scientists and elders make sense of change (Laidler 2007). However, particular settings can also create path-dependency, whereby a particular epistemological perspective may disqualify some methods while prioritizing others. For instance, adopting PGE (as proposed by Maffie 2009) as an epistemological approach would favor indigenous driven bridging methods that encourage self-determination, such as sharing of oral histories. Likewise, particular methods employed to bridge knowledge systems lend themselves to specific evaluation techniques. For example, Fazey and colleagues (2014) describe that when knowledge is perceived as an ‘item’ that can be detached from its source, evaluation of knowledge exchange is limited to “experimental evaluations, with the success of the knowledge exchange being determined by measuring how much a person holds of a particular item or set of facts” (Fazey et al. 2014, 212).

In recent years, there has been an expansion of the various methods and processes to bridge knowledge systems in an environmental change context (Gomez-Baggethun et al. 2013; Fazey et al. 2014; Tengö et al. 2014). More conventional scientific methods of mapping and monitoring that seek the expertise of local indigenous perspectives have been enriched with artistic processes such as role-play, oral history sharing or documentary film making (Cruikshank 2005; Kunuk and Mauro 2010). Place based processes such as hunting trips are highlighted as important sites for bridging (Laidler 2006). The enactment of various methods to bridge scientific and indigenous knowledge systems by participants has lead to enhanced overall understandings of environmental change and has provided settings that give voice to a diversity of participants (e.g. social scientists, natural scientists, hunters, youth).

The SIKU-Inuit Sea Ice Use and Occupancy Project engaged with multiple bridging settings (Table 2). This project provides an example of how various methods for bridging indigenous and scientific knowledge can act in synergy to facilitate a robust and culturally sensitive research program. Methods and processes used to design the project were informed by science and community-based research methodologies. Participatory mapping, sea ice trips and focus groups using photo imagery of sea ice, each contributed to global understandings for the assessment of Inuit sea ice occupancy and use. Boundary objects, such as the SIKU Atlas provide online platforms for participants, community members and academics to learn about and monitor project progress and to contribute to online discourse. The SIKU project is nested within he International Polar Year (IPY), which has served as a kind of bridging setting and organization.

5.6. Policy implications

Our typology can inform policy and practice, but not all individual aspects of the typology have a clear policy connection. This is a potential limitation. However, recognition of the diverse settings in which to bridge knowledge systems points to associated implications for policy and practice. This typology provides four specific lessons for policy and participatory action that include: 1) enabling policy makers to understand how efforts to bridge knowledge systems need to be appropriately supported by adopting a bundle of settings (e.g. using diverse methods and brokerage); 2) encouraging practitioners to use clear definitions of ‘knowledge’ and ‘bridging’ in proposals and research reports to support reflexive processes, monitoring and evaluation; 3) reflecting on how bridging organizations and social networks can support, enhance and/or prevent the reach of knowledge system bridging activities and outcomes; and 4) developing evaluation metrics that reflect the process dimensions of bridging in the various settings which cannot be captured if metrics are concerned merely with efficiency. We discuss each in turn.

Programs that adopt bundles of settings require input from diverse knowledge systems to identify and engage appropriate and complementary settings. By practicing multiple methods of knowledge systems bridging, participants allow

Table 2: Example of bundling settings: Laidler and colleagues have engaged with multiple bridging settings during the SIKU- Inuit Sea Ice Use and Occupancy Project (bit.ly/1lyY4G4) (Laidler 2006, 2007; Laidler et al. 2010, 2011).

Category	Setting	Example and rational
Methods and processes	Mapping	Participatory mapping; 'Out on the land together' (i.e. sea ice trips); Focus groups using photo imagery for maps
Brokerage	Boundary Object	A website is maintained to communicate ongoing research to communities and academics (http://straightupnorth.ca/Sikuliriji/SUN_Home.html); The SIKU-ISIUOP project has created a user Atlas to provide information to hunters on the trail (http://sikuatlas.ca/index.html)
	Boundary Organization	International Polar Year (IPY) is an international initiative to connect Polar science and policy.
Institutional/ Governance	Environmental Assessment	The SIKU-ISIUOP project seeks to provide an overall assessment of Inuit Sea ice Use and Occupancy, information crucial to future resource management projects and government decision-making.

for a broader spectrum of insights, including for example, cultural and place-based knowledge that can be shared through collaborative fieldwork (Laidler 2006). By bundling settings, certain processes may favor scientific institutions, but these can be balanced with settings that indigenous participants may deem more appropriate (Weiss et al. 2013).

Policy makers and funders are within their bounds to request clear definitions of knowledge and knowledge system bridging from those they fund. Outlining an epistemological approach in research design or policy programming signals an awareness of the philosophical, ethical and political dimensions of bridging processes. This can help ascertain if/how projects are prepared to respect and engage with diverse knowledge systems.

Bridging organizations and social networks can support or hinder the reach of knowledge system bridging processes and outcomes in the context of governing changing environmental commons (Bodin and Crona 2009; Rathwell and Peterson 2012). International initiatives, such as the IPBES, can consciously determine how social networks and bridging/boundary organizations are best leveraged to connect knowledge across all levels. For example, boundary organizations may or may not have local indigenous buy-in. Knowing how bridging organizations and boundary organization facilitate or inhibit local knowledge from traveling through networks informs legitimate and salient governance of environmental commons.

Development of evaluation metrics for settings that bridge knowledge systems is a research/policy 'next step'. Metrics can emphasize the importance of trust and reciprocity in the context of bridging indigenous and scientific knowledge systems. Metrics of success must consider outcomes beyond efficiency, to account for attributes such as inclusion, capacity building, respect and trust. Metrics can include aspects of *process* (e.g. "were participants respectful?") in addition to tangible knowledge bridging *outcomes* or lessons learned.

5.7. Research development implications of knowledge bridging

Outcomes of the meta-synthesis and development of the typology point to several areas for future research, and specifically participatory research. First, much more attention must be given to the epistemological settings of research programming when bridging indigenous and scientific knowledge systems. Scholars must take the time, perhaps by engaging in multi- or transdisciplinary research programs, to identify how knowledge systems are conceptualized. Second, research programs that encourage bundles of methods and processes for bridging foster insights that have more depth and contextual relevance (Laidler 2006; Reed et al. 2011). Combining methods such as interviews about climate change with the creation of documentary film (including oral history) is an example of creating synergy by leveraging complementary methods (Kunuk and Mauro 2010). Third, social networks and governance/institutional settings offer arenas for bridging knowledge systems at higher levels of governance (regional, global). However, how knowledge is 'scaled up' and recognized as relevant at regional and global levels, whist maintaining knowledge integrity, continues to be a pressing challenge and research concern. Fourth, more effort is required to respectfully and successfully evaluate knowledge contributions, such that insights are salient, legitimate and credible for governance of the environmental commons.

Bridging activities take time and require resources. Meaningful engagement in a cross-cultural context with a sensitive political history (as is the case when bridging scientific and indigenous knowledge systems) requires trust building. Trust building takes time (Castleden et al. 2012). Bridging activities may span months or years. Ongoing support from funders, for example, is needed to facilitate interaction over longer time horizons and to foster more ethical, engaged and informed bridging processes.

The typology offers lessons to bridge diverse knowledge systems, although our emphasis here has been on bridging indigenous and scientific knowledge. The rich literature on indigenous and scientific knowledge system bridging helps inform how any two different ways of seeing the world (e.g. local, traditional, citizen, policy) can be better included into discussions of governance of environmental commons. Projects that engage with diverse knowledge groups (e.g. farmers, citizens groups, or artists) can use the typology to better reflect on the settings in which they are bridging knowledge systems. Increasingly projects (both scientific and policy) have mandates for stakeholder engagement, as one way to legitimize and decentralize decision-making. The typology we offer can be used as a guide post for any project or development that seeks to bridge diverse knowledges to inform governance of environmental commons.

6. Conclusions

Major international initiatives on environmental change are seeking novel ways to incorporate diverse knowledge systems, following the lead of the

Millennium Ecosystem Assessment (Reid et al. 2006). The Arctic Climate Impact Assessment, (2005) demonstrates an early effort to bridge indigenous perspectives with western insights at a regional level to guide knowledge and practice. Global studies, such as the Intergovernmental Panel on Climate Change (IPCC) started looking at bridging seriously only after a UNESCO report provided evidence that there is in fact a scientifically "respectable", peer-reviewed literature base on indigenous knowledge and climate change (Nakashima et al. 2012). In the case of the IPBES, the biodiversity equivalent of IPCC, knowledge bridging started as soon as IPBES itself came into being (Thaman et al. 2013). It remains to be seen, however, if IPBES can live up to its promise, or if knowledge bridging will succumb to the power politics of knowledge, whereby, for example, lack of engagement with diverse epistemologies results in narrow conceptualizations of phenomena such as biodiversity – limiting local perceived legitimacy of policies and environmental governance decisions (Turnhout et al. 2013).

Research and policy is often initiated and mediated by western institutions (universities, governments, international initiatives). Knowledge system bridging activities that are open to proposals and initiatives emerging from within indigenous knowledge communities are critical. Gratani et al. (2014) provide some insights as to why indigenous participants do not initiate knowledge-bridging practices, and why natural resource management practitioners find it difficult to integrate indigenous and scientific knowledge for environmental management in the Australian context. They point out to three factors: weak indigenous internal and external governance related to colonial disempowerment, the tendency of practitioners to validate indigenous knowledge using scientific knowledge, and a struggle with understanding *how* to engage. The typology offered in this paper provides clarity on this third point. We show that many settings exist to address this challenge. Moreover, there are likely many additional settings, including processes initiated and facilitated by indigenous peoples to connect indigenous and scientific knowledge not reflected in the academic discourse.

There are moral, political and practical reasons to bridge diverse knowledge systems in the context of environmental change. Overcoming the continued marginalization of indigenous knowledge and discouraging extractive methods that dishonor indigenous knowledge are of central concern (Smith and Sharp 2012; Turnhout et al. 2013). Bridging knowledge systems show promise of enhancing collective understandings of, and collective capacity to navigate, complex environmental change (Eicken 2010; Krupnik et al. 2010) and encourage mutual learning (Idrobo and Berkes 2012). Achieving these outcomes, however, requires a more careful reflection on the settings in which knowledge systems are brought together. The typology we have outlined here is a modest offering towards improving knowledge bridging. Robust strategies to bridge indigenous and scientific knowledge systems are ultimately a key dimension of the effort to govern local to global commons under conditions of change and uncertainty.

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