Exploring the public value of networked science in the Canadian Arctic

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ACUNS – Association of Canadian Universities for Northern Studies

ASA - ArcticNet Student Association

ASTIS - Arctic Science and Technology Information System

BoD - Board of Directors

CCGS Amundsen - Canadian Coast Guard Ship Amundsen

CEN - Centre d'études nordiques

CREATE EI - Collaborative Research and Training Experience Program (CREATE) Environmental Innovations (EI)

GoC – Government of Canada

HQP - Highly qualified personnel

INAC - Indian and Northern Affairs Canada

IPY - International Polar Year

IRA - Inuit Research Advisor

IRIS - Integrated Regional Impact Studies

ISAC - International Arctic Science Committee

ITK – Inuit Tapiriit Kanatami

NAO - Network Administrative Organization

NCE - Network of Centres of Excellence

NCP - Northern Contaminants Program

NI - Network Investigators

NSERC - Natural Science and Engineering Research Council of Canada

PL - Project Leaders

PVM - Public Value Mapping

RMC - Research Management Committee

SSC – Science Council of Canada

SSHRC - Social Sciences and Humanities Research Council

TRC - Truth and Reconciliation Commission

UArctic – University of the Arctic

Abstract

The Arctic is one of the world's most rapidly changing regions and faces a series of unprecedented and complex challenges. It has been argued that science-informed innovation will be key in supporting sustainable regional development and improved policy outcomes. Despite significant and increasing public investment in Arctic research, Northern communities continue to assert that existing research governance structures have been unable to create public value, failing to deliver research that reflects public expectations, interests, and innovation needs. Given that little is known about how Arctic scientific research is embedded in broader innovation and value creation processes, this dissertation takes a systems approach to examine the complex and dynamic governance contexts that shape how networked scientific research creates public value in the Canadian Arctic. It begins with a literature review that connects the concepts of innovation ecosystems and public value with Canada's efforts to guide Northern and Arctic research to identify salient challenges and opportunities relevant to research and innovation policy. Then, the remainder of the dissertation examines public value creation processes by focusing on the instrumental case of ArcticNet, a large Canadian research network responsible for connecting public, private, government, not-for-profit and Indigenous stakeholders to study the impacts of climate change in the Arctic with the goal of informing adaptation strategies and national policies. This empirical research focused on three levels of organization: 1) networked scientific research actors; 2) a network administrative organization; and 3) institutional mechanisms for delegating authority. A Social Network Analysis was conducted to map the configuration of science-based innovation actors in ArcticNet and its evolution over a 13-year period. Results suggest that the network was centralized around non-local public-sector actors who played central boundary spanning roles that facilitated collaboration, while local Arctic actors had an increasing propensity for carrying out boundary spanning roles and closing structural holes in the network. Next, the Network Administrative Organization (NAO) was used as the unit of analysis to explore the network-level public values associated with ArcticNet to inform network-level evaluation strategies. Public Value Mapping revealed that the NAO targeted diverse publics, seeking to create a range of public values that were identified both at the outset of the network and emerging later. Results point to the need for research networks to improve clarity in value articulation across public facing documents and different scales (e.g., research versus network impacts). Turning to the larger contract between science and society, principal-agent theory and the public value Strategic Triangle were used to identify the overlapping, multi-level principal-agent contracts for delegating public value creation in Arctic science. Findings illustrate that the adoption of networked models for science governance corresponded with a trend towards contracting roles for public value management to Arctic scientific research actors; however, it remains unclear how core elements of public value management (i.e., identifying public value, political legitimacy and operational capacity) have been realized. This dissertation presents new insights into the complex, networked and multi-dimensional nature of Arctic scientific research governance in Canada, raising important questions about how publicly-funded research efforts can be designed to enhance public value, with potential implications for the strategic design and operation of Arctic research efforts, as well as for regional research and innovation policy.

Résumé

L’Arctique est l’une des régions du monde qui évolue le plus rapidement et fait face à une série de défis complexes et sans précédent. Il a été avancé que les efforts d'innovation scientifique seront essentiels pour soutenir le développement régional durable et améliorer les résultats des politiques. Malgré des investissements publics importants et croissants dans la recherche sur l'Arctique, les communautés du Nord continuent d'affirmer que les structures de gouvernance de la recherche existantes n'ont pas été en mesure de créer de la valeur publique, ne réussissant pas à fournir des recherches qui reflètent les attentes, les intérêts et les besoins d'innovation du public. Cette thèse adopte une approche systémique pour examiner les contextes de gouvernance complexes et dynamiques qui façonnent la manière dont la recherche scientifique en réseau crée de la valeur publique dans l'Arctique canadien. Il commence par une analyse documentaire qui relie les concepts d’écosystèmes d’innovation et de valeur publique aux efforts déployés par le Canada pour guider la recherche dans l’Arctique. Le reste de la thèse examine les processus de création de valeur publique en se concentrant sur le cas instrumental d'ArcticNet, un grand réseau de recherche canadien chargé de connecter les intervenants pour étudier les impacts du changement climatique dans l'Arctique dans le but d'éclairer les stratégies d'adaptation et les politiques nationales. Cette recherche empirique s'est concentrée sur trois niveaux d'organisation: 1) des acteurs de la recherche scientifique en réseau; 2) une organisation administrative du réseau (OAR); et 3) mécanismes institutionnels de délégation de pouvoir. Une analyse des réseaux sociaux a été menée pour cartographier la configuration des acteurs de l'innovation scientifique dans ArcticNet et son évolution sur une période de 13 ans. Les résultats suggèrent que le réseau était centralisé autour des les acteurs du secteur public local qui jouaient de rôles qui se sont étendus de la frontière centrale qui ont facilité la collaboration, tandis que les acteurs locaux de l'Arctique avaient une propension croissante à jouer des rôles de franchissement de frontières et à combler les trous structurels du réseau. Ensuite, l'OAR a été utilisée comme unité d'analyse pour explorer les valeurs publiques au niveau du réseau associées à ArcticNet. La cartographie de la valeur publique a révélé que l'OAR ciblait des publics divers, cherchant à créer une gamme de valeurs publiques qui ont été identifiées à la fois au début du réseau et émergentes plus tard. Les résultats soulignent la nécessité pour les réseaux de recherche d'améliorer la clarté de l'articulation des valeurs entre les documents destinés au public et à différentes échelles (la recherche par rapport aux impacts du réseau). La théorie principe-agent et le triangle stratégique de la valeur publique ont été utilisés pour identifier les contrats principe-agent qui se chevauchent et qui sont multi-niveaux pour déléguer la création de valeur publique dans la science arctique. Les résultats montrent que l'adoption de modèles en réseau de gouvernance scientifique correspondait à une tendance à confier les rôles de gestion de la valeur publique aux acteurs de la recherche scientifique dans l'Arctique; Cependant, il demeure incertain comment les éléments essentiels de la gestion de la valeur publique ont été réalisés. Cette thèse présente de nouvelles perspectives sur la nature complexe, en réseau et multidimensionnelle de la gouvernance de la recherche scientifique dans l'Arctique au Canada, soulevant des questions importantes sur la façon dont les efforts de recherche financés par l'État peuvent être conçus pour accroître la valeur publique, avec des implications potentielles pour la conception et l'exploitation stratégiques des efforts de recherche dans l'Arctique, ainsi que pour la politique régionale de recherche et d'innovation.

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I dedicate this work to those who come next, to those who will help guide Arctic science in the pursuit of improved public value creation.

> *"You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete." Buckminster Fuller*

Contributions to Knowledge

This dissertation provides original scholarship and evidence in support of scientific research governance approaches that can help to enhance science-informed innovation and public value outcomes in the Canadian Arctic. Since this thesis follows a manuscript-based format there is some repetition in the text.

Chapter 2

- Identifies key challenges with promoting coordinated science and innovation governance across multiple, fragmented, evolving, and nested boundaries in the Canadian Arctic.
- Introduces the inclusive concept of innovation ecosystems to discuss the potential for an expanded, systems-based model to help garner a more complete understanding of the dynamic relationships that promote innovation and public value creation processes in the Canadian Arctic.

Chapter 3

- Presents new insight into the networked nature of collaborative scientific research designed to promote innovation and create public value in the Canadian Arctic.
- Identifies the central role that non-local public sector actors have played in an Arctic scientific research network, calling attention to the boundary spanning and entrepreneurial roles that academics occupy in support of network building and cross-boundary linkages.
- Shows how the less central, local/Northern actors gained an increasing propensity for carrying out boundary spanning roles and closing structural holes in the network, supporting calls for policies that facilitate more central network roles for local actors.

Chapter 4

- Provides an in-depth examination of the network-level public values articulated by an Arctic scientific research network and identifies the diverse publics/stakeholders targeted by network-level actions.
- Proposes novel network-level evaluation strategies that may help to better assess the dynamics of network-level public value creation.

Chapter 5

- Assesses the multi-level and overlapping principal-agent relationships through which public value management is delegated within an Arctic scientific research network.
- Illustrates that networked models of Arctic science governance correspond with a trend towards contracting public value management roles to Arctic scientific research actors without clarifying how core elements of public value management (i.e., identifying public value, political legitimacy, and operational capacity) are to be realized.

Author Contributions

This dissertation follows a manuscript-based format and I affirm that I am the primary author for all chapters included. In the case of co-authored articles, I am the first author. Chapters 2, 3, 4 and 5 are co-authored with my supervisors Prof. Gordon M. Hickey (McGill University) and Prof. Laurens Klerkx (Wageningen University). Prof. Hickey and Prof. Klerkx provided academic supervision, intellectual input, methodological and theoretical support and writing support for all chapters. Chapter 2 has been published in *Arctic Yearbook* (2017) and Chapter 3 has been submitted to *Arctic* and is under review (March 2020). Chapter 4 has been prepared for submission to *Research Evaluation* and Chapter 5 has been prepared for submission to *Science and Public Policy*. Several of the discussion points around innovation ecosystems that are introduced in Chapter 1 and discussed in Chapter 6 have been published in an article co-authored with my supervisors and re-interpreted for the Arctic context. See:

> Pigford, A. A. E., Hickey, G. M., & Klerkx, L. (2018). Beyond agricultural innovation systems? Exploring an agricultural innovation ecosystems approach for niche design and development in sustainability transitions. *Agricultural Systems*, *164*, 116-121.

Chapter 1. General Introduction

1.1 Background

The Arctic comprises one of the world's most important emerging and dynamic regions. Diverse assessments suggest that the Arctic is facing a series of unprecedented, parallel, and multi-level pressures that challenge the integrity of existing social, political, and environmental systems (Arctic Monitoring and Assessment Programme, 2019; Graybill & Petrov, 2020; Kofinas et al., 2005; Overpeck et al., 1997; Steinberg et al., 2015; Wehrmann, 2016). For example, Arctic governments are increasingly faced with addressing complex challenges related to sustainability, climate change, governance, changing livelihoods, national security, economic expansion, infrastructure, and community wellness (Chapin III et al., 2004; ISAC, 2020; Kofinas et al., 2005; Pelaudeix, 2012). Within this context of change, innovation[1] has been identified as a potential avenue to support sustainable development and improved policy outcomes (Exner-Pirot, 2018; Hall, 2020; Healy, 2017). Such innovation is broadly understood as being a social, co-evolutionary process that results from co-learning, collaboration, and interactions between multiple actors (e.g., universities, research, and public organizations, knowledge infrastructures, the private sector, local knowledge holders, and other end-users) (Braun, 2008; Clark, 2002; Hall, 2007; Klerkx et al., 2017; Nelson, 1993). While innovation can be driven by many different factors and actors, this thesis focuses primarily on science-informed innovation efforts.

It is well recognized that scientific research often plays an important role in informing innovation efforts that can improve collective societal outcomes (McNie, 2007). To be effective,

[1] Innovation is both 1) the process whereby ideas are transformed into something new and 2) the novel outcomes of such processes, such as a product, service, policy or practice (Baregheh et al., 2009; Borrás & Edquist, 2013). Innovation can include the production or recombination of knowledge, transformation of new knowledge into artifacts, and the continuous adjustment of artifacts to market changes (Bathelt, Feldman, & Kogler, 2012).

science-informed innovation requires the establishment of systematic and effective links between a diversity of actors and activities (Owen et al., 2012; Wittmayer & Schäpke, 2014; Youtie et al., 2017). For example, scientific researchers are often required to collaborate with local policy actors that have knowledge related to processes (like decision making procedures) and other content expertise (e.g., local and traditional knowledges) in order to contribute towards innovation (McNie, 2007; Schut et al., 2013). Arctic scientists often work alongside a diverse range of stakeholders and Indigenous rights-holders[2] who come together to access information and make decisions on Arctic issues that span multiple geographic, administrative, and cultural boundaries (Nilsson & Koivurova, 2016; Pigford et al., 2017; Wong et al., 2020). Co-occurring knowledge systems often come together, drawing Indigenous knowledge alongside technological and scientific domains to help inform pathways to innovation (Healy, 2017). Canadian examples include the co-development of more resilient boats for Northern waters, the experimental re-establishment of an Indigenous commercial fishery (SCC, 1991), the use of geospatial technology and Inuit knowledge to create maps to promote safer travel (Sheremata et al., 2016), the creation of a mobile platform to share information about traditional knowledge, safety, and weather (Arctic Eider Society, 2019), and co-designed recommendations to support low impact shipping corridors (Olsen et al., 2019).

While these examples speak to the possibility of science-informed innovation in the Arctic, there remains a general lack of understanding about Arctic innovation processes (Exner-Pirot, 2018; Hall, 2020) and even less information concerning how Arctic scientific research is embedded within Arctic innovation processes (Kofinas et al., 2020). Overall, there have been relatively few northern-specific innovations despite significant and sustained public investment in

[2] Indigenous people who have constitutionally protected rights in Canada.

northern science (Coates & Poelzer, 2014; Exner-Pirot, 2018). Additionally, Arctic residents have consistently reported that research investments and science governance processes do not necessarily support the types of scientific research that can address community needs nor foster local innovation (Audla & Smith, 2014; Brunet et al., 2016; GY, GNWT &, GN, 2016; Healy, 2017; Ibarguchi et al., 2018; ITK, 2016, 2018; Ogden et al., 2016). These gaps raise key questions about the public value[3,4] and role of Canadian Arctic scientific research, as well as the associated governance processes that are intended to promote innovation and support sustainable development. In what follows I provide additional background to set the scene for the thesis and the topics it addresses, exploring issues related to Canadian Arctic scientific research governance, the need for systems approaches to understand innovation processes, and reflexive science governance approaches that promote transdisciplinary networks and boundary spanning.

1.1.1 Problems facing Arctic science governance in Canada

As a region undergoing concurrent environmental and social change, the Arctic is quickly becoming one of the most researched contexts in the world (ITK, 2018; Nilsson & Koivurova, 2016; Bone, 2012). In Canada, there has been intensive investment in Arctic research, driven in part by natural resource exploration, economic development, northern sovereignty, relationships with Indigenous people and international circumpolar geo-politics (Borgerson, 2008; Nicol, 2016). The vast majority of Arctic research has focused on the natural sciences with less investment in

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[3] Public value is a multifaceted concept that consists of (1) what is valued by the public or is good for the public (that which can be created) and (2) what strengthens or adds value to the public sphere (that which can be delivered) (Benington & Moore, 2011b; Moore, 1995). The public value of scientific research can extend beyond academic and economic considerations (e.g. publications and return on investment) to also include social, political, cultural, health and environmental aspects of value (benefits, quality, relevance) (Joly et al., 2015).

[4] The public value concept is further unpacked in Section 1.4.

the social sciences, resulting in limited insight into socio-economic and innovation challenges (Bastmeijer, 2018; Coates, 2020; Giles, 2015; ITK, 2018; Mineev et al., 2020; Ogden et al., 2016). This gap may, in part, be why relatively little is known about how Arctic science is governed or organized and how it fits within or contributes to innovation efforts in the region. While this is a general challenge facing Arctic research internationally, a lack of research on the connections between science governance and innovation processes is particularly evident in Canada.

Based on the assumption that scientific research will translate into Arctic innovation, the Canadian government has allocated substantial public resources to support Arctic scientific research since the 1960's (Nicol, 2016; Ogden et al., 2016; SCC, 1968; Task Force on Northern Research, 2000). For example, in response to the release of a report in 2000 claiming that Canada was on the verge of failing to meet its northern commitments because Canadian Arctic science was in a state of crisis, Canada made substantial investments in science with the goal of stimulating innovation in the Arctic (Institute On Governance 2005; Task Force on Northern Research, 2000). These efforts reflect a notion that scientific research has long been central to the Canadian Arctic narrative (Bocking, 2007, 2010; Gearhead & Shirley, 2007; ITK, 2018) and has largely been driven by the idea that *"Science has much to offer in the quest to make sure that the full economic potential of Canada's North is realized and that the cultural life of the population of this area is enriched"* (SCC, 1968). Despite these efforts, and the potential value of ongoing government innovation investments (Hall, Leader, & Coates, 2017), existing Arctic science and innovation efforts have not always been evidently useful (SCC, 1991) and the efficacy of the adopted science-innovation approach remains largely unknown.

The few existing evaluations of the Canadian Arctic research landscape have focused on economic flows and offer preliminary insights into the flow of financial resources from federal funding agencies to Arctic research projects, academics, and communities (Carr et al., 2013; Ibarguchi et al., 2018; Mallory et al., 2018). Arctic residents have also identified that the approaches adopted by Canadian governments have not been working as intended, suggesting that Arctic scientific governance may lack the flexibility needed to support the needs of the Arctic community (Burn, 2008; ITK, 2018; Ogden et al., 2016). This may be due, in part, to entrenched and/or conflicting institutions[5] that guide systems of research reward and evaluation, causing a range of direct and indirect outcomes. For example, Arctic research is situated in both traditional academic institutions (e.g., training students, generating high-quality scientific research) and emergent institutions linked to community-based research approaches (e.g., community engagement, relationship building, meaningful outcomes) (Cournoyea et al., 2014; Pigford et al., 2018; Tondu et al., 2014). Additionally, Canada's lack of an integrated, national approach to Arctic scientific research has led to an inherently fragmented and uncoordinated science and innovation landscape (England, 2010; Institute On Governance 2005; ITK, 2018; Obed, 2016, 2018; Pigford et al., 2017; Pyc, 2000; Task Force on Northern Research, 2000). Given the dynamic and multi-layered institutional contexts within which Arctic scientific research operates (Pigford et al., 2017), this thesis aims to contribute to an improved understanding of the systems that support or inhibit science-informed innovation efforts.

1.1.2 Systems approaches for understanding science-informed innovation

Recognizing that the process of using scientific knowledge to inform innovation is highly complex, this dissertation adopts a systems approach to better consider complexity and the associated factors

[5] Institutions are the 'rules of the game,' which are formed through the uneven patching together of old practices, accepted norms and new arrangements (Cleaver, 2012).

that may affect science-informed innovation (Allison & Hobbs, 2006). Although there is a growing interest in assessing and communicating the diverse impacts of scientific research across the Canadian research system (Severinson, 2017), few studies have taken a systems approach to enrich our understanding of how scientific research may or may not support public value creation in the Canadian Arctic.

Drawing on the emerging concept of innovation ecosystems, defined as *"a multi-level, multi-modal, multi-nodal and multi-agent system of systems"* that influences the way that societies generate, exchange, and use knowledge (Carayannis & Campbell, 2009), this dissertation employs innovation ecosystems thinking to help understand science-informed innovation in the Arctic. Innovation ecosystems thinking offers an inclusive way to conceptualize and highlight the multiple inputs, actors, networks, institutions, and enabling factors that come together to foster innovation. Using an ecosystem analogy, it emphasizes the range of actors and common pool resources available to support innovation, while concurrently highlighting the collective and relational dimensions of the system (Jackson, 2011). It also argues that innovation-based value creation efforts and resources must be gathered around local strengths (Oksanen & Hautamäki, 2015), which is in-line with calls to respect traditional Indigenous knowledge (Ford et al., 2015; ITK, 2007; Tagalik, 2010; Wandel et al, 2011) and the collaborative models of research being employed in the Arctic [e.g., participatory (Brunet et al., 2016; Edwards et al, 2008; Provencher et al., 2013; Vlasova & Volkov, 2016) and capacity building (Arctic Council, 2013; Carter et al., 2019; Kwiatkowski et al., 2009; McCarthy et al., 2012)]. Figure 1.1 presents a summary of the main elements that may shape science-informed Arctic innovation ecosystem processes. For an enhanced description of innovation ecosystems thinking, please refer to Section 1.4.3.

Innovation ecosystems thinking also has the potential to facilitate understandings of value creation processes (Adner & Kapoor, 2010; de Vasconcelos Gomes et al., 2016), as it can shed light on innovation governance, definitions of value, negotiated boundaries between actors, coordination mechanisms, and how science policy is mobilized to support innovation. Although the value created through innovation ecosystems can be of a public or private nature, the innovation literature has largely focused on private sector outcomes (Hartley, 2011, 2015). This thesis focuses on the creation of value in the public sphere (for a definition of public value, see page 3). Understanding how public value gets created requires a reflection on how actors, organizations, rules, knowledge, and other resources come together (Benington & Moore, 2011a; Moore, 1995), which can lead to the formation of a 'successful' innovation ecosystem. The process of creating and delivering public value is further elaborated on in Section 1.4.1. Since Arctic scientific research often addresses complex issues that inherently span multiple geographic and administrative boundaries, an improved understanding of scientific research governance and the mechanisms that can facilitate boundary spanning and coordination between actors in the innovation ecosystem to create public value is required (Petrov et al., 2016).

Figure 1.1 Conceptualizing the factors that may shape Arctic innovation ecosystem processes

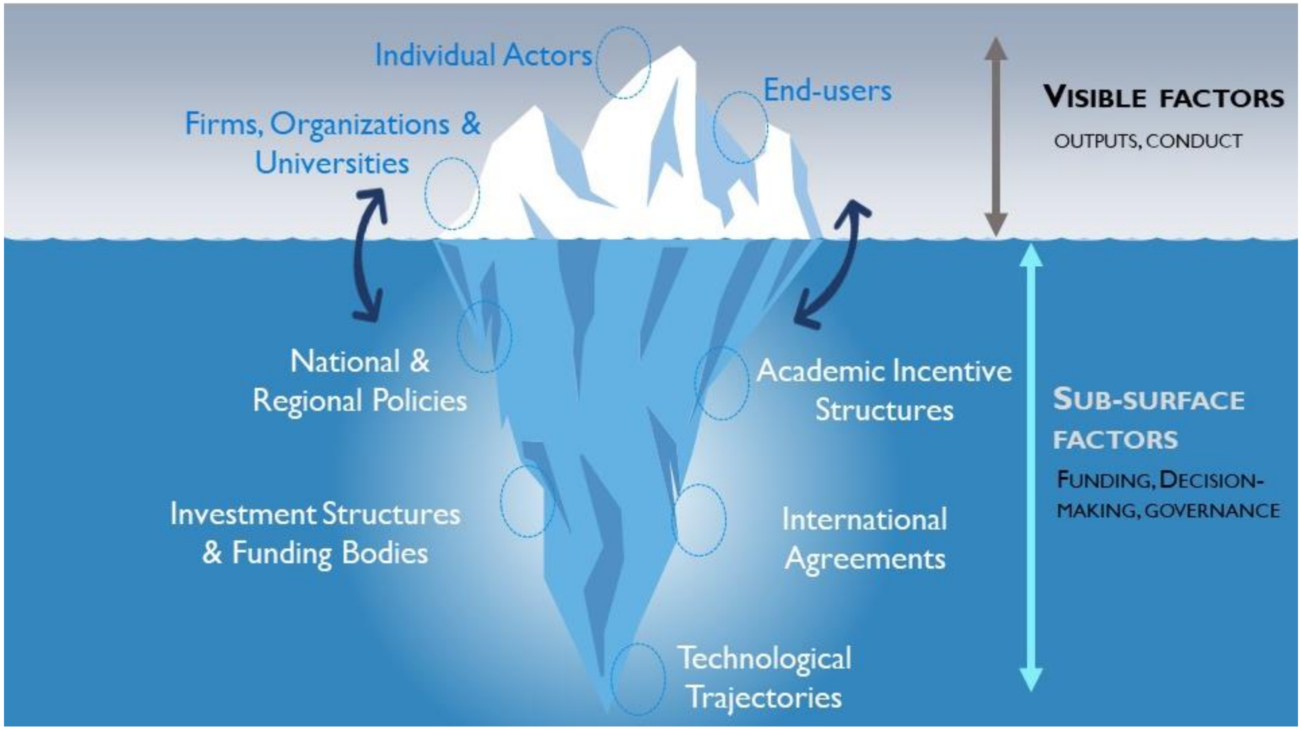


Figure 1.1 presents a summary of the key factors that may shape science-informed Arctic innovation ecosystem processes. Innovation ecosystems include the dynamic and interactive networks that shape the way that societies generate, exchange, and use knowledge (Carayannis & Campbell, 2009). The 'visible' factors relate to systems outputs and the way research is conducted. Sub-surface factors are more nuanced than those above the surface and link to underlying institutions which may guide systems outcomes.

Modified from: https://www.showeet.com/04/02/2013/charts-and-diagrams/iceberg-diagram-for-powerpoint

1.1.3 Reflexive science governance and network approaches for boundary spanning

Science governance[6] plays an important role in organizing the production, dissemination, and application of information; however, it has generally struggled to address key innovation concerns. For example, it is recognized that the Arctic has struggled with building effective science and innovation governance capacities (Fleming & Pyenson, 2017; Kofinas et al., 2020). In general, science governance has largely focused on how best to allocate funding and resources among existing research programs rather than focusing on the societal implications of such decisions and broader capacities linked to effective governance (Macnaghten & Chilvers, 2014; Sarewitz & Pielke, 2007). This limited scope may be related to a general lack of strategies designed to facilitate and promote reflexivity in the scientific research enterprise (Keeler et al., 2017; Miller et al., 2011; Sarewitz & Pielke, 2007). Reflexivity highlights, *"the understanding that the institution itself is part of the dynamics of the system that it seeks to change, thus it continually re-examines and re-evaluates the foundational assumptions of its work by 'opening up' its boundaries to multiple representations and discourses outside the institution"* (Miller et al., 2011). By inviting multiple configurations and interpretations, reflexive activities such as monitoring, assessments, and evaluations can help to support an iterative process of re-adjusting principles, goals, and processes in support of public value creation (Macnaghten & Chilvers, 2014; Miller et al., 2011).

Complex problems, whereby no one discipline or knowledge holder can have enough relevant knowledge or skills to effectively address the issues, require transdisciplinary approaches (both within science and between science and other stakeholders) (Beebeejaun et al., 2015; Roux, et al., 2010). However, society can only reap the benefits of scientific research that has been

[6] Governance can broadly be understood as the result of the interaction between multiple actors seeking to define collective problems, formulate goals, and coordinate strategies to solve these problems (Voß & Kemp 2006).

transformed by a series of actors into accessible products, services or processes (Bornmann, 2013; Joly et al., 2015). Therefore, approaches capable of linking diverse actors from different formal disciplines and sectors (often in new combinations) into coordinated networks are considered key for innovation and addressing complex challenges (Haley, 2017; Roux et al., 2010). For example, transdisciplinary research networks are often comprised of heterogeneous actors in order to enable the crossing or merging of multiple conceptual, epistemological, cultural, and institutional boundaries (de Raymond, 2018). Importantly, it is the way in which these actors negotiate such boundaries that will shape the types of problems that can be addressed (Felt et al., 2016). In order to generate scientific knowledge in the context of application, there is therefore a recognized need to support and enhance coordination across boundaries in the scientific research system (Schneidewind et al., 2016).

Since the boundaries of science can be sustained, enlarged, enforced, breached, and at times erased (Gieryn, 1999), there is a need to further consider how Arctic researchers coordinate across boundaries. Boundaries in transdisciplinary scientific research are reflected by constraining and enabling environments that are framed by institutionalized norms, communication networks and systems of reward and evaluation (Gieryn, 1999; Miller et al., 2011). This makes it important to consider the different institutions within which research organizations are embedded (Klerkx et al., 2017), the patterns of power relations and knowledge utilization (Sternlieb et al., 2013), as well as the evolving nature of boundary arrangements, which tend to result from defining relationships between scientific and other 'non-scientific' actors (Hoppe, 2010; Schut et al., 2013). Group dynamics, relationships, trust, and social capital have all been found to influence the way that the interfaces between science and policy are navigated in innovation systems (McNie, 2007). A range of concepts have subsequently been used to capture the different actors that play a role in ‘connecting’ actors and networks across the various boundaries of science (e.g., intermediaries, innovation brokers, boundary spanners or boundary organizations) (Braun, 2003; Hoppe, 2010; Schut et al., 2013; Wittmayer & Schäpke, 2014).

This thesis focuses particularly on of the role of ‘boundary spanning’ actors, which foster connections in support of innovation (Sternlieb et al., 2013). Boundary spanning is defined as *“work to enable exchange between the production and use of knowledge to support evidence-informed decision making in a specific context*,” while boundary spanners are the “*individuals or organizations that specifically and actively facilitate this process*” (Bednarek et al., 2018 p 1176). Boundary spanning actors function at the interface between science and decision making to negotiate and facilitate the communication and integration of research findings between knowledge suppliers and users (Guston, 1999). According to Guston (2001), these actors can span various boundaries through different forms of interaction which evolve as innovation processes unfold, linking actors from universities, non-university research institutes, government research departments, administrative agencies, policy advisors and other relevant political authorities.

1.2 Research Opportunity

In general, there has been increasing pressure for science to adopt more applied and engaged roles to help inform innovation in support of public value creation (McNie, 2007; Turnhout et al., 2013). This pressure is particularly relevant in the Arctic where there have been repeated calls over the last decade to strengthen and restructure the science-policy interface (Fleming & Pyenson, 2017; Kofinas et al., 2005; Tesar et al., 2016). As a result, a growing number of collaborative efforts have been commissioned to promote coordinated action and capacity building in order to facilitate improved linkages between science and meaningful regional outcomes (e.g., University of the

Arctic, the International Arctic Science Committee, Canada's ArcticNet, EU PolarNet, the Arctic Council's Scientific Cooperation Agreement). However, while Arctic science approaches often promote concepts and language around networks, there has been limited application of network methods to analyze governance patterns (Kofinas et al., 2020). Further, despite ongoing and increasing investments, there have been few empirical studies into how collaborative Arctic scientific research is governed in relation to achieving Arctic innovation objectives and creating public value (see Section 1.11).

In order to broadly assess the embedding of Arctic scientific research in innovation and value creation processes, it is necessary to move beyond linear/stepwise approaches (i.e., those that presuppose that knowledge, once generated, will passively diffuse and benefit society) towards systems approaches that better consider and accommodate the complexity inherent in Arctic research (see Section 1.1.2). Such approaches will need to promote reflexive science governance that considers the dynamic collaborative networks that shape who produces and uses Arctic scientific knowledge, the ways in which actors interact, and how they coordinate across negotiated boundaries (see Section 1.1.3). Since there has been insufficient systematic inquiry into these core aspects that shape Arctic scientific research governance, there is ample opportunity to improve our understanding of the systems and processes that inform how Arctic research is transformed and integrated into meaningful public value outcomes.

1.3 Research Objectives and Questions

Adopting a systems-based approach, my research aims to explore the diverse linkages and intersections that exist among scientific research *actors, networks, and institutions* operating in the Canadian Arctic to better understand how they influence science-informed innovation in support of public value creation. The thesis also aspires to generate knowledge that can inform future policy and practice. My research broadly seeks to answer the question: *how does networked scientific research designed to support innovation shape public value creation in the Arctic?* This guiding question forms the basis for the following four research objectives, each of which informs a chapter in this thesis. Each objective is associated with a broad research question:

- Conceptualize and frame the innovation challenges and opportunities facing Arctic scientific research in Canada using systems thinking to better understand the public value of Arctic scientific research (Chapter 2).
  - *What is known about the systems that support or inhibit science-informed innovation in the Canadian Arctic and how can innovation ecosystems thinking enhance understanding about the public value of Arctic scientific research?*
- Characterize and describe the collaborative network structure of science-based innovation actors in the Canadian Arctic (Chapter 3).
  - *How do diverse science-based innovation actors interact and foster boundary spanning within a large Arctic scientific research network?*
- Capture the network-level public values articulated by an Arctic scientific research network and identify considerations for network-level evaluation (Chapter 4).
  - *What are the network-level public values associated with networked Arctic science and how does adopting the network as a fundamental unit of assessment shape opportunities for network evaluation?*
- Examine the delegation dynamics associated with public value management roles in principal-agent contracts for networked Arctic science (Chapter 5).

- *Who is responsible for public value management in a large Arctic scientific research network mediated by a NAO?*

1.4 Conceptual Foundations

This section further elaborates on the three main concepts that serve as the conceptual foundation for the thesis. Each chapter also draws on complementary theories and concepts, which are further detailed in the respective literature review sections (Chapter 3: innovation in peripheral regions, Chapter 4: network administrative organizations, and Chapter 5: principal-agent theory).

1.4.1 Public value

The public value concept first emerged in 1995 when Moore (1995) developed a conceptual framework for public sector managers to encourage strategic thinking and entrepreneurial activity in order to address complex public challenges. Public value has since been applied and critiqued within several fields of research, including ecology, economics, philosophy, political science, and public administration and management (for more details see Benington & Moore, 2011b). While the concept has been informed by the literature on co-production, collaboration, innovation and developing responsive institutions (Liddle, 2018), there is limited empirical research on the topic (Hartley et al., 2017).

The core tenant of the public value framework is that the public sector, often government, has an important role in society for creating public value and proactively shaping the public sphere (politically, economically, socially, and culturally) (Benington & Moore, 2011b), which can support continuous improvement in public services and outcomes (Faulkner & Kaufman, 2018). The concept positions ‘public managers’ as active agents in seeking and creating value for the public, while delivering it in an efficient, effective, and accountable way (Bryson, Crosby, &

Bloomberg, 2015; Moore, 1995). While public value thinking contends that value can be created in many ways, three interdependent processes are identified as necessary for creating public value: defining public value by clarifying and specifying strategic goals (identifying public value), creating the authorizing environment necessary to achieve the desired public value outcomes (political legitimacy), and building operational capacity to use resources (operational capacity). Together these three elements form 'the Strategic Triangle', which public sector actors are therefore responsible for bringing together (Moore, 1995). The Strategic Triangle can be used to diagnose existing situations, help to structure thinking about ideal value creation processes, and it also offers categories to analyze public sector service delivery (Alford & O'Flynn, 2009).

Public value scholarship recognizes that the needs and problems facing citizens, communities and governments are complex and diverse rather than simple (Benington & Moore, 2011b). Public value offers an adaptive, deliberative process that is more democratic and acknowledges competing interests, the need to debate and negotiate, providing a conceptual framework to guide the emergent paradigm of network governance (see Section 1.4.2 for more details on network governance) (Benington, 2011; Koliba et al., 2018). While networked governance illustrates a shift away from centralized governance towards the inclusion of civil society and other relevant actors, public value asserts that public sector actors are still responsible for bringing together the network of partners and stakeholders and negotiating different interests and agencies (from across the public, private, voluntary, and informal community sectors) and to support them in achieving their goals (Benington & Moore, 2011b). Thus, the public value concept can help to derive insight into how networks contribute to the benefits and costs of creating effective public services (Benington, 2011; Benington & Moore, 2011a; Moore, 1995).

It has been argued that networked public sector actors need to adopt champion and leadership roles that allow them to facilitate collaborative processes in order to promote innovation and create public value (Crosby et al., 2017; Faulkner & Kaufman, 2018). For example, it is generally expected that governments and other public organizations use policy instruments to formally oversee processes for defining and implementing science and innovation agendas (Borrás & Edquist, 2013; Martin, 2016). Thus, governments are often tasked with coordinating resources from various sources (e.g., private sector, the civil society sector, and the state) to find and support common priorities (Benington & Moore, 2011b; Moore, 1995; Stoker, 2006). It is therefore important that public sector organizations adopt flexible, innovative, or creative approaches for creating and delivering public value while also seeking to improve the efficiency, effectiveness, and responsiveness of public organizations (Benington & Moore, 2011b). This need for flexibility is relevant for promoting value creation among publicly-funded scientific research, which may not always be supported by existing institutional policies and practices (Doern & Stoney, 2009).

Expectations that scientific research should support innovation and contribute towards practical solutions aligns with increasing demand for scientific research that creates public value (Potvin & Armstrong, 2013). However, it has been argued that public value is often *"displaced, minimized, misrepresented or altogether missing"* in publicly-funded science programmes (Bozeman & Sarewitz, 2011). Such 'public value failure' may occur because the demand for scientific excellence and economic value take priority, often overlooking the non-scientific and non-economic goals that constitute broader public value creation (Bozeman & Sarewitz, 2011). Further, scientists are often unaware that their research has societal impact (Bornmann, 2013) and the public value concept has rarely been operationalized in scientific contexts. A public value analytical approach that emphasizes a variety of public values (e.g., social, cultural, environmental, economic value) and value creation processes rather than focusing explicitly on inputs and outputs (e.g., research findings) is needed (Benington, 2011; Bornmann, 2013). For my research, the creation and delivery of public value through scientific research is assumed to be collaborative, multidimensional and inclusive of transdisciplinary innovation ecosystem actors with various roles, as well as being a non-linear process (Joly et al., 2015). This dissertation largely views public value as an administrative concept focused on conceptualizing the management of common resources (Chapters 2-5), while also employing it as an analytical heuristic through Public Value Mapping (Chapter 4) and the Strategic Triangle (Chapter 5).

1.4.2 Network governance

A network emerges when multiple actors that often span sectors and scale collaborate to exchange ideas, build relationships, identify common interests, and work together to solve common problems (Koliba et al., 2018; Scarlett & McKinney, 2016). They are characterized by flexible, inclusive, interdependent structures that allow public agencies to leverage outside expertise in order to manage complex policy problems (Agranoff, 2007; Isett et al., 2011; Klijn & Koppenjan, 2015). The establishment of a collaborative network can lead to improved policy outcomes by: 1) addressing difficult policy problems that no one organization can tackle; 2) overcoming the limitations on direct government intervention; 3) recognizing the need for broad coalitions of interests to overcome political imperatives to solve problems; 4) capturing second order effects that create interdependencies; and 5) coping with layers of mandates and requirements (Agranoff, 2007; O'Toole, 1997).

As an important form of multi-organizational governance, network governance aims to address the limitations associated with traditional views of government roles, responsibilities and structures, which have been unable to account for the complexity inherent in modern policy systems (Koliba et al., 2018). Although governance networks are still largely steered by governments (Ojo & Mellouli, 2018), there has been an increasing trend towards devolving authority, privatizing, and contracting out services, as well as adopting partnership models (Koliba et al., 2018). In contrast to public management paradigms associated with hierarchical (traditional public management) or market (new public management) approaches (Dedeurwaerdere, 2007; Stoker, 2006), network governance presents a way of organizing economic and public activities in a way that optimizes a mix of vertical/horizontal coordination, as well as control and command approaches, competition and collaboration (Skeberdytė, 2014) (see Table 1.1). This approach to conceptualizing governance activities relies on a range of public sector governments and agencies working alongside non-state stakeholders in public, private and civic spheres in order to deliver deliberative decision-making processes (Provan & Kenis, 2008; Robinson et al., 2019). Effective network governance can enhance learning, lead to more efficient use of resources, improve competitiveness, and facilitate the creation of products and services that deliver public value (Provan & Kenis, 2008).

Table 1.1 The emergence of networked governance in public administration

	Traditional Public Administration	New Public Management	Networked (Community) Governance
Theory	Public goods, political theory	Public choice, economic theory	Public value, democratic theory
Actors	Public servants	Clients, contractors	Civic leaders
Strategy	State – Producer	Market – Customer	Shaped by civil society
Population	Homogenous	Atomised	Diverse
Governance via	Hierarchies	Markets	Multifaceted networks, partnerships
Context	Stable, straightforward	Competitive, via market	Changing, complex, volatile
Role of government	Rowing: designing and implementing policies and programs in response to politically defined objectives	Steering: determining objectives and catalyzing service delivery via tool choice, markets, businesses & non-profits	Convener, Catalyst, Collaborator: Sometimes steering, sometimes rowing, sometimes partnering, sometimes staying out of the way
Role of manager	Ensure rules and procedures are followed	Help define and meet performance objectives	Active role in helping create and guide networks of deliberation and deliver and maintain accountability and capacity of system

Adapted from Benington 2011, Bryson 2014, and Stoker 2005.

Network governance processes have been identified as having the potential to unlock innovation and facilitate the co-production of public value (Bathelt et al., 2012; Bland et al., 2010; Skeberdytė, 2014). Since knowledge and skills are often distributed across multiple actors, collaborative networks and knowledge exchanges can act as a catalyst to transform knowledge from several sources into innovation (De Noni et al., 2018; Klijn & Koppenjan, 2015; Ritala & Almpanopoulou, 2017). Formal scientific networks are typically large organizations that draw together collaborative teams of academic and partner organizations (e.g., representatives from the state, the private market, civil society, and informal community organizations) and are particularly important for facilitating knowledge transfer and learning in the pursuit of solutions to urgent sustainability problems (Coutinho & Young, 2016; Keeler et al., 2017; Mukhopadhyay et al., 2014). In these governance arrangements research is often assigned a facilitating rather than decisive role, responsible for generating new insights and investigating potential solutions in order to assist other actors involved in decision making processes (Klijn & Koppenjan, 2015). This approach requires research to be responsive to public value needs while connecting knowledge producers and users to answer the questions that emerge during the process of designing and implementing policies (Klijn & Koppenjan, 2015; McNie, 2007; Mukhopadhyay et al., 2014). Thus, network delegation in science calls attention to the need for systems thinking, boundary spanning, knowledge sharing, and the facilitative role governments can play in public value management (Braun, 2003). Therefore, this thesis draws on the concept of network governance to explore how Arctic research networks are created and managed in an evolving governance context, recognizing that the Arctic requires sophisticated public policies to help address key innovation challenges, as discussed in Section 1.1. In this thesis, I examine a scientific research network from the perspective of a network as a collection of collaborative actors (Chapter 3), an administrative unit (Chapters 4, 5), and a structural unit of analysis (Chapter 4).

1.4.3 Innovation ecosystems

Innovation ecosystems consist of nested, transitional, and interdependent networks of actors that evolve as people and organizations come together to produce, use and/or exchange knowledge (Adner & Kapoor, 2010; de Vasconcelos Gomes et al., 2016; Oksanen & Hautamäki, 2015; Ritala et al., 2013; Wang, 2009). These complex systems cross boundaries, connecting various actors and networks in an exchange that is embedded in institutional, socio-cultural, and technical environments (Aarikka-Stenroos & Ritala, 2017). Thus, there is a need to foster innovation environments where scientists, policymakers, producers, end-users, and entrepreneurs can mobilize their collective knowledge and resources to innovate (Oksanen & Hautamäki, 2015). This can be done through the construction of coordinated, multi-actor networks referred to as innovation communities, which consist of a dynamic collection of interconnected actors (e.g., governments, universities, industry, supporting institutions, specialized people, entrepreneurs, the financial system, consumers, civil society, cultural groups) (Adner & Kapoor, 2010; de Vasconcelos Gomes et al., 2016; Wang, 2009).

The pluralism that is inherent in innovation ecosystem communities requires explicit acknowledgment of deep interdependent multi-dimensional relational linkages (Jackson, 2011; Jucevičius & Grumadaitė, 2014; Oksanen & Hautamäki, 2015). Since the success of one actor is considered dependent on the efforts of other actors, innovation ecosystem communities emphasize the resolution of relational, power, and cultural issues within and between the group to ensure that innovation community members operate from a set of common objectives that reflect shared knowledge and skills (Jackson, 2011; Jucevičius & Grumadaitė, 2014). Innovation ecosystems also allow for, and accommodate, the multiple (and at times contradictory) goals that may exist within the ecosystem community (Nambisan & Baron, 2013).

Drawing on an ecosystem analogy, innovation ecosystems also serve to highlight that a range of specialized organisms (i.e., diverse actors/actants) cooperate, feed-off, adapt to, support, compete, and interact with each other and are inseparable from the environment within which they form the (innovation) ecosystem (Jackson, 2011). While Ritala and Almpanopoulou (2017) argue that *"the prefix eco in innovation ecosystems implies a specifically ecological aspect"* (p39), the relevance of the ecosystem analogy has been debated in the context of business and management innovation and is yet to become a rigorous construct (de Vasconcelos Gomes et al., 2016; Oh et al., 2016; Ritala & Almpanopoulou, 2017). Nonetheless, the ecosystem metaphor has helped to broaden the scope and types of innovation ecosystem actors considered to also include actants as contributors to innovation (e.g., technology, software, information, and communications platforms as well as information content) (Chen & Hung, 2016; Kolloch & Dellermann, 2017). By embracing plurality (e.g., actors/actants, scales, networks), multifunctionality, interdependent, and multi-dimensional relational system linkages (e.g., identities, networks, connections, trust, cooperation), innovation ecosystems have the potential to promote 'path-breaking' and systems change by challenging existing ways of approaching challenges (Walrave et al., 2018).

While, innovation ecosystem thinking has yet to formally engage with the research, innovation or development narratives used in the Canadian Arctic, it has been previously identified as being well-suited to help address the types of problems facing other circumpolar Arctic regions (see Andersen et al., 2007; Asheim & Coenen, 2005; Hintsala et al., 2015; Middleton et al., 2020; Oksanen & Hautamäki, 2015). Such an approach may help to expand the frame of innovation to consider the 'ecosystem' level (de Vasconcelos Gomes et al., 2016), which can include the multitude of innovation systems operating in multiple research contexts. To this end, my thesis adopts innovation ecosystems thinking as a way to contemplate the complexity inherent in the nested systems of actors, networks, and institutions that come together to create public value through science-informed innovation in the Canadian Arctic.

1.5 Methodological Approach

I adopted an exploratory case study research design (Yin, 2013), considered appropriate for topics and issues with limited existing knowledge about the processes being studied (Babbie, 2015; Stebbins, 2001). A reflexive approach was also followed by "*…call[ing] into question the foundations of governance itself, that is, the concepts, practices, and institutions by which societal development is governed, and that one envisions alternatives and reinvents and shapes those foundations"* (Voß & Kemp, 2006). By engaging in exploratory, reflexive activities (e.g., monitoring, evaluation, and assessments), it was possible to explore the underlying factors that are contributing towards (un)desirable Arctic science public value outcomes.

This dissertation employs a mixed methods research design that draws on both qualitative and quantitative research approaches (Creswell & Plano Clark, 2007). Mixed methods are well suited for complex research questions (Mertens, 2007) and can foster increased validity among findings, inform secondary data source identification and assist with knowledge creation (Hurmerinta-Peltomäki & Nummela, 2006). I employ a mix of quantitative and qualitative research methods including literature reviews, case studies, key-informant stakeholder interviews, public value mapping and secondary document analyses, further described in each chapter, including their methodological limitations. Each thesis chapter (including measures and objectives) are informed by the findings from previous chapters, allowing opportunities to refine and validate previous findings. See Figure 1.2 and Section 1.8 for more details on the research design and thesis structure.

Case study research enables insight into contemporary phenomena where contextual conditions are relevant and information is limited (Yin, 2013). The case investigation presented in each chapter builds on and complements the chapters that preceded it, each seeking to explore a different aspect of the Arctic innovation ecosystem (Figure 1.3). The second chapter presents a detailed review of the literature and examines the institutional arrangements that shape Arctic science in Canada (Case 1). The remainder of the dissertation (Chapters 3-5) engages the instrumental case of ArcticNet (Case 2), a publicly-funded Arctic scientific research network to examine how diverse linkages influence and intersect with public value creation at three levels of organization: 1) networked scientific research actors, 2) a network administrative organization, and 3) institutional mechanisms for delegating authority.

Data collection consisted of a comprehensive review of publicly available network documentation and a 4-month internship that provided an immersion into network affairs and allowed participant observation for research purposes. As an intern, I participated in staff meetings, provided support for the review of funding proposals and assisted in efforts for a network renewal application. As part of the internship arrangement ArcticNet consented to participating in this research and provided access to select network materials. Of note, much of the data that informed this dissertation is available in the public domain (e.g., financial and annual reports, conference proceedings, and research compendia). To inform research directions, identify resources and contextualize findings, ten key-informant scoping interviews were conducted in late 2018 (McGill Research Ethics Board file 44-0618). Semi-structured interviews (~1.5 hours) focused on key individuals who worked closely on the design and implementation of ArcticNet programming, inclusive of ArcticNet staff and committee members (current and past). Interviews followed a broad interview guide designed to capture general information about ArcticNet, focusing on core institutional and operational mechanisms associated with centers of excellence schemes – design; application, selection and funding; implementation and governance; monitoring and evaluation (Klerkx & Guimón, 2017) (Appendix 1A). To facilitate analysis all interviews were recorded, transcribed, rendered anonymous during the transcription process before being imported into qualitative data analysis software (Nvivo, QSR International, Doncaster, Australia). Inductive content analysis was used to identify common themes among participant responses (Neuendorf, 2016; Vaismoradi et al., 2013).

Figure 1.2 Research design

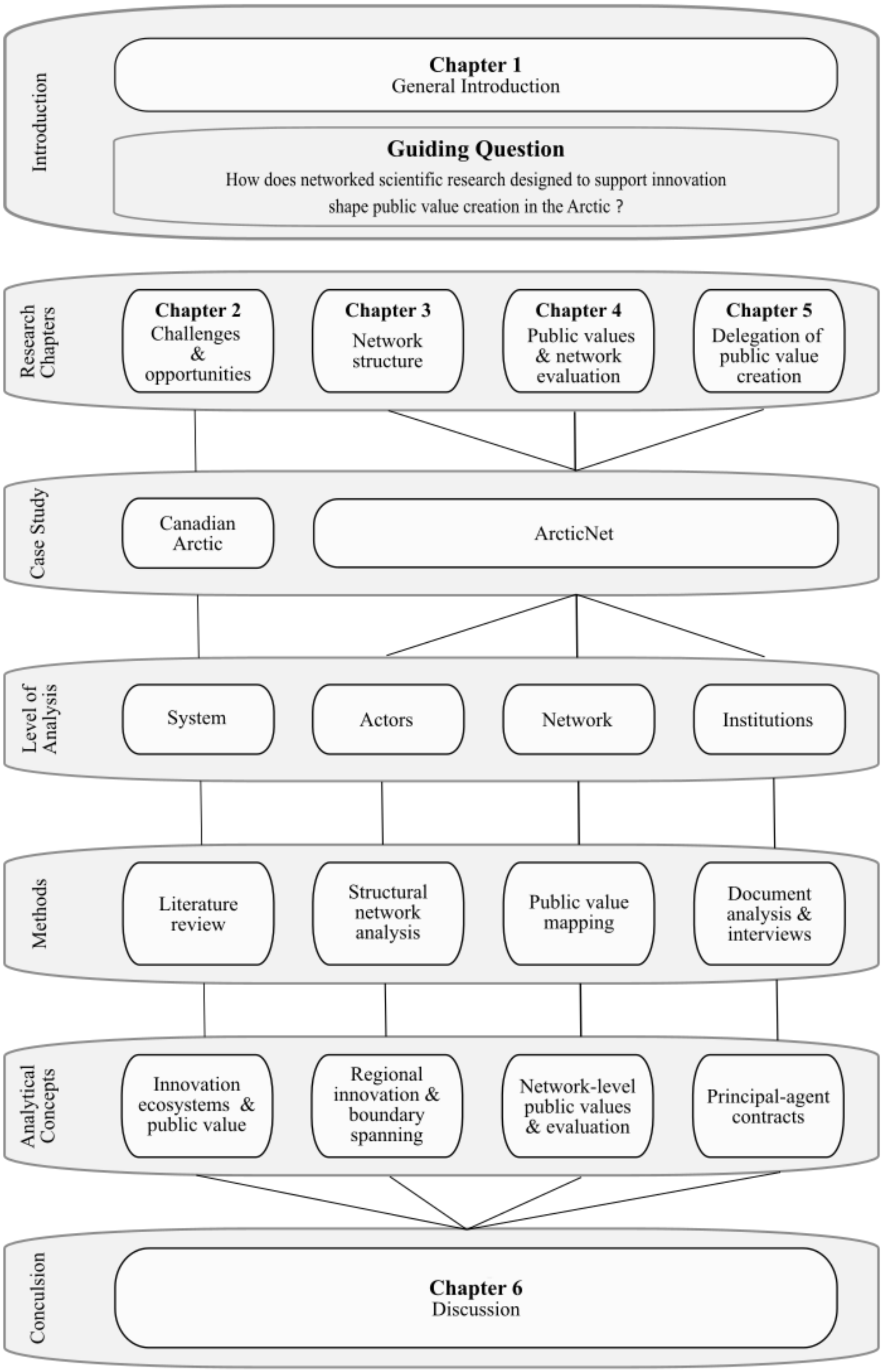


Figure 1.2 presents a visual representation of the dissertation, outlining core aspects of the research design.

Figure 1.3 Visualization of case progression by chapter

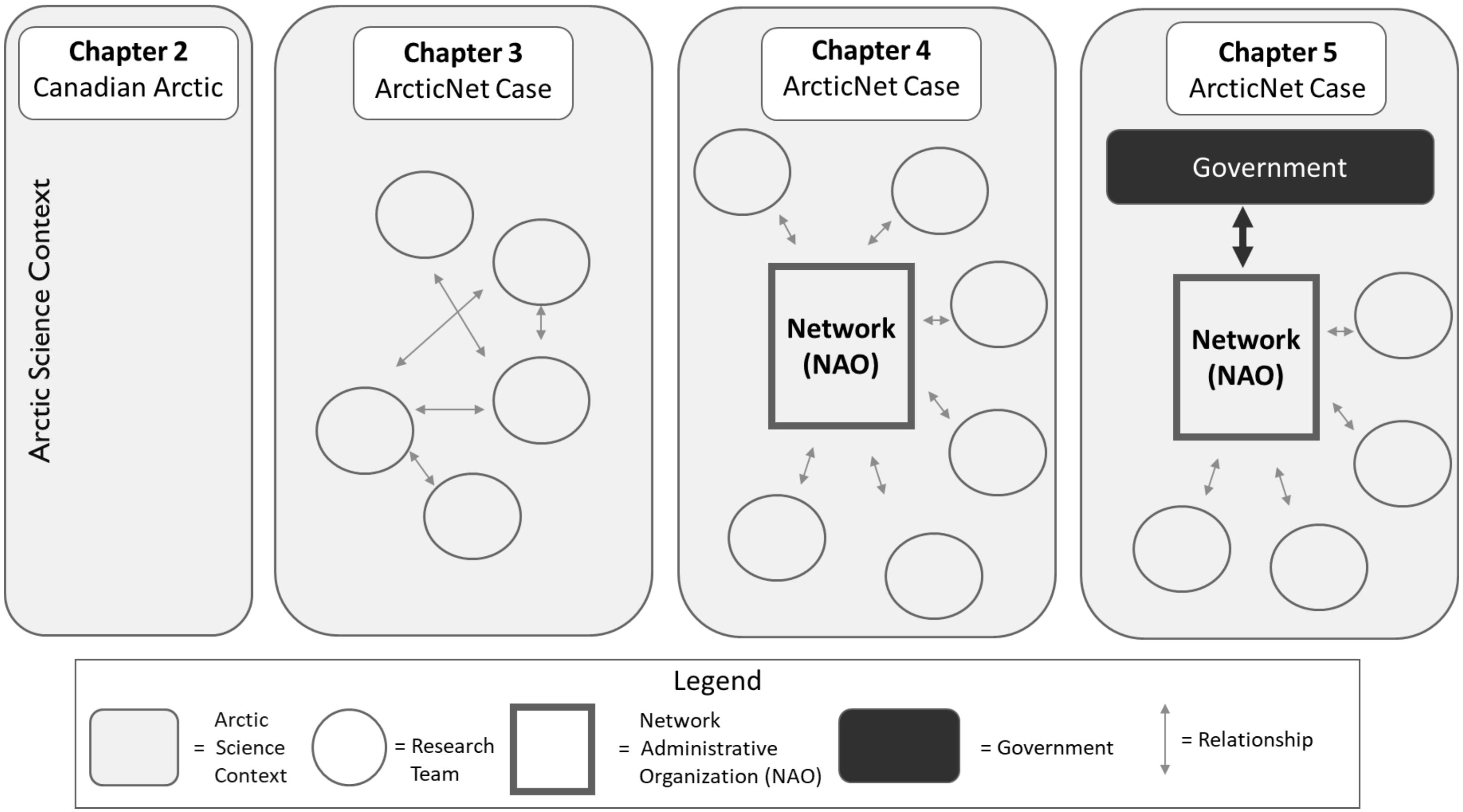
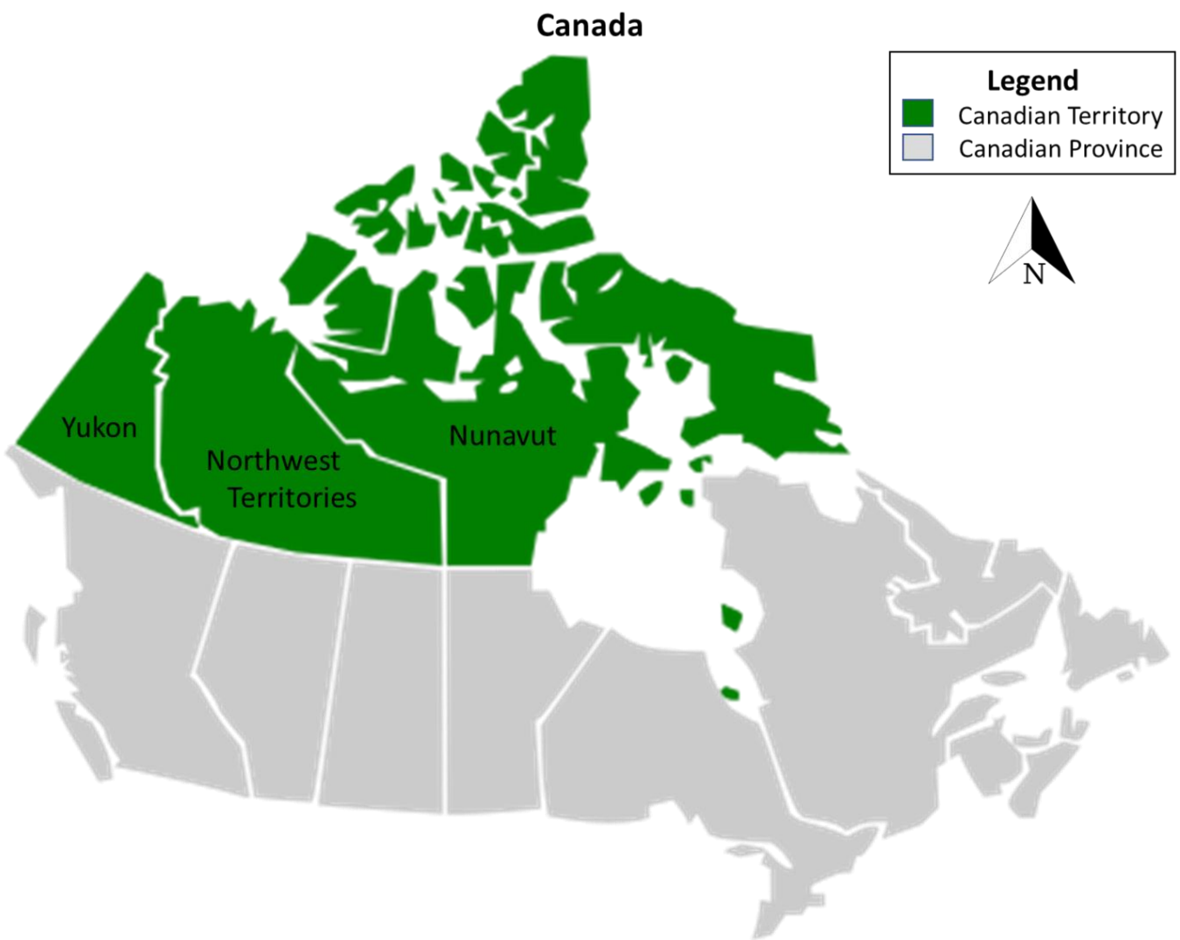


Figure 1.3 illustrates the progression of cases presented in each chapter, each building on the preceding chapter to explore different aspects of the Arctic innovation ecosystem. The thesis begins with an examination of the Arctic science context (Chapter 2), then focuses on collaborative relationships between networked scientific research actors (Chapter 3), moving on to examine the public values associated with a network administrative organization (Chapter 4), and concludes with an examination of institutional mechanisms for delegating authority from government through to research team members.

1.6 Research Setting

This dissertation focuses on the Canadian Arctic, inclusive of the three Canadian territories (Yukon, Northwest Territories, and Nunavut), which account for approximately three percent of the Canadian population and are located primarily north of 60º latitude, spanning northern Canada and covering 40% of Canada's land mass (GoC, 2010), see map in Figure 1.4. While this is not the only accepted definition of the Canadian Arctic, it is the most generic. Chapter 2 explores several additional considerations that have shaped the conceptualization of Arctic in the Canadian context (i.e., Indigenous land claims, territory/province jurisdictions, geographic considerations) (also see Bone, 2012; pp2-4). While each Arctic territory is distinct, communities in the Canadian Arctic can be generally characterized as facing a range of concurrent social, political, cultural, economic changes that are in part driven by environmental transitions (Ford et al., 2017; Prowse et al., 2009). For example, climate-induced changes have disrupted some traditional hunting activities impacting livelihoods and there has been amplified national and international interest in surrounding waterways, resource extraction, and economic development (Borgerson, 2008; Nicol, 2016). Unlike other regions in Canada, the Arctic is often governed in accordance with land claims agreements, representing jointly managed regions and complex policy environments. Thus, a range of co-management systems are in place where authority is shared and integrated across multiple levels of decision-making (e.g., local, regional, territorial/provincial, federal) (Rusnak, 1997). The largest employer in the territories is the public sector (Coates et al., 2014; GoC, 2010) and distinct knowledge economies have emerged in the three territories, with concentrations of highly qualified personnel in the territorial capitals (Petrov, 2008, 2016). Historically regional collaboration between the three territories has been high, but collaboration has slowed as each territory turns its focus on the unique challenges facing its own jurisdiction (Coates et al., 2014).

Figure 1.4 Map of Canada's Territories in the Arctic



Modified from Source: https://commons.wikimedia.org/wiki/File:Canada_territories_map.svg

1.7 Statement of Positionality: Personal Motivations for the Research

"*A researcher's background and position will affect what they choose to investigate, the angle of investigation, the methods judged most adequate for this purpose, the findings considered most appropriate, and the framing and communication of conclusions"* (Malterud, 2001 p. 483-484). With this in mind, I acknowledge that the knowledge produced in this dissertation is reflective of my identity and past experiences. In this section I aim to identify the ways in which my background has created the lens through which I see the world and how it relates to and influences this research. By reflecting on both myself as a researcher and the relationship that I have with the research I aim to help readers understand how my assumptions and preconceptions may affect the decisions that were made leading up to and throughout the research process.

In many ways my worldview and approach to research has evolved as a result of my early research experiences and past professional employment. I am a non-indigenous researcher from Alberta, Canada who has worked on research projects in archaeology, health, education, knowledge translation and policy for over 15 years. Most of my work has been on community-based projects with Indigenous communities in rural and Northern Canada. I was first introduced to research and the Arctic during my undergraduate degree (BA Hon. Anthropology, University of Alberta). I was fortunate to participate in multiple archaeological field seasons in Nunatsiavut, Canada working on a multidisciplinary project that explored human and landscape interactions during a time of environmental and cultural transition. As a result of these experiences, I reflected a lot on the role of Northern researchers and the impacts that we had on local communities, even if only passing through on route to a more remote field site. I began to question the systems that I was unconsciously endorsing by participating in existing research structures, wondering who determines what should be studied and how resources were being allocated. Wanting to participate in research that had more direct relevance for communities, for my Master's degree I shifted my research focus to health research, working on a community-driven diabetes research project with an Alberta First Nations community (MSc. Nutrition and Metabolism, University of Alberta). I continue to be inspired by the social-action research approach the team undertook, teaching me that when you take the time to consciously and collaboratively design a project, the resulting research can serve many different parties. Following my Master's degree my professional career included work advocating for equitable health and social outcomes for Indigenous women (Pauktuutit Inuit Women of Canada, Native Women's Association of Canada), as well as time spent working in a hospital environment researching medical education and knowledge translation processes (the Ottawa Hospital Research Institute).

It was through my work as a policy advocate for national Indigenous women's organizations that I became acutely aware of the challenges with leveraging scientific evidence (when available) to help guide decision making, which was complimented by my work at the hospital where I learned about the complexities within knowledge translation processes. Applying what I had learned, I returned to academia in 2016 to pursue a PhD in Renewable Resources at McGill University with the initial intention to examine knowledge flows in the Canadian Arctic in order to better understand what happens to academic research once produced (i.e., how it is used and who uses it). My goal was to explore the processes that enable/impeded the Arctic science-policy interface, while also considering how these processes interact with local and Indigenous knowledge systems. However, as most research goes, it became evident early in the PhD that very little had been documented about the Canadian Arctic research system itself. As a result, instead of studying knowledge flows, my PhD has focused on synthesizing available information and on mapping elements of the Canadian Arctic science and innovation landscapes. The research has taken me through a journey of several different literatures and concepts, settling on the core concepts of public value, network governance and innovation ecosystems.

It is important to note that the PhD has been informed by more than the research included in this dissertation and that my understanding of the Canadian Arctic scientific research enterprise has been shaped by several internships undertaken during the PhD. As a research intern I conducted background work on Inuit Tapiriit Kanatami's (ITK) National Inuit Strategy on Research with ITK's Inuit Qaujisarvingat Knowledge Center; I carried out a range of tasks in support of the knowledge mobilization section at Polar Knowledge Canada; and I supported core services and developed a detailed report for the ArcticNet Secretariat. Each of these experiences brought me greater appreciation and a breadth of insight into the variety of organizations and perspectives associated with Canadian Arctic science efforts.

The 4-month ArcticNet internship presented the ideal opportunity for ArcticNet to be a core case study for my thesis, facilitating access to network materials and expertise. Prior to my internship I had attended two ArcticNet conferences and had no other involvement with the network. The internship allowed me to participate in, and observe, network activities, providing me with insider perspectives on network affairs. The knowledge gained throughout this experience informed my subsequent research, leading me to ask broader questions, ultimately shifting my focus away from an examination of project-level impacts and outcomes towards the impact of network-level effects and management relationships. Further, the internship helped me identify the most appropriate individuals to consult for key-informant interviewees. All research presented in this thesis was conducted and interpreted at arm's length from ArcticNet. As per my internship agreement, the network used preliminary findings from the Social Network Analysis in their 2018 funding renewal application. I have since maintained the informal relationships built during the internship and ArcticNet has expressed interest in exploring future collaboration with my PhD supervisor Prof. Hickey. I acknowledge that the choice of analytical methods and the interpretation of the analyses presented in this dissertation may have been influenced or biased by my familiarity with ArcticNet, however this has been minimized through regular peer debriefing and review with my academic supervisors.

Ultimately, this doctoral research is a culmination of my past experiences, building on core questions that I have been pondering since my first archaeological field season 15 years ago. I emphatically believe in reflecting on the transformative potential and impacts of research given that no research is done in a ‘bubble’, even when there is no direct human subject under study. Throughout this PhD I have been motivated by the notion of cultivating reflection among academia and have been fortunate to have learned from many conversations with peers and mentors about the perceived role and responsibilities of the academy. I believe that effective science-informed innovation can emerge from asking slightly different questions, informed by an awareness of institutions that guide and shape our everyday choices. I believe that as researchers and scientists we have a role to play in shaping academic institutions and shifting the southern-based research narrative that has repeated in Canada since the 1960’s. With that acknowledged, I am acutely aware of the irony of this dissertation which focused on studying Arctic science and Arctic science governance without ever once requiring travel to the Arctic. This speaks to the volume of work still needed to transform the Canadian Arctic into a fully functioning innovation ecosystem. Nonetheless, I remain motivated by the belief that research has inherent value and I believe that it is possible to build more reflexive systems if only we pause, reflect, and then take deliberate action.

1.8 Organization of the Dissertation

This is a manuscript-based thesis and therefore a certain level of repetition is unavoidable. Most of the chapters are at various stages of submission and publication in international peer-reviewed journals. In order to offer insights into how science may create public value in the Canadian Arctic each chapter examines unique concepts and mechanisms at a different scale. Chapter 2 presents a literature review focusing on the Canadian Arctic context, exploring the challenges and opportunities facing Arctic science and innovation. It argues for a systems approach to understanding Arctic scientific research governance and illustrates the complexity of the Canadian Arctic science landscape, including the substantial coordination challenges affecting the formation of innovation ecosystems. This chapter was published in *Arctic Yearbook* (2017). Results Chapters 3-5 focus on the case of ArcticNet, the largest Arctic research network in Canada, and are structured to progressively transition from an exploration of more granular elements of Arctic science (actors and networks) to then consider broader institutional influences (i.e., the relevance of evaluation metrics and pathways of public value creation). Chapter 3 has been submitted to the journal *Arctic* (March 2020) and maps the configuration of science-based innovation actors involved with ArcticNet-funded research over time. The aim of this chapter is to identify the organization and evolution of networked actors. The results show how the network grew over time and more central, non-local actors were most likely to facilitate support boundary spanning, yet it was the less central local actors that had an increased propensity for closing structural holes in the network. Chapter 4 builds on this finding to inventory the network-level public values associated with ArcticNet as well as the diverse publics targeted by network administrative activities. Novel network-level evaluation strategies are then offered in order to better assess the dynamics of network-level public value creation. Chapter 5 explores the multi-level and overlapping principal-agent relationships through which public value management is being delegated within ArcticNet.

Findings illustrate that the adoption of networked models of scientific research governance correspond with a trend towards contracting the roles for public value management to Arctic research actors through a mediating NAO; however, it remains unclear how core elements of public value management are being approached and communicated to public managers. The final chapters of the dissertation represent a general discussion, inclusive of future research directions that aim to situate the findings within the broader research and policy landscape, and a conclusion.

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Preface to Chapter 2

Chapter 1 identifies several important knowledge gaps concerning the potential role of Arctic scientific research as it relates to science-informed innovation and sustainable development. Chapter 2 presents a detailed literature review on the scientific research and innovation governance issues relevant to the Canadian Arctic. It establishes the necessary foundation from which to further explore the public value of Arctic scientific research.

Chapter 2. Literature Review

Towards Innovation Ecosystems: Enhancing the Public Value of Scientific Research in the Canadian Arctic

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Abstract

Over the past decade, the Canadian Arctic has seen an intensification of scientific research designed to foster innovation (i.e., the process of transforming ideas into new products, services, practices or policies). However, innovation remains generally low. This paper argues that before we can meaningfully promote innovation in the Arctic, there is a need to first identify the complex systems that support or inhibit innovation. Few, if any studies have taken a systems approach to enrich our understanding of how existing networks may or may not support innovation in the Canadian Arctic. A promising, but under-explored approach is to consider innovation ecosystems, defined as the multi-level, multi-modal, multi-nodal, and multi-agent system of systems that shape the way that societies generate, exchange, and use knowledge. This paper presents innovation (eco)systems as a potentially valuable systems-based approach for policy actors to enhance innovation linkages in the Arctic. From a policy perspective, there is a need to embrace and promote more networked approaches to co-create public value and to consider the lifespan of any innovation. Potential directions for future research include: mapping the actors involved in Arctic innovation ecosystems (including intermediaries and bridging agents) at multiple scales; the role that formal and informal institutions play in shaping co-innovation; case studies to evaluate innovation processes; and an assessment of the coupled functional-structural aspects that influence innovation outcomes in the Canadian Arctic.

2.1 Introduction: Innovation in the Canadian Arctic

The Canadian Arctic has been identified as an 'up-and-coming' region and has attracted increasing national and international policy interest (Steinberg & Tasch, 2015). It has also been characterized as a region undergoing a series of unprecedented parallel social, political, and environmental transitions (Pauktuutit Inuit Women of Canada, 2006; Wehrmann, 2016). Much attention has been paid to understanding the impacts of climate change, as well as the vulnerability and resilience of Arctic residents who are faced with increasing pressures to adapt to the changing environment (Chapin III et al., 2004; Overpeck et al., 1997; Pelaudeix, 2012; Prowse et al., 2009). Concentrated attempts to better link contributions from scientific research and other public interventions to innovation are key to meeting the complex multi-level challenges (e.g., marginalization, poverty, limited infrastructure, poor housing conditions, food insecurity, and limited access to health and education services) associated with concurrent transitions in the Canadian Arctic (Coates & Poelzer, 2014; Exner-Pirot, 2015).

Innovation can be conceptualized as a *"new or better way of doing valued things"* (The Expert Panel on Business Innovation, 2009) or "*as a response to, and as a means for change"* (UArctic, 2017). More specifically, innovation is both 1) the process whereby ideas are transformed into something new, and 2) the novel outcomes of such processes, such as a product, service, policy or practice (Baregheh et al., 2009; Borrás & Edquist, 2013). Innovations are the result of (co-)learning, collaboration, and interactions between multiple actors (e.g., firms, universities, research, and public organizations, knowledge infrastructures, end-users, and local knowledge holders) (Doloreux, 2004; Klerkx et al., 2017), and are often a co-evolutionary process in which technological change is accompanied by social and institutional changes (Geels, 2004; Kilelu et al., 2013). Therefore, coordinated approaches that link interested actors can help to support innovation (Lundvall, 2010).

There is a general expectation that governments and other public organizations make use of policy instruments to formally oversee the processes of defining and implementing innovation agendas to guide innovation efforts (Borrás & Edquist, 2013; Braun, 2008; Martin, 2016). Governments are usually tasked with the coordination of resources from various sources (e.g., private sector, the civil society sector, and the state) to find and support common priorities with a view to creating public value (Benington & Moore, 2011; Moore, 1995). The concept of public value simultaneously reflects what the public values and what strengthens (i.e., adds value to) the public sphere (Benington & Moore, 2011; Moore, 1995), extending the conversation of value beyond purely economic considerations (e.g., returns on research investment) to also consider social, political, cultural, and environmental aspects of value (Joly et al., 2015). Public value can be enhanced through the development of innovations (Hartley, 2015).

One way that governments seek to foster innovation (and promote public value) is through policies that stimulate the production and diffusion of 'useful' scientific knowledge, which has the potential to expand policy alternatives, clarify policy choices, and form the basis of new technologies, services, practices, and processes (Martin, 2016; McNie, 2007; Schut et al., 2013). Over the past decade, the Canadian government has committed substantial financial resources to Arctic research (Nicol, 2016; Ogden et al., 2016). National Arctic research funding has supported programs such as: the International Polar Year, the Canadian High Arctic Research Station, the NSERC Northern Chairs program, the Northern Scientific Training Program, ArcticNet, Arctic Research Infrastructure Fund, Churchill Marine Observatory, National Research Council Arctic Program, Sentinel North, the Canadian Polar Commission and Polar Knowledge Canada among other initiatives (GoC, 2016, 2017a; Ogden et al., 2016). In 2017, Canada, along with other member states of the Arctic Council, signed the Fairbanks Declaration,

> *"…announc[ing] the Agreement on Enhancing International Arctic Scientific Cooperation, the third legally binding agreement negotiated under the auspices of the Arctic Council, which will help increase effectiveness and efficiency in the development of scientific knowledge about the region as well as strengthen scientific cooperation in the Arctic region" (Arctic Council, 2017).*

Continued and increasing public investments in the production of Arctic-related scientific knowledge implies that Arctic research has public value (McNie et al., 2016), which may also translate into private value that furthers the public interest (Mazzucato, 2011). However, Arctic residents have repeatedly questioned the public value of Arctic research, arguing that outcomes do not often well-reflect the values, interests, and needs of Arctic communities (Brunet et al., 2016; Coates et al., 2014; Ibarguchi et al., 2015; ITK, 2016; Ogden et al., 2016; Tesar et al., 2016). Despite investments in northern research there has been a relative dearth of research directed towards informing the development of northern-specific innovations, resulting in Arctic communities adopting innovations that were designed for southern communities with mixed success (Coates & Poelzer, 2014). Consequently, there have been calls to strengthen science-policy and science-practice interfaces in the region (Tesar et al., 2016), including a recommendation by the Arctic Science Planning Committee to develop improved methods to align research and policy agendas (Kofinas et al., 2005).

The process of transforming scientific knowledge into innovation is complex and requires diverse actors (e.g., from government, university, private sector, civil society, and northern citizenry) to navigate large and rapidly growing amounts of information embedded within complex ecological, social, economic, cultural, organizational, and political landscapes (Hammond, et al., 1983; Joly et al., 2015). A key question that emerges for decision makers is: how to better understand and intervene in the complex systems that support or inhibit innovation at different scales in the Canadian Arctic to enhance the public value of scientific research? This paper seeks to explore this question. In what follows, we present a brief background on the current state of governance and innovation in the Canadian Arctic. This is followed by a review of Canada's efforts to promote scientific research in support of Arctic innovation to identify some of the opportunities for, and challenges to, delivering public value. We then draw on the concept of innovation ecosystems to discuss the potential for an expanded and systems-based model to enhance the public value of northern scientific research investments.

2.2 Governance: Policy Coordination Issues Influence Innovation in the Canadian Arctic

Like many countries, Canada has placed increasing policy emphasis on the need to promote innovation to be competitive in a rapidly globalizing world. This is evidenced by the 2017 Federal Budget that focused efforts and resources on promoting innovation, emphasizing that Canada has *"an opportunity to be one of the most innovative and competitive countries in the world"* (GoC, 2017b). However, to date, evaluations suggest that Canada's innovation performance has been poor (Creutzberg, 2011; Jenkins, 2017; Mitacs, 2016; The Expert Panel on Business Innovation, 2009). Canada has been criticized as having limited innovation from the private sector (Innovation Canada, 2011), poor linkages between high quality university academic research and commercialization (Conference Board of Canada, 2015), and overall poor research and development indicators compared to other countries in the Organisation for Economic Development and Cooperation (OECD) (Science Technology and Innovation Council, 2014).

The most common explanation for Canada's comparatively low innovation performance is that it lacks coordination and policy alignment across and between multiple levels of government (Hawkins, 2009; Mitacs, 2016; Tamtik, 2016). This is likely due to jurisdictional challenges embedded in Canadian constitutional governance structures[7] that divide power between the federal government (power over macro-economic policy, foreign policy, banking, defense) and provincial governments (power over natural resources, property laws, and education) (Halliwell & Smith, 2011). These also include the co-management of shared jurisdictions between provinces and the federal government (social welfare, health care, agriculture, and immigration) (Halliwell & Smith, 2011). To varying degrees, local governments also retain community-specific responsibilities which overlap with federal and provincial jurisdictions (power over local security, transportation, infrastructure, planning, services, and recreation). Such jurisdictional overlap can create barriers to coordination, communication, and collective action with implications for innovation (Creutzberg, 2011; Hawkins, 2009; Mitacs, 2016; Tamtik, 2016).

Focusing on the Arctic region of Canada, it becomes clear that jurisdictional complications are amplified. Nationally, Canada represents both federal and unitary theories of constitutional design, where the federal government manages both constitutionally recognized provinces and federal protectorates, also referred to as territories.[8] In this system, provincial and federal governments cannot unilaterally alter the powers of the others (Hueglin & Fenna, 2015). However, unlike provinces, Canadian territories do not exercise their own constitutional powers; rather they exercise delegated powers under the legislative authority of the federal parliament, which holds supreme legislative power to delegate administrative and regulatory responsibilities and can withdraw these powers from the territories at any time (GoC, 2010; Hueglin & Fenna, 2015).

[7] Much of the literature on innovation in Canada highlights the federal nature of the country and the division of powers between the federal and provincial governments. There has been limited evaluation of innovation in the territories, which are constitutionally distinct from the provinces.

[8] The three Canadian territories (Yukon, Northwest Territories, and Nunavut) account for approximately three percent of the Canadian population and are located primarily north of 60º latitude, spanning northern Canada and covering 40% of Canada’s land mass (GoC, 2010).

Therefore, although the political, logistical, cultural, environmental, and organizational challenges that the territories face can be quite similar to the northern regions of most provinces (Coates et al., 2014), they are nested within very different governance structures. In practice, this has important implications for policy outcomes and support for research and/or innovation initiatives. For example:

> *"The Arctic was better studied than the provincial northern hinterlands for two major reasons. The first was the continuing lure of the Arctic, as revealed in its climate, remote grandeur, very special biological productivity, and culture. The second was an administrative consideration. The federal government could direct and mobilize scientific activities more easily within its jurisdiction (Yukon and NWT) than in areas where provincial agreement was needed. In general, provinces had fewer scientific resources than the federal government" (SCC, 1977).*

The federal government has devolved a range of powers to the three territories, which each have their own legislative assemblies and executive councils (GoC, 2010). This partial decentralization has resulted in the transformation of territories into 'quasi-provinces' with increasing powers and resources (Alcantara et al., 2012; Cameron & Simeon, 2002). However, the extent of devolution differs depending on the territory (Alcantara et al., 2012). All three Canadian territories are dependent on financial transfers for the majority of their budgets (Rocher & Smith, 2003), such that in 2015-2016 transfers (including grants) from the Canadian government reflected 74% of the Yukon's budget (Government of Yukon, 2017), 78% of NWT's budget (Government of Northwest Territories, 2017) and 89% of Nunavut's budget (Government of Nunavut, 2017). The public sector is the largest employer in the territories, which have become *"home to the richest and most entrenched government-centric political environment in the country*" (Coates et al., 2014; GoC, 2010). Distinct knowledge economies have also emerged in the three territories, with concentrations of highly qualified personnel in Whitehorse, Yukon, and Yellowknife, Northwest

Territories (Petrov, 2008, 2016). Historically, regional collaboration between the three territories has been high, but collaboration has slowed, and territories have become more competitive, instead focusing on their differences and the unique challenges facing each jurisdiction (Coates et al., 2014).

Indigenous rights movements have also resulted in substantial changes to the governance of the Canadian Arctic, leading to increasing regional capacity and reduced federal administrative presence. Indigenous peoples in the Canadian Arctic include Inuit, First Nations, and Métis, most of whom reside in isolated rural and remote settlements. Comprehensive land claims were first recognized by Canada's federal government in 1973 and are *"based on the assessment that there may be continuing Aboriginal rights to lands and natural resources. These kinds of claims come up in those parts of Canada where Aboriginal title has not previously been dealt with by treaty and other legal means"* (INAC, 2012). Land claims often involve parallel discussion about self-governance agreements, which includes arrangements for Indigenous groups to assume responsibility and govern their own affairs including social and economic well-being (e.g., education, healthcare, social services, housing, property and land rights, economic development) (INAC, 2015). As a result, the Canadian Arctic has regions of Indigenous self-government as well as regions with public government arrangements, whereby Aboriginal self-government arrangements are negotiated within broader public governments (INAC, 2016; Rodon, 2014). There are also a range of co-management systems in place where authority is shared and integrated across multiple levels of decision-making in the Canadian Arctic (e.g., local, territorial/provincial, federal) (Rusnak, 1997). Additionally, Indigenous groups have established bi-lateral agreements with the federal government, most recently the *Inuit Nunangat Declaration on Inuit-Crown*

Partnership, which applies to the Inuit homeland, spanning areas in the three territories and the northern regions of two provinces (Québec and Labrador) (GoC, 2017c).

At the international level, Canada participates in several circumpolar transboundary governing bodies, including the Arctic Council, an intergovernmental forum that promotes cooperation and interaction between Arctic states, Indigenous peoples, and other Arctic inhabitants (Heininen et al., 2016). Canada is a signatory to the Arctic Council's Agreement on Enhancing International Arctic Scientific Cooperation, which will shape future regional research and innovation systems. Canada also participates in the Northern Forum and other international civil society organizations/councils that represent the interests of Indigenous people living in Canada, including the Inuit Circumpolar Council, Gwich'in Council International, and the Arctic Athabaskan Council (Dubreuil, 2011). In 2016, Canada announced its full support for the United Nations Declaration on the Rights of Indigenous People (UNDRIP), which states that *"Indigenous peoples have the right to self-determination…[to] freely determine their political status and freely pursue their economic, social and cultural development"* (United Nations, 2008). Here, self-determination signifies the right and ability of a defined group to have control over their future beyond the influence of other entities (Christie, 2007). The implications of this declaration for Indigenous peoples living in the Canadian Arctic are in the process of being discussed (ITK, 2017; Mitchell & Enns, 2014).

Clearly, the Canadian Arctic is governed by a diversity of structures, stakeholders and rights- holders that come together to access information and make decisions on issues that span jurisdictional boundaries and are embedded within existing national, territorial, Indigenous, and international frameworks. Decisions are therefore made in the context of multi-stakeholder frameworks (Binder & Hanbidge, 1993; Rusnak, 1997), ongoing land claims agreements (INAC, 2016), calls to respect traditional Indigenous knowledge (ITK, 2007; Tagalik, 2010), evolving jurisdictional and regulatory requirements (ACUNS, 2003; ITK, 2007), and geo-political considerations (Steinberg & Tasch, 2015). Furthermore, past policy and strategic directions have used inconsistent and at times conflicting boundaries (e.g., geo-political boundaries, climate boundaries, bio-physical and geographic considerations, and Indigenous homelands) to capture 'the Northern regions', 'Northern Canada', 'the North', and 'the Arctic' (Callaghan, Matveyeva, Chernov & Brooker, 2001; Dubreuil, 2011; Steinberg & Tasch, 2015). The fragmented, evolving, nested and transboundary nature of Arctic governance means that the coordination challenges characterizing Canada more broadly (Hawkins, 2009) are likely amplified in the Arctic research and innovation contexts with significant implications for policy design and effectiveness.

2.3 Developments in Innovation Policy in the Canadian Arctic: A Focus on Research

Approaches to innovation have evolved from more 'linear' views that assume that scientific knowledge, once generated, will passively diffuse and produce public value (Braun, 2008). Models of complex systems thinking conceptualize innovation as a self-organizing process, bringing together market and non-market resources at various scales to support innovation beyond the production of scientific knowledge and the co-evolution of the technological and socio-institutional products (Braun, 2008; Jucevičius & Grumadaitė, 2014; Klerkx et al., 2012). Innovation systems are the dynamic and interactive networks that shape the way that societies generate, exchange, and use knowledge (Hall & Clark, 2010; Lundvall, 2010). However, despite this more integrative understanding of innovation, Canadian research policy has yet to embrace complex innovation systems thinking in the Arctic, instead tending towards more linear and sectoral views of what innovation is and how scientific research might best support innovation outcomes.

National Canadian innovation policy generally aims to support technological innovation carried out by universities and the private sector to facilitate job creation (GoC, 2017b; Hawkins, 2009). There is, however, a recognized need to reconsider the scope of the innovation concept itself so that it more explicitly includes cultural and institutional change (Strand et al., 2018; Wallner & Menrad, 2011). For example, recommendations for a new National Advisory Council on Research and Innovation include moving away from the current focus on 'science and technology' to be more inclusive of all research disciplines, including the social sciences and humanities (Naylor et al., 2017). There have also been calls to better align innovation incentives with efficacy goals and empower end-users to play a role in stimulating innovative activity (Blomqvist & Busby, 2017). Further, national innovation policies tend to focus on urban areas, and it is unclear if innovation patterns are replicated in more sparsely populated rural and remote areas (Kelemen & Teo, 2014). The divergent nature of Canada's national technology-focused innovation policy and the diverse realities of local Arctic communities suggests the need for a more systematic and integrative examination of the dynamic properties that contribute to systems of innovation in the Arctic.

Regional approaches to innovation in other circumpolar nations have also promoted business-centered socio-technological approaches to innovation (Andersen et al., 2007; Hintsala, Niemelä & Tervonen, 2015). Researchers in Finland have examined the existence of an 'Arctic business ecosystem' assessing organizations based on their economic value (Hintsala et al., 2015; Hintsala et al., 2016). Another report reflects on Nordic innovation systems as a way to increase national economic competitiveness (Andersen et al., 2007). These approaches tend not to be reflective of the Canadian Arctic context where a social economy dominates[9] and the universities and businesses that might participate in Arctic-focused product innovation are located in southern Canada (Abele, 2009, 2016; Natcher, 2009; Simon, 2017; Southcott & Walker, 2015). Canada is also the only Arctic nation that does not have an Arctic university [at the time of publication in 2017]. While each territory has a college (Nunavut Arctic College, Aurora College and Yukon College), existing funding structures and eligibility requirements often direct investment for training, research and innovation towards universities in the south, raising important questions for local capacity development and the treatment of northern interests (Carr et al., 2013; ITK, 2016; Simon, 2017).

The Canadian Arctic does not have a regional innovation policy; however, several overlapping research-focused strategies have been employed to promote the production and use of scientific research in support of innovation in the Canadian Arctic (Table 2.1). Although discussion about developing federal guidelines for Arctic research emerged in the early 1970's, in 1977 the Science Council of Canada released the first report on Arctic science policy entitled: *Northward looking: a strategy and science policy for northern development* (SCC, 1977). While the report established the foundation for future research policy, it was criticized for failing to recognize the role that political, social, and economic factors play in scientific activities (de la Barre, 1979). Subsequent strategies have yet to fully address these issues (Simon, 2017) and recent national policies continue to echo the directions detailed in the 1977 report. In 2016, the three territories launched a 'pan-northern' approach to science policy (GY, GNWT &, GN, 2016), framing

[9] The extensive northern 'social economy' is *"the part of the social productive system that lies outside the direct ambit of government programs and large business. It includes small business, not-for-profits, co-operatives, family-based production, traditional or non-commodified production, and volunteer support to others"* (Abele, 2009).

northern research as something that needs to be determined by northerners, with a solution-driven, needs-oriented and partnership-based focus. More specifically, they have identified six roles for themselves in the science system: practitioners, consumers of science information, educators, facilitators of research within their own jurisdictions, regulators of research, and partners in regional, national, and international science initiatives (GY, GNWT &, GN, 2016).

These roles reflect the increasing importance of collaborative research networks and knowledge exchanges across diverse institutions, sectors, and countries (Martin, 2016). They also reflect the emergence of multi-stakeholder frameworks to engage in participatory and community-based, co-production research models in the Canadian Arctic (Brunet et al., 2014; Brunet et al., 2016; Fletcher, 2003; ITK, 2007), with explicit guidelines and requirements for Indigenous engagement and local capacity building in place (ACUNS, 2003; Arctic Council, 2013; GoC, 2014; ITK, 2007; Schnarch, 2004; Simon, 2017; Yukon Indian People, 1973).

Importantly, innovation has been, and continues to be, central to life and livelihoods in the Canadian Arctic. Local knowledge systems, *"consist of the knowledge, beliefs, traditions, practices, institutions, and worldviews developed and sustained by [I]ndigenous and local communities, and are believed to represent an adaptive strategy to the environment in which these communities live"* (Vandebroek et al., 2011). According to Wallner and Menrad (2011), innovativeness is a characteristic of culture, making culture a critical component to consider when examining innovation. In the Arctic, institutions that support cultural, social, and ecological diversity are recognized as important supports to foster innovation (Chapin III et al., 2004). Recognizing that the production (and use) of scientific research is only one of many enabling factors embedded within an innovation system (Wieczorek & Hekkert, 2012), it is important that we adopt a systems approach to garner a complete understanding of the dynamic relationships that promote innovation processes.

2.4 Why an Innovation Ecosystem Approach for the Canadian Arctic?

An innovation ecosystem is defined as *"a multi-level, multi-modal, multi-nodal and multi-agent system of systems"* (Carayannis & Campbell, 2009) and may offer more nuanced insights for policy actors seeking to design innovation policy for the Canadian Arctic. Innovation ecosystems are generally not considered distinct in many aspects from innovation systems, rather they build on national innovation systems thinking (Lundvall, 2010), placing emphasis on the importance of pluralism with respect to actors, institutions, types of knowledge and paradigms (Adner, 2006; Carayannis & Campbell, 2009). Conceptually, innovation ecosystems seek to explicitly consider the interdependent, nested, transitional, and interconnected networks of actors involved in innovation processes, their actions and interactions, and the socio-cultural institutions (e.g., laws, rules, norms) that influence their practices and behaviours (de Vasconcelos Gomes et al., 2016; Jackson, 2011; Oksanen & Hautamäki, 2015). Differing from business ecosystems, which focus primarily on value capture, innovation ecosystems focus on value creation (de Vasconcelos Gomes et al., 2016). Therefore, innovation ecosystems emphasize the multiple positions and roles of local or regional actors in innovation processes that focus on value creation (Oksanen & Hautamäki, 2015). In the context of the Canadian Arctic, innovation ecosystem perspectives have the potential to provide additional scope to reveal opportunities to better manage the formal and informal institutional and relational contexts that govern innovation (de Vasconcelos Gomes et al., 2016; Rabelo et al., 2015).

Table 2.1 National research policy directions: Strategies and reports for the Canadian Arctic

Year	Name	Author	Document Purpose	Innovation Considerations
1972	Science and the North: A Seminar on Guidelines for Scientific Activities in Northern Canada	Sub-Committee on Science and Technology of the Advisory Committee on Northern Development (Federal level)	This report presents background material, statements and other information from a seminar held to assist the Government of Canada in developing guidelines and priorities for scientific activities in northern Canada.	- Various factors shape the adoption of southern innovations in the North. - Innovation needs to reflect and adapt to concurrent environmental and technological changes. - Northern development is a dynamic process involving people, resources, the environment, and new technological innovations. - To support innovation, one must support northern Indigenous people.
1977	Northward Looking: A Strategy and Science Policy for Northern Development	Science Council of Canada (Federal level)	This is a report on the 3.5 year 'Study of Northern Development' and a proposed strategy based on findings.	- Focus on promoting innovation by implementing science policies for northern development. - Promote technological sovereignty through innovations. - Industrial innovation can be stimulated by research and development programs. - A theoretical Arctic university would promote innovation of northern technologies - Administrative and legislative innovation should aim to provide research support to committees and bolster provincial resources to be equivalent to those offered by the Library of Parliament.
1987	Canada and Polar Science	Indian Affairs and Northern Development (Federal level)	This report advises on the feasibility of establishing a national polar institute in Canada.	- Innovation is not explicitly identified. - The document calls for science to be more quantitative, technology-oriented, better integrated and more directly involved with or responsive to local concerns.

Year	Name	Author	Document Purpose	Innovation Considerations
1991	Northern Science for Northern Society – Building Economic Self-Reliance	Science Council of Canada (Federal level)	This is a report on a study from 1988-1990 on the institutional changes needed to help northerners apply science and technology to support economic development.	- Northern communities partially reject innovation because the conventional structures and methods of science and technology are not evidently useful. - To build northern capacity leaders must foster innovative approaches to technology.
1997	Chapter 8 – Supporting Scientific, Educational and Cultural Cooperation in the Arctic In: Building the Circumpolar Framework- Exercising Canadian Leadership	Library of Parliament Research Branch; House of Commons Standing Committee on Foreign Affairs and International Trade (Federal & International levels)	This extensive review discusses the domestic and international concerns in the circumpolar region in the context of recent changes in technology, communications and geopolitical factors.	- There is a need to balance national interest and science promotion in innovative national, regional and global frameworks. - Recent technological innovations open new opportunities for North-South partnerships.
2000	Northern Science and Technology in Canada – Federal Framework & Research Plan	Indigenous and Northern Affairs Canada (Federal level)	The Federal Framework and Research Plan presents directions for partnerships with governments, universities and northern peoples to improve the return on federal investment in science and technology.	- Encourage the development of innovative partnerships and links to other programs. - Support for the transfer of scientific knowledge and technology innovation to the private sector to promote economic growth. - Government departments, agencies, and branches are responsible for innovation through science and technology development, trade and market expansion, tourism and youth entrepreneurship, and research and development.
2000	From Crisis to Opportunity: Rebuilding	Natural Sciences and Engineering Research Council of Canada and	This report summarizes the findings from consultations by a multidisciplinary Taskforce	- The North is identified as a leader in satellite-based innovation.

Year	Name	Author	Document Purpose	Innovation Considerations
	Canada's Role in Northern Research	the Social Sciences and Humanities Research Council of Canada (Federal level)	(established 1998) that investigated concerns about the decline of research in the North.	- Northern research institutes are seeking innovative ways of involving local people in the research. - Recommendation to support multidisciplinary northern research projects.
2005	From Opportunity to Action: A Progress Report on Canada's Renewal of Northern Research	Institute on Governance (Federal level)	This report summarizes the results from the Working Group on Northern Research's (established 2003) 'Dialogue on Northern Research Workshop'.	- The North is identified as a welcoming environment for innovation. - Participants identified areas of focus: technological innovation in research & training. - Efforts should be made to modify education in innovative ways (e.g., traditional knowledge). - Action had not occurred with respect to the placement of 'innovators' with field expertise in local schools.
2008	Vision for the Canadian Arctic Research Initiative: Assessing the Opportunities	Canadian Council of Academies upon request of Indian and Northern Affairs Canada (INAC) (Federal level)	This commissioned report is an independent external perspective on findings from the Visioning Workshop on a new research station.	- Northern citizens have a key role in innovative partnerships to develop community-based environmental monitoring. - Biomimicry may be a key source of innovation in the North. - Technology will play an important role through innovation and commercialization. - Key factors such as the caliber of scientists and infrastructure will likely play a role in the innovation (or lack of innovation) of new technologies. - A call for innovation to be leveraged in the approach to science and technology as identified in the stations defined priorities.

Year	Name	Author	Document Purpose	Innovation Considerations
2009	Canada's Northern Strategy: Our North, Our Heritage, Our Future	Government of Canada; Minister of INAC (Federal level)	This document provides an overview of the federal government's Northern Strategy (vision, four pillars, and activities to date).	- Support for industrial innovation through support to university granting councils. - Highlight existing innovative consultative process.
2014	The State of Northern Knowledge in Canada	Canadian Polar Commission (Federal level)	This report summarizes a study that examined knowledge gains during the seven-year period commencing with International Polar Year in 2007.	- A call for research on governance innovation. - Encourage future collaborative work to identify innovative ways to address socio-economic challenges.
2017	A New Shared Arctic Leadership Model	INAC 'Minister's Special Representative on Arctic Leadership (Federal level)	This independent report outlines advice toward the development of a new Shared Arctic Leadership Model.	- Arctic policy should be based in reciprocal relationships built in trust, inclusiveness and transparency to inform innovative policy. - Current innovative thinking supports the creation of an Arctic university. - Innovation and transition will require major investments from public and private sectors. - Clean and renewable energy innovation will require collaboration with key partners. - Structural changes to funding and transfer payments are necessary to ensure that resources are optimized.

2.5 The 'Eco' Analogy & Innovation Ecosystems in the Canadian Arctic

Much of the literature on innovation ecosystems takes a somewhat limited view of the relationships between innovation and public value, instead placing emphasis on economic outcomes (similar to innovation systems literature). The conceptualization of innovation ecosystems has been subject to considerable debate (Oh et al., 2016; Ritala & Almpanopoulou, 2017; Suominen et al., 2016), and a range of definitions have subsequently emerged (de Vasconcelos Gomes et al., 2016; Durst & Poutanen, 2013). Nevertheless, *"[t]he prefix eco in innovation ecosystems implies a specifically ecological aspect"* (Ritala & Almpanopoulou, 2017), with a biological ecosystem defined as *"a system that includes all living organisms (biotic factors) in an area as well as its physical environments (abiotic factors) functioning together as a unit"* (Jackson, 2011). Building on this thinking, an innovation ecosystem similarly includes all of the elements that come together, to influence innovation dynamics and potential (Jackson, 2011). Shifting emphasis to the ecosystem analogy may also help policy actors at different levels of already established decision-making hierarchies to better consider their roles and responsibilities as well as the agency of natural ecosystems in innovation processes and outcomes (Pilinkienė & Mačiulis, 2014; Vermunt et al., 2017).

In the Canadian Arctic, the analogy to a natural ecosystem has the potential to enable diverse actors to better comprehend the complex systems underlying the creation of public value through innovation and improve understanding of the roles of different actors in this process. Ecological analogies have already been used by Arctic residents to describe the research system, with analogies being drawn between researchers and snow geese, both of which arrive in the summer, make a lot of noise, leave at the end of the summer and return the following year to repeat the process (Lemelin et al., 2010). Similar analogies have been made between researchers and ground squirrels, known as 'siksiks' in Inuktitut (Gearhead & Shirley, 2007). Borrowing from ecology, an innovation ecosystem implies a system of systems supporting a range of specialized actors that cooperate, feed-off, adapt to, support, compete, and interact with each other (de Vasconcelos Gomes et al., 2016; Shaw & Allen, 2016). Additionally, innovation ecosystems can also be characterized as systems in flux that are emergent, with lifecycles driven by co-evolution processes (de Vasconcelos Gomes et al., 2016). Every part of an ecosystem must be considered in order to comprehend the complex functioning of the whole system (Jackson, 2011).

2.6 Arctic Innovation Communities

An innovation community is a collection of actors that dynamically evolve as people and organizations come together to produce and/or use a specific innovation (Wang, 2009). They have also been conceptualized as innovation platforms, hubs, clusters, learning alliances, etc. (Kilelu et al., 2013; Schut et al., 2016). Innovation communities also reflect the *"protected spaces that allow experimentation with the co-evolution of technology, user practices, and regulatory structures"* that might promote sustainable development through transitions, as characterized in strategic niche management[10] (Schot & Geels, 2008).

The complex governance issues of the Canadian Arctic speak to the diverse actors that come together to cultivate a multi-innovation, multi-community Arctic innovation ecosystem. Figure 2.1 presents a re-interpretation of Wang's (2009) theoretical model for innovation ecosystems. As infinite, related innovations co-evolve in the ecosystem, it is important to

[10] Similar to ecological niches, which reflect an animal's place in the biotic environment and its relationship to food sources and other animals, innovation community niches have a finite amount of resources, leading to competition. According to Wang (2009) *"[j]ust like an Arctic fox subsisting upon guillemot eggs and the remains of seals killed by polar bears, an innovation concept consumes attention from the member organizations and their people in the community."* Conceptualizing innovation as part of an ecosystem means that different innovations 'consume attention' and resources from the same community, thus there can be 'innovations' competing for the available resources.

recognize their relationships to the innovation community. Figure 2.1 conveys a network of three different innovations, selected to reflect the common Arctic innovations that are briefly discussed later in this paper (technological innovation, administrative innovation, and social innovation). The three larger boxes contain an innovation community comprised of diverse actors engaging in the production and use of an innovation, governed by the supply and demand of the innovation. Community members can engage in both the production and use of the innovation and can also participate in multiple innovation communities. Actors may include organizations and individuals (e.g., governments, universities, industry, supporting institutions, specialized people, entrepreneurs, the financial system, consumers, civil society, cultural groups), as well as the emergent relationships, which play various roles throughout the life of an innovation ecosystem (Rabelo & Bernus, 2015). Arctic innovation communities are reflective of the features unique to the complex, hybrid institutions and societies that govern the Canadian Arctic (Abele, 2015). In the Canadian Arctic where the traditional actors in an innovation ecosystem (e.g., universities and a large private sector) may be underrepresented, many actors likely reorganize to form different innovation communities. Figure 2.1 shows the interactive nature of the three innovations, illustrating that as resources move to support one innovation, they 'consume attention' requiring additional resources (i.e., time and money), thus influencing the available resources for related innovations. Members of the innovation community can also migrate within and between innovation communities, participating in multiple activities (Wang, 2009). For example, a community member may sit on multiple committees and be both a producer and a user of all three innovations.

Figure 2.1 Co-occurring innovation communities within innovation ecosystems

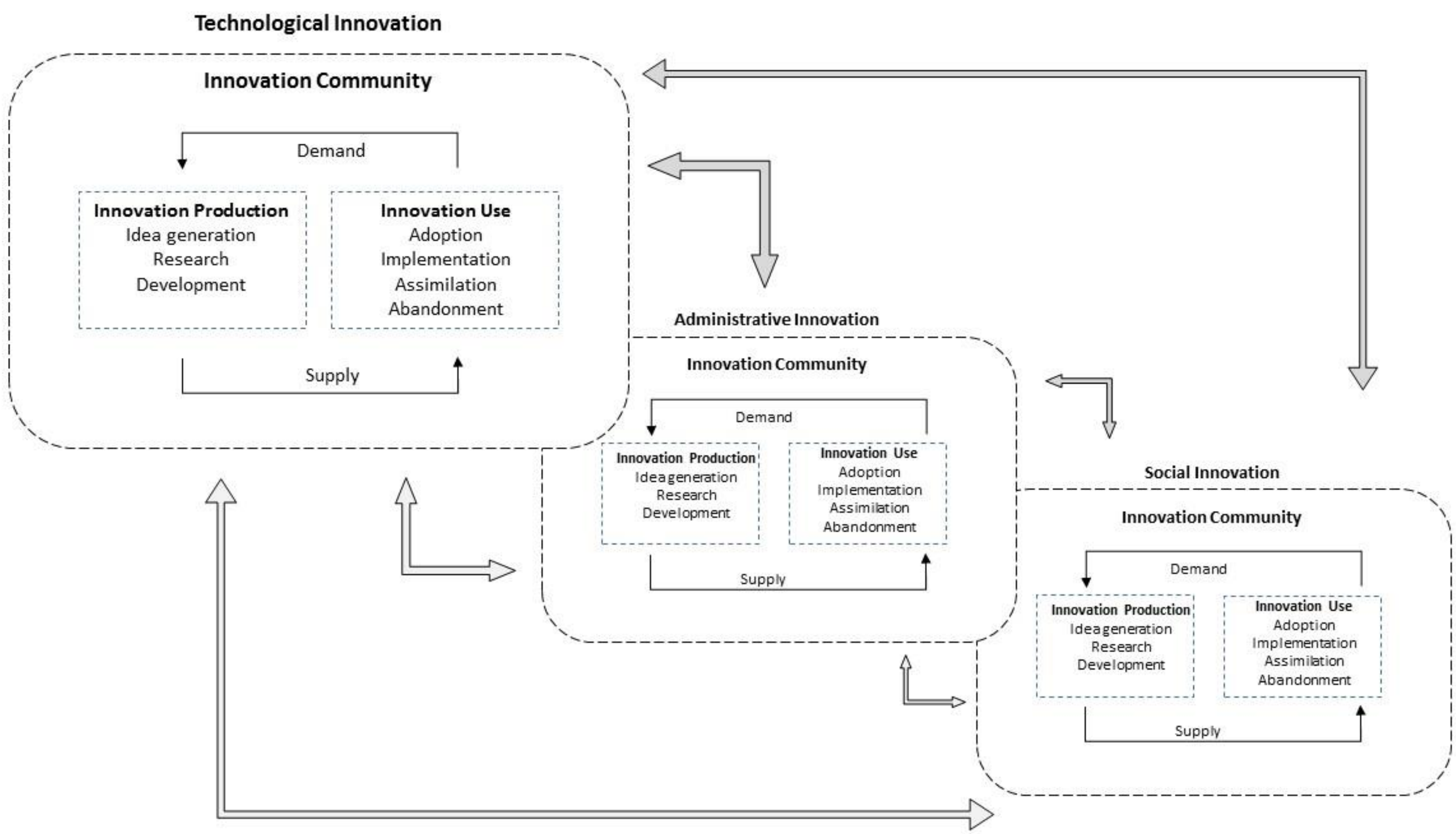

Figure 2.1 presents an example of an innovation ecosystem inclusive of three common types of Arctic innovations (technological innovation, administrative innovation, and social innovation) based on Wang's (2009) theoretical model for innovation ecosystems. The three larger boxes each contain an innovation community comprised of diverse actors engaging in the production and use of an innovation, governed by the supply and demand of the innovation (smaller boxes describe these processes). Innovation community members can engage in both the production and use of the innovation and can also participate in multiple innovation communities. Arrows represent the potential flow of knowledge and resources between innovation communities.

To date, innovation communities have not been identified in the literature on the Canadian Arctic. At first glance, it may appear that the innovation ecosystem is like a barren landscape in which only a few pioneer species are present. However, it can be argued that diversity characterizes the Canadian Arctic innovation ecosystem, much like that of the physical ecosystem:

> *"[a]lthough species diversity is generally lower [in the Arctic] than at more southerly latitudes, the diversity of animals and plants, communities, and landforms are surprisingly rich. Patterns of biodiversity are strongly coupled with the wide variety of Arctic environments…[t]he Arctic is therefore far from uniform" (Callaghan et al., 2001).*

Diversity of the Arctic innovation ecosystem is reflected by co-occurring knowledge systems, whereby Indigenous local knowledge systems co-exist and interact with formal research and innovation systems in diverse ways (Pierotti, 2010; Scott & Humphries, In Press), as well as the alternative economies that can and do co-exist with larger northern market economies (Abele, 2009; Southcott & Walker, 2015). Since biotic and abiotic actors come together to form innovation communities within the innovation ecosystem, an examination of community dynamics can help to provide insight into interdependencies between people and nature. It has been argued that the Canadian Arctic has the potential for an 'innovation environment' with the capacity to support and inspire future innovation based on the ingenuity of Arctic residents, who have persisted in extreme environments for centuries (Coates et al., 2014). Support for an 'innovation environment' is also coupled with the rapid pace and variety of successful administrative innovations (e.g., self-government, co-management, economic development, modern treaty negotiations) (Coates et al., 2014), as well as social innovations that merge southern-based administration and northern cultural values in response to opportunities and pressures from new technologies (Abele, 2015, 2016; Natcher, 2009).

2.7 Implications & Future Directions

This review suggests that if governments aim to support the formation of innovation ecosystems in the Canadian Arctic, they likely need to focus their efforts on engaging dynamic innovation communities nested within complex overlaying governance structures and to expand their definition of innovation to better reflect the multiple economies present in the Canadian Arctic.

From a policy perspective, there is a need to embrace and promote more networked approaches to value co-creation, requiring decision-makers to negotiate various boundaries between multiple actors representing diverse interests (i.e., the interests of the state, the private market, civil society and informal community organizations) to co-create public value (Benington & Moore, 2011; Braun, 2008). Aspects such as science-policy linkages, relationships, group dynamics, trust and social capital need to be more carefully considered as they can influence the way that relationships are navigated (McNie, 2007; McNie et al., 2016; Schut et al., 2016). Further research into the actors involved in Arctic innovation ecosystems (Brunet et al., 2016) and the nature and impacts of the knowledge flows between these actors would be helpful. This should include assessment of actors that span boundaries (i.e., intermediaries and bridging agents) and coordinate efforts to support innovation (Howells, 2006). Here, it also becomes important to consider the different institutional dimensions affecting research and innovation organization (Klerkx et al., 2012; Schut et al., 2016), as well as to consider patterns of power relations and knowledge utilization (Steinberg & Tasch, 2015). The mobility of innovation communities is also integral to understanding innovation ecosystems in the Canadian Arctic. For example, people, knowledge and physical supplies are constantly moving between northern and southern Canada for Arctic scientific research and the Arctic Council's *Agreement on Enhancing International Arctic Scientific Cooperation* aims to further promote international mobility among the scientific community (Arctic Council, 2017). Relatively little is known about how mobility influences knowledge flows between members of the Arctic innovation ecosystem and this is an area that requires further research and policy attention.

A key challenge for research and innovation policy is to more meaningfully consider the lifespan of any innovation, including the various co-occurring processes of creation and destruction, something that innovation ecosystems thinking may assist with. For example, the boundary between collaborative research–stakeholder relationships is path-dependent, meaning that their feasibility or credibility is influenced by earlier arrangements (Schut et al., 2013). Here, careful efforts to promote path-breaking by challenging the rules, artifacts, and habits of the underlying societal system may be warranted to avoid ‘groupthink’ and path-dependency scenarios (Ölander & Thøgersen, 2014; Walrave et al., 2018). In search of sustainable development, diverse actors will need to develop new modes of production and new institutional arrangements to support these production models (Bouma, et al., 2011). Future research could consider how open innovation systems (Chesbrough, 2006), can be designed to encourage path-breaking. Innovation actors (and communities) that take opportunities to innovate during times of change can also play a unique role in providing bridges to help solve issues and may inadvertently change the system itself (Hartley, 2015).

Future research to better understand the complex dynamics of innovation communities and processes in Canadian Arctic innovation ecosystems is needed. More specifically, there is a need for innovation policy frameworks at different levels to better recognize the coupled functional-structural aspects that influence innovation outcomes in the Canadian Arctic. This will help to identify key leverage points and ‘bottlenecks’ requiring attention (Meadows, 2008). Here, mapping the various elements of an innovation ecosystem (e.g., actors, capital, infrastructure, regulations, knowledge, ideas, culture, architectural principles, and interface) (Rabelo & Bernus,

2015) would be a useful first step (Wieczorek & Hekkert, 2012). Such an exercise might lead to improved understandings of how institutional dimensions (Schut et al., 2013), and multi-dimensional linkages (i.e., relationships, connections, interactions) (Poteete, 2012) shape innovation outcomes in different Arctic contexts. Further, comprehensive case studies that evaluate innovation successes and failures are needed to examine innovation processes in different contexts. Future research into the current models of co-innovation (Botha et al., 2017; Klerkx et al., 2017) that exist in the Arctic and the potential for 'grassroots innovation' (Hermans et al., 2016) and 'inclusive innovation' approaches to better engage marginalized groups within the innovation ecosystem (Foster & Heeks, 2013) are also warranted.

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Preface to Chapter 3

Chapter 2 reviews the need for new approaches that can help to conceptualize the complex systems that support or inhibit innovation at different scales in the Canadian Arctic. Drawing primarily on public value and innovation ecosystems thinking, Chapter 2 argues for in-depth case studies that can supply an improved understanding about the structure and function of Arctic innovation communities, which support ecosystem function. Responding to this call, Chapter 3 employs Social Network Analysis to identify the structural configuration of a Canadian Arctic research network designed to transform scientific knowledge into innovative outcomes in support of public value creation. It examines the ways in which diverse science-based innovation actors in the Arctic interacted and coordinated across multiple boundaries over time. Chapter 3 therefore represents a shift in focus from the broad Canadian Arctic science landscape (Chapter 2) towards a single case study on networked relationships between Arctic innovation actors.

Chapter 3. Collaborative Networks for Science-informed Innovation in the Arctic: Insights on the Structure and Evolution of a Canadian Scientific Research Network

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Abstract

In remote peripheral regions like the Arctic, collaborative research networks have been identified as being an important mechanism for nurturing science-informed innovation. Given that relatively little is known about the collaborative structures that support Arctic innovation processes, we employ Social Network Analysis techniques to examine the structural organization and evolution of ArcticNet, a large Canadian Arctic scientific research network over a 13-year period (2004-2017). ArcticNet funded 152 multidisciplinary research teams, connecting multiple types of science-based innovation actors, not including students (301 organizations; 1659 individuals). The research network grew without reaching saturation (increasing size, decreasing density) suggesting that ArcticNet was successful in recruiting new actors over the 13-year period. ArcticNet was centralized around non-local public-sector actors (mainly Canadian academics). The emergence of collaborations across several boundaries (sectoral, geographic, thematic) suggests that non-local Canadian academic actors played an important boundary spanning role, particularly in the early stages of the network. Participation by local/Northern actors doubled from Phase 1 to Phase 4, and with time, local/Northern actors had an increasing propensity for carrying out boundary spanning roles and addressing 'structural holes.' This study presents new insights into the networked nature of Arctic scientific research with potential implications for future research and innovation policy.

3.1 Introduction

There is an increasing need for innovative solutions that can help to address the unprecedented and complex sustainability challenges facing the Arctic (Steinberg et al., 2015; Wehrmann, 2016). Recent assessments suggest that as concurrent environmental and social pressures intensify, the integrity of Arctic systems will be tested, raising key governance questions about how to best support sustainable Arctic futures (Arctic Council, 2016; Ford et al., 2017; GoC, 2019; Huntington al., 2019). It has been increasingly argued that the Arctic would benefit from public policies that better support and promote innovation – often defined as the creation of something new (e.g., product, process, practice or relationship) (Hall et al., 2017; Hall, 2020; Hintsala et al., 2015; Exner-Pirot, 2018; Oksanen & Hautamäki, 2015). Examples include calls for new technologies that can better deal with the consequences of climate change (e.g., melting permafrost, declining sea-ice) and for new governance processes that better reflect Indigenous political movements and shifting geo-political relationships.

Despite the recognized need for greater Arctic-focused innovation policy, there has been limited attention paid to existing innovation processes in Arctic regions (Hall et al., 2017; Pigford et al., 2017; Exner-Pirot, 2018). More generally, studies on innovation have focused on large economic centers, without fully considering innovation processes in less developed economies (Schaeffer et al., 2018), and non-urban, remote peripheral regions (Oksanen & Hautamäki, 2014; Carter & Vodden, 2018; Eder & Trippl, 2019). Since peripheral regions are far from core economic areas, they often exhibit lower innovation when compared to core regions and face unique innovation challenges (McAdam et al., 2004; Tödtling & Trippl, 2005; Isaksen &Trippl, 2017). As a peripheral region the Arctic likely faces innovation challenges related to geographic, social, and economic isolation, limited access to some innovation actors, and the existence of few targeted regional innovation strategies (Suorsa, 2007; Hall et al., 2017). Insight into how existing Arctic innovation efforts attempt to overcome these challenges is important for informing policies that aim to nurture innovation.

3.1.1 Collaborative networks for innovation

Since peripheral regions tend to lack access to traditional innovation actors and infrastructures, innovation efforts in peripheral regions have been found to rely heavily on well-positioned local/regional actors and on effective collaboration networks (Tura & Harmaakorpi, 2005; Grillitsch & Nilsson, 2015; De Noni et al., 2018). While local actors are considered essential for regionally relevant innovation outcomes (Oksanen & Hautamäki, 2015), innovation processes are generally enhanced when local actors are able to work with non-local actors in order to access knowledge and expertise that are not locally available (Grillitsch & Nilsson, 2015; De Noni et al., 2018). Effective collaboration can therefore support interactive learning by promoting discourse and knowledge exchange among local and non-local actors (Eder & Trippl, 2019; Fitjar et al., 2019). Such collaborative interactions generally occur through multi-actor networks designed to support the collective production and sharing of information concerning issues that cannot be solved or easily solved by a single actor (Agranoff & McGuire, 2001; Agranoff, 2007). This process is often adopted in the Arctic where actors need share information in a coordinated manner in order to address a range of complex issues that tend to span multiple geographic, administrative, epistemological, and cultural boundaries (Nilsson & Koivurova, 2016; Pigford, et al., 2017).

Collaborative research networks are increasingly seen as a catalyst for driving science-informed innovation in Arctic regions (Task Force on Northern Research, 2000; Alfred-Wegener-Institut, 2015; Lee et al., 2015; Vlasova & Volkov, 2016; Arctic Council, 2017). This thinking has been based on the idea that scientific actors (e.g., researchers, universities, and research institutions) can contribute to innovation efforts when they collaborate with policy actors (e.g., communities, government, and industry decision makers) and other content experts (e.g., local knowledge holders, and end users) (Owen et al., 2012; Wittmayer & Schäpke, 2014). Key network actors can facilitate this process by bringing different groups of actors together, effectively fulfilling ‘boundary spanning’ roles within a network (Schut et al., 2013; Turnhout et al., 2013). In many Arctic regions private sector firms have been identified as focal actors for stimulating regional innovation by bringing diverse innovation actors together around a common goal (Asheim & Coenen, 2005; Andersen et al., 2007; Hintsala et al., 2012; Oksanen & Hautamäki, 2015).

In Canada, the federal government has identified publicly-funded scientific research actors as important drivers of Arctic development and innovation for more than 60 years (SCC, 1968; Pigford et al., 2017). Recent attempts to promote innovation have focused on supporting decentralized scientific research networks (e.g., Canadian Network of Northern Research Operators, ArcticNet, Social Economy Research Network of Northern Canada, Canadian Cryospheric Information Network, Canadian Mountain Network, ArcticNet). In this paper we focus on ArcticNet, one of the largest and most established Arctic research networks in Canada. ArcticNet was established in 2003 to bring diverse actors together from different organizations and sectors in order to examine the impacts of climate change in the Canadian Arctic with the goal of supporting innovation (e.g., new policies, strategies) (ArcticNet, 2020). ArcticNet was funded under the Canadian Network of Centres of Excellence (NCE) program and received $113.7 million (CAD) from the federal government and $249.4 million (CAD) from partner organizations between 2004-2017 (GoC, 2020). The ArcticNet network includes multidisciplinary research teams funded by ArcticNet. These teams include scientists, managers, Indigenous organizations, Northern communities, government, and private firms who work together to address issues that cross multiple disciplines (e.g., natural, human health, and social sciences) and sectors, while also leveraging funding from other sources (Coutinho & Young, 2016).

3.1.2 Research aims and objectives

An understanding of how a collaborative network is organized (including the identification of boundary spanning actors) has been identified as being important for nurturing regional innovation processes (Jacobsson & Bergek, 2011; Panetti et al., 2019). To date, efforts to evaluate Arctic scientific research have largely focused on describing project-specific outcomes and/or the quality of partnership engagement mechanisms (e.g., Gearhead & Shirley, 2007; Pearce et al., 2009; Felt & Natcher, 2011; Brunet et al., 2017; Callaghan et al., 2019; Eerkes-Medrano et al., 2019). These efforts have not paid much attention to how diverse actors might interact within broader networks of collaboration. While there has been a recent examination of co-authorship patterns among Arctic researchers (Natcher et al., 2020), there has yet to be a broader structural analysis on the organization and evolution of networked Arctic science that also includes non-academic actors (Pigford et al., 2017). The research presented in this paper aims to address this gap, while also recognizing growing claims that existing Canadian Arctic research structures have been exclusionary, and that Arctic scientific research has not met public needs, expectations nor delivered innovative outcomes (GY, GNWT &, GN, 2016; Ogden et al., 2016; ITK, 2018; Obed, 2018). Our objective was therefore to take a holistic approach in evaluating an Arctic scientific research network (in this case, ArcticNet) in order to capture the structural aspects of Arctic science collaboration and to better understand how research networks operate in support of Arctic innovation. In what follows, we employ Social Network Analysis techniques (Scott, 2012) to offer insights on how science-based innovation actors in the Canadian Arctic are organized, evolve, and span disciplinary, organizational, and geographic boundaries. We begin by describing our conceptual framework before presenting the network analysis.

3.2 Conceptual Framework

3.2.1 Identifying regional innovation actors

In general, innovation actors can include private sector firms, non-profit organizations, universities, research, and public organizations, knowledge infrastructures, end-users, and local knowledge holders (Aarikka-Stenroos & Ritala, 2017; Järvi et al., 2018). Since contexts can shape regional innovation outcomes, different geographic locations may require different actor configurations depending on the availability of local innovation actors (Suorsa, 2007; Clarysse et al., 2014). Factors that can affect the structure and performance of regional innovation efforts include: 1) Private/public sector leadership (Doloreux & Dionne, 2008; Pierrakis & Saridakis, 2019); 2) Involvement of universities in research, development, and training (Grillitsch & Nilsson, 2015; Kempton, 2015; Brown, 2016; Benneworth & Fitjar, 2019); and 3) Local/non-local relationship configurations (Clarysse, Wright et al., 2014; Oksanen & Hautamäki, 2015). Each of these factors need to be considered when evaluating the structure of networks in peripheral regions.

3.2.2 Spanning boundaries to support innovation

Boundary spanning is defined as *"work to enable exchange between the production and use of knowledge to support evidence-informed decision making in a specific context,"* while boundary spanners are the *"individuals or organizations that specifically and actively facilitate this process"* (Bednarek et al., 2018 p. 1176). Boundary spanning is not characterized by a single function or role, instead it reflects a broad range of activities carried out by individuals, teams, or entire organizations (Posner & Cvitanovic, 2019). Boundary spanning actors engage in strategies to support cross-boundary connections (Zietsma & Lawrence, 2010), which can result in improved understanding and relationships (Smink et al., 2015), stronger and more diverse social networks, and improved knowledge exchange between knowledge suppliers (e.g., universities, research institutes, government research) and users (e.g., administrative agencies, policy organizations, communities) (Bednarek et al., 2018; Posner & Cvitanovic, 2019). Such improved cross boundary relationships can help to stimulate innovation. Although the actors that have adopted formal leadership roles within a network are inherently assigned boundary spanning responsibilities, other actors can also carry out this function. The extent that actors act as boundary spanners can be determined by considering their networked relationships (Posner & Cvitanovic, 2019).

3.2.3 Capturing dynamic network configurations

Social network analysis has been previously used in other contexts to examine academic co-authorship patterns (Ding, 2011; Uddin et al., 2011; Guan & Liu, 2016), inform the planning, implementation and monitoring of research activities (Morel et al., 2009; Klenk et al., 2010; Ginexi et al., 2017), as well as to examine the role of research in fostering innovation (Quiédeville et al., 2018) and the shaping of innovation ecosystems (Panetti et al., 2019). To capture the relational aspects of actors, network analysis employs social network theory to examine the connections between pairs of actors that form larger relational systems (Scott, 2012). Actors reflect a social unit, which in an innovation context may reflect individuals, firms, universities, research projects, research networks and knowledge repositories (Contractor et al., 2006; Klenk et al., 2009). A 'networked' relationship can be considered a process by which two or more actors collaborate to achieve a common goal (Hanneman & Riddle, 2011). Networks essentially arise from personal relationships between actors (Leite & Pinho, 2017); therefore, network analysis can provide insight into the presence, strength, and changing nature of relationships including the identification of actors that act as a boundary spanners and are positioned to foster new relationships or facilitate information flows among actors (Posner & Cvitanovic, 2019). An examination of the following indicators can present insight into the structural dimensions of a research network:

Measures of network cohesion: Network-level measures that describe the strength of relationships distributed across the overall network and can be used to help determine changes over time.

- **Network size:** The size of a network refers to the total number of actors in the network. Size is important in understanding the structure of networked relations because each actor has limited resources and capacities for building and maintaining relationships (ties) (Hanneman & Riddle, 2005).
- **Network density:** Density is calculated by examining the total number of networked ties and the total number of possible interactions. It captures the extent to which the network is interconnected and can be used as a proxy for the amount of collaborative activity in the network (Scott, 2012).
- **Network centrality**: Centrality refers to the extent that collaborations are focused around individual actors (Scott, 2012). Being centrally located implies an advantageous position, often associated with a higher status and associated source of power (Zheng, 2010).

Node-level network measures: These measures can be used to understand the characteristics of individual actors in the network.

- **Ego network size:** The size of an individual's ego network is the total number of contacts an actor has in its network (Hanneman & Riddle, 2005). Ego network size is generally seen to have a positive effect on innovation since a larger network means increased opportunities for collaborative interactions (Zheng, 2010).

- **Degrees centrality:** Degree centrality accounts for the number of ties between actors (Scott, 2012). The higher the level of degrees the more likelihood an actor has of being exposed to opportunities for innovation (Zheng, 2010).
- **Betweenness centrality:** Betweenness centrality captures the extent that an actor acts as the shortest path (i.e., bridge) between two other actors (Ginexi et al., 2017). The identification of actors with a high degree of betweenness suggests that actors likely facilitate a high degree of boundary spanning in the network (Quiédeville et al., 2018).
- **Structural holes:** The existence of a gap or empty space in a person's network (the absence of ties between actors who are connected to the same ego) is considered a structural hole (Burt, 1982, 2009). Actors on either side of the structural hole have access to different flows of information; therefore, actors who can fill or bridge the structural hole are important boundary spanning agents (Burt, 1982). From an innovation perspective structural holes are seen to be positive for idea generation but detrimental to coordination and idea implementation (Zheng, 2010). Structural holes can be investigated using effective size which reflects the total number of connected actors minus the average number of ties that each actor has to other alters (i.e., total impact) and efficiency which reflects the portion of ties that are not redundant (i.e., effective size divided by network size) (Hanneman & Riddle, 2005).

3.2.4 Analytical framework

To examine network connections that are relevant to innovation in peripheral regions, an analytical framework was developed by linking key network analysis measures to the literature discussed above (e.g., innovation in peripheral regions and boundary-spanning) (Table 3.1). Recognizing that networks learn and change over time, a longitudinal lens is also applied to the analysis.

Table 3.1 Analytical framework

Network characteristic	Analysis measure
General network description	
Network changes over time	Actor descriptors Longitudinal analysis Overall network cohesion: density, centrality, network size
Central actors	
Identification of central actors - local / non-local - dominant sectors (e.g., universities) - project leaders	Actors with large ego networks Average degree centrality/ normalized degree by category
Boundary spanning	
Patterns of cross-boundary collaborations (e.g., sector, discipline/theme)	Description of cross sector activity Average degree centrality by sector
Boundary spanning: Structural holes	Effective size Efficiency
Identification of boundary spanners: - local / non-local - dominant sectors (e.g., universities) - project leaders	Actors with high betweenness centrality

3.3 Study Methods

3.3.1 Network Analysis

A Social Network Analysis (Scott, 2012) was conducted to identify the structure of collaborative relationships within ArcticNet using the organizational and individual network linkages reported between actors and to assess the network's configuration and its evolution over time.

3.3.2 Data description

Network data were generated using information derived from research projects funded by ArcticNet from 2004 until 2017. A database was created using annual report data obtained from the ArcticNet Secretariat in the summer of 2018, which was then cross-referenced with online project summaries (available on the ArcticNet website). Data were extracted for the Project Leaders (PL), Network Investigators (NIs), Collaborators, and Research Staff. Of note, trainees (e.g., Undergraduate, Masters, Doctoral, and Post-Doctoral) were excluded from the analysis based on the assumption that their organizational affiliations are the same as their supervisor. Demographic data related to members' affiliations and sex were included. To supplement the dataset, a web search was performed to identify the location of the organization when location data were missing. For academics who had government and university appointments, the organization indicated on the project summary was used for organization-level analysis, while for individual-level analysis, the affiliation that appeared on the greatest number of project summaries was used. Categorization by sector was assigned to organizational affiliations: Canadian Academic, International, Federal Government, Provincial Government, Private Sector, Non-profit, and Northern Canada. Of note, ArcticNet recognizes actors with Northern-based affiliations as a distinct 'sector', which is also reflected in our analysis. Actors with Northern Canadian affiliations (i.e., those located in the territories or in Inuit Nunangat) were categorized as 'Northern' only.

Although Northern actors reflected a range of public and non-profit actors (e.g., community, regional, and territorial governments, hunting and trapping organizations, and Northern colleges) and a few private sector actors (mostly consulting firms), they were not included in other category counts or further differentiated for analysis. While this categorization helped us to align with ArcticNet rhetoric, we acknowledge that it did not allow us to explore nuanced relationships between diverse Northern actors and other sectors, thus we recognize this as a limitation of our dataset. To facilitate discussion about the relationship between local and non-local actors, actors in the Northern category were considered local actors and were compared to non-local Canadian actors (i.e., those located in Canada but not in the territories or Inuit regions), and non-local international actors, including international actors located in other circumpolar regions.

Research projects were funded by ArcticNet in four distinct phases (Phase 1 2004-08; Phase 2 2008-10; Phase 3 2010-15; Phase 4 2015-18), making it relatively straightforward to examine changes over time. Of note, only partial data were available for Phase 4 because ArcticNet changed its reporting structure in 2017-2018 and comparative data was not available. Therefore, all data reflects relationships between 2004-2017. ArcticNet projects are also organized by five theme (Marine Systems- 48 projects; Terrestrial Systems- 34 projects; Inuit Health, Education and Adaptation- 44 projects; Northern Policy and Development 20 projects; Knowledge Transfer- 6 projects). Of note, Theme 5: Knowledge Transfer was only added to the network in Phase 3. Since the themes in Phase 1 were different, Phase 1 themes were re-coded in consultation with the ArcticNet Executive Director in 2018 to facilitate cross-phase comparisons.

3.3.3 Data analysis

In order to provide informative depictions of ArcticNet's network structure, data transformations and network metrics were calculated using UCINET 6 software for Windows and visualizations were prepared using NetDraw 2.164 software (Borgatti et al., 2002). Data were analyzed by examining collaborative relationships between individual actors as well as by organizational actors to garner a general description of the network (binary, undirected relationships). For this analysis, a relationship was seen as occurring between two actors (individuals or organizations) if they participated in at least one project together. Metrics presented for the comprehensive network include a cumulative view of all relationships formed over the duration of ArcticNet given that once a relationship is formed the collaborator is retained as a contact. The size of the network in each phase is not cumulative and represents the relationship during that phase only in order to provide clearer insight to the network structure at several points in time.

Two-mode matrices were created to examine how individual actors collaborated across projects (individual × project) for the entire network and each of the four phases. These were then converted into one-mode adjacency matrices to represent the relationships between the individuals connected through ArcticNet funded projects (individual × individual). To represent the organizational relationships across projects, the same process was repeated for organizational actors (i.e., transforming two-mode organization × project matrices to one-mode organization × organization matrices). Network metrics and visualizations were generated to identify changes in relationships between ArcticNet actors. Visualizations by phase were presented as inter-organizational collaborations. Our decision to focus visualizations on organizational connections did not inhibit our ability to map the ArcticNet network structure and was informed in part by the recognition that there are limitations to visualizing an entire network with every actor's connections being represented (Klenk et al., 2009). To gain insight into cross-discipline (theme) collaboration across projects the two-mode matrix (individual x project) was converted into a one-mode adjacency matrix (project × project).

The analysis was based on the framework outlined in Table 3.1. To show the extent to which individual and organizational actors were connected over time, network cohesion measures (density, centrality, size) were assessed for the overall network and for each phase. To identify central/predominant actors several characteristics were calculated for each individual: ego network size, average degree (number of links per actor) and normalized average degree. Individual actors appointed as project leaders were also described and network characteristics were calculated. To understand areas of boundary spanning, we examined three types of boundaries that ArcticNet was intended to cross: sectoral, disciplinary (captured by theme), and geographic. We describe project collaborations by theme as a measure of interdisciplinary collaboration and identify the projects that facilitated a high degree of boundary spanning. We then consider measures of individual boundary spanning by identifying actors with a high betweenness centrality and aim to identify the potential presence of structural holes by calculating average effective size and efficiency. A supplemental analysis was also conducted to present further insight into the network's evolution over time by exploring networked relationships. See Appendix 3A for details.

3.3.4 Ethics

ArcticNet is aware that this research has been conducted. Research Ethics Board approval (file 44-0618) was received on 15 June 2018 for ten scoping interviews that were used to help identify the secondary sources used in this analysis.

3.4 Results

3.4.1 Description of network characteristics: A multi-actor network

Over the 13-year period from 2004-2017, ArcticNet funded a total of 152 multidisciplinary research teams (i.e., projects) over four distinct funding phases (Table 3.2). There were 301 unique organizations from multiple sectors: Canadian Academic (n=55; 18% total), Northern Canada (n=96; 32% total), International (n=102; 34% total), Government (n=20; 7% total), Private Sector (n=15; 5% total), and Non-profit (n=13; 5% total). The total number of unique organizations in the network doubled over time, suggesting that from an organizational diversity perspective it appears that the network was successful in recruiting individuals from new organizations into the network. Each phase saw the introduction of new organizational actors, with increasing participation from different Northern and International organizations (see Figure 3.1 and Appendix 3B for breakdown by phase). There was also increased organizational turnover within the non-profit and international sectors by phase; however, overall there was ongoing participation by a range of organizational actors (e.g., 51 organizations appeared in all four phases, 30 in three phases, 66 in two phases and 155 in only one phase - see Appendix 3C for breakdown by sector). The network analysis included 1659 individual actors; location data was missing for 134 individuals, so they were excluded in the analysis by geography, but were included in all other analyses. Individual actors represented several sectors: Canadian Academic (n=862; 52% total), Northern Canada (n=416; 25% total), International (n=147; 9% total), Government (n=185; 11% total), Private Sector (n=20; 1% total), and Non-profit (n=28; 2% total). In all phases, over half of the individual actors in ArcticNet were from Canadian Academic institutions; however, there was a general trend of increasing participation from individuals affiliated with Northern and International institutions (Figure 3.1; Appendix 3B). This trend was not observed in Phase 4; however, this may be an artifact of only having partial data for that Phase. When examining the other phases, projects tended to incorporate more non-academic actors at later stages of each phase. Of the individual actors from Canada, the majority of network participants were from Quebec (35%), Ontario (15%), Nunavut (11%), and Newfoundland and Labrador (11%) followed by

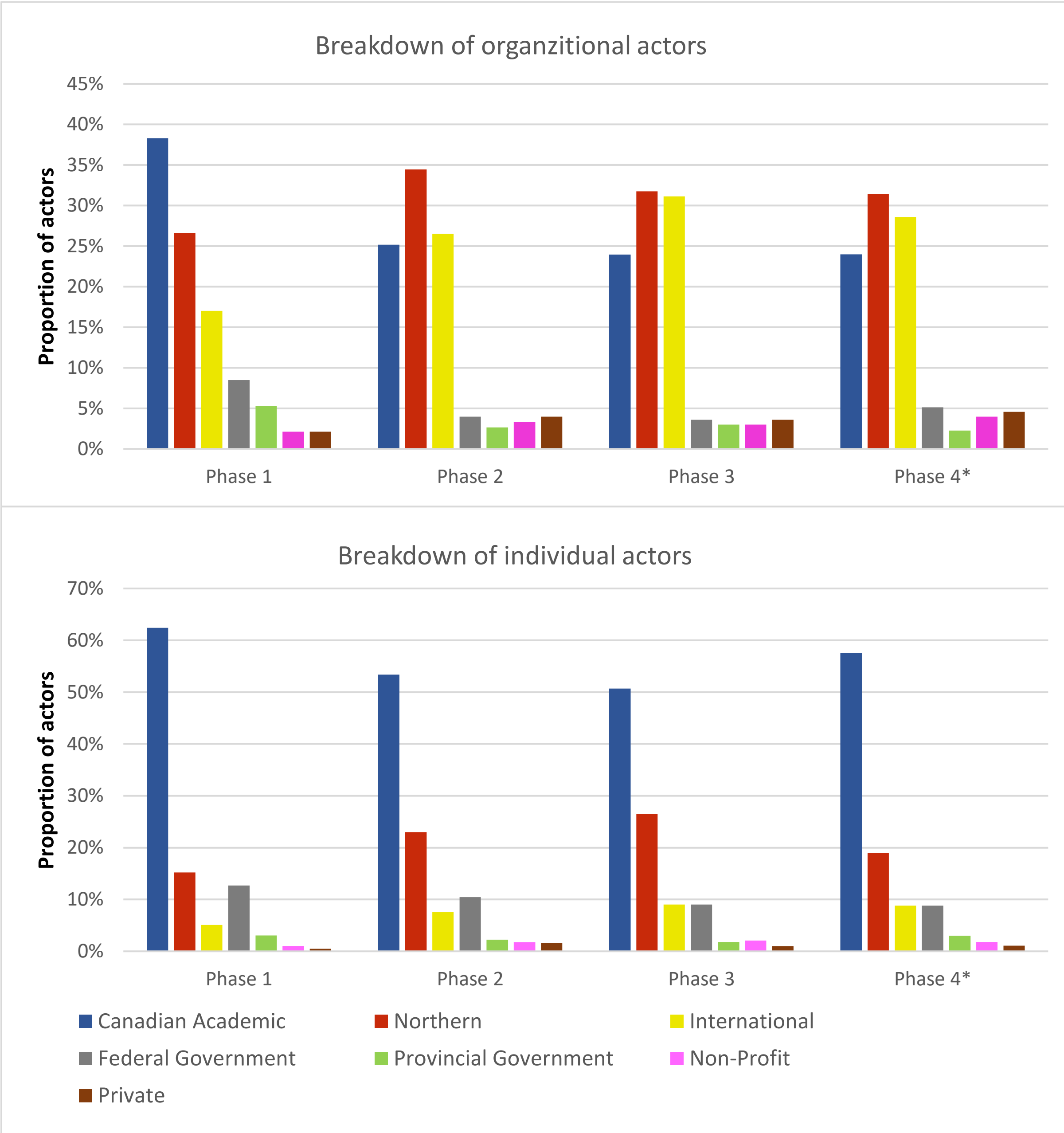
Table 3.2 ArcticNet network characteristics

	Complete Network*	Phase 1	Phase 2	Phase 3	Phase 4**
Years	2004-2019	2004-2008	2008-2011	2011-2015	2015-2019
# Projects	152	30	40	40	42
# Unique Organizations	301	94	151	167	175
# Individuals [%female]	1659 [44%]	394 [37%]	622 [41%]	732 [40%]	728 [39%]
# Project Leaders [%female]	91 [13%]	38 [5%]	45 [6%]	47 [9%]	49 [16%]

** The complete network captures all possible networked connections.*

*** Analysis includes available data only; thus, data from 2017-18 & 2018-19 is not included.*

Figure 3.1 Distribution of unique organizational / individual Arctic actors by phase



** Analysis includes available data only; thus, data from 2017-18 & 2018-19 is not included.*

Figure 3.1 captures the breakdown of unique actors (both organizational and individual) over time.

Manitoba, Alberta, Northwest Territories, British Columbia, Nova Scotia, Saskatchewan, New Brunswick, Prince Edward Island, and Yukon. International actors were largely from the USA (42%), the United Kingdom (11%), Norway (11%), France (9%), the Denmark and Greenland (6%), Germany (6%), and Russia (6%), with several individuals from Iceland, Australia, China, Finland, the Republic of Ireland, Japan, the Netherlands, Portugal, Spain, and Switzerland.

3.4.2 Changes to network structure over time

When examining ArcticNet's connections over time we found an increasing trend in collaborations, evidenced by the doubling of the number of actors (both individual and organizational), and network ties in Phase 1 to Phase 4, suggesting the inclusion of new individual and organizational actors (see previous section for details). Measures of network density decreased from Phase 1 to Phase 4 indicating that while the network grew, it had not reached saturation by 2017 (Table 3.3; Figure 3.2). The patterns of connectivity for individual actors trended towards a flatter hierarchy and decentralization over time (i.e., increasing connections, decreasing density, decreasing centralization). From an organizational perspective, centrality remained similar over time, suggesting that despite increasing in size, the network remained centralized with some organizations retaining their dominant positions. Figure 3.2 illustrates the collaboration networks based on organizational connections in each of the four phases, with the nodes representing organizational actors and lines representing the relationships between actors in each phase. For the visualizations, node colors reflect the sector, node size represents the degree of centrality for each node.

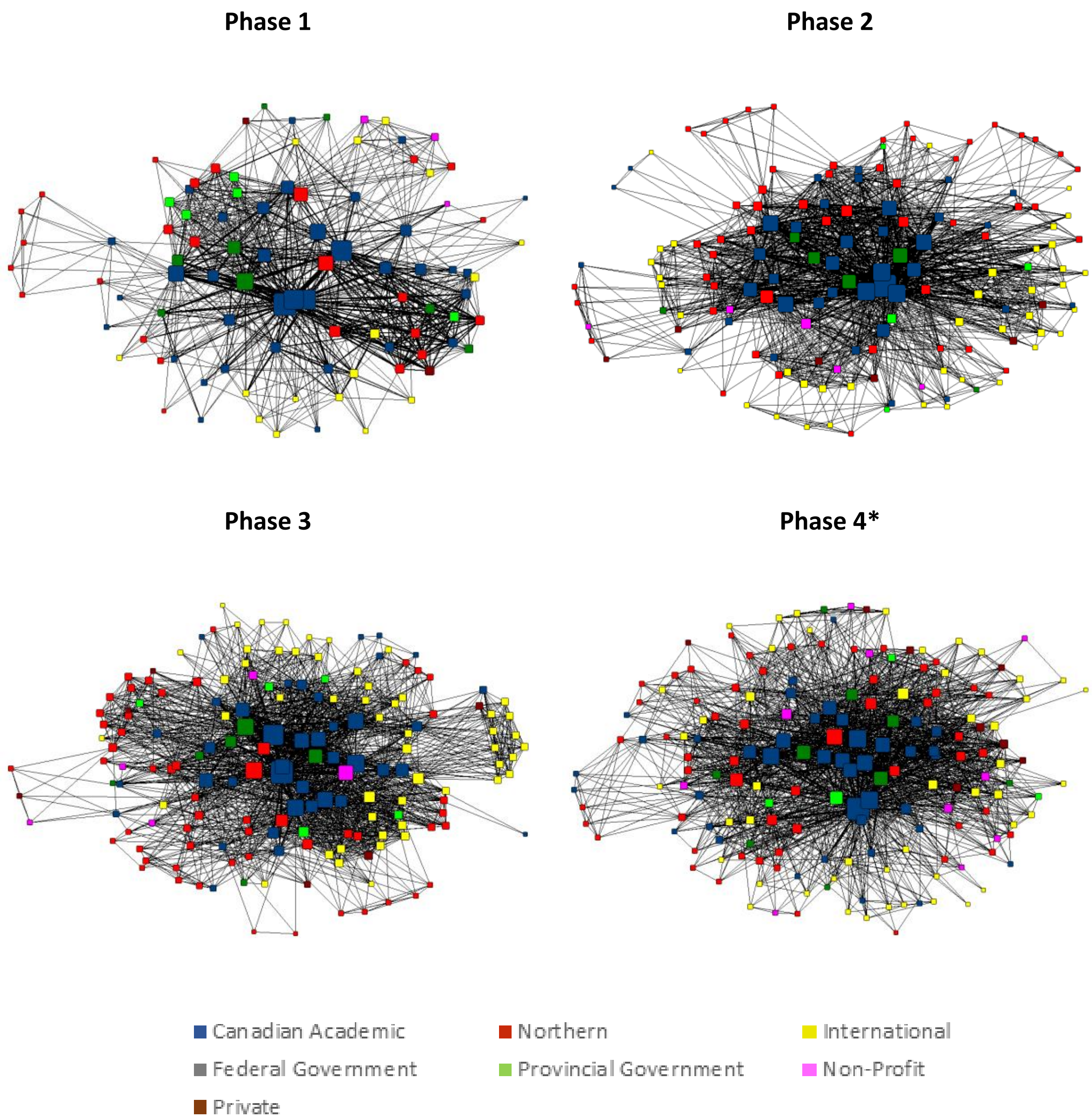
Table 3.3 Structural measures of ArcticNet's relationships between actors over time

	Complete Network*	Phase 1	Phase 2	Phase 3	Phase 4**
Organizational relationships					
Density	10.4%	20.4%	14.3%	14.8%	13.5%
Centrality	59.6%	54.9%	57.8%	53.3%	56.1%
Network size	301	94	151	167	175
Number of ties	9416	1786	3246	4100	4116
Ratio ties : nodes	31:1	19:1	21:1	25:1	24:1
Alpha	0.97	0.96	0.96	0.97	0.96
Individual relationships					
Density	2.6%	7.4%	5.2%	5.3%	4.3%
Centrality	21.4%	26.6%	19.8%	20.2%	13.9%
Network size	1659	394	622	732	728
Number of ties	71728	11482	20278	28482	22926
Ratio ties : nodes	43:1	29:1	33:1	39:1	32:1
Alpha	0.98	0.97	0.97	0.98	0.97

** The complete network captures all possible networked connections.*

*** Analysis includes available data only; thus, data from 2017-18 & 2018-19 is not included.*

Figure 3.2 Visualization of ArcticNet organizational connections by phase



***** *Analysis includes available data only; thus, data from 2017-18 & 2017-19 is not included.*

Figure 3.2 illustrates actor collaboration networks based on organizational connections in each of the four phases, with the nodes (squares) representing organizational actors and the lines representing the relationships between actors. Node colors reflect the sector, node size represents the degree of centrality for each node.

3.4.3 Dominant Actors: Non-local public sector actors, with increasing local participation

To identify the actors who hold the key positions in the network we paid particular attention to the position of 1) the most central sector actors, 2) local/Northern actors, and 3) ArcticNet's project leaders. To identify the types of actors that played a central role in the network, we examined actors with a large ego network size and degree centrality, also considering sector and geographic location (local, non-local national and non-local international). Descriptions of average actor centrality and ego network size by location are in Table 3.4; for sectors see Appendix 3D.

The average degree centrality for the entire network was 31 for organizations, meaning that the average organizational actor had 31 connections to other organizations inclusive of multiple connections to the same actor; for individual actors the average ego network size was 43 (Appendix 3D). An examination of average degree illustrates that more than half of the Canadian academic organizational actors had ego networks larger than the network average in all phases and in the complete network. For the complete network, the organizations with the largest ego networks included Université Laval, Université du Québec à Rimouski, Government of Nunavut, University of British Columbia, and Université de Montréal, and the individuals with the greatest ego network size were male actors from Fisheries and Oceans Canada (2 actors), University of Manitoba, Trent University, and Memorial University of Newfoundland (Appendix 3E). Further, the organization that occurred on the greatest number of projects in each Phase was ArcticNet's host organization, Université Laval. In summary, the largest ego networks were found among public sector actors (e.g., Canadian academic and federal governments) with more representation from Northern actors (e.g., Government of Nunavut, Nunatsiavut Government) in later phases.

Table 3.4 Centrality and boundary spanning measures for innovation actors by geography

	Organizations			Individuals		
	Complete Network*	Phase 1	Phase 4 **	Complete Network*	Phase 1	Phase 4 **
Avg. of degree	**31.3**	**19.0**	**23.5**	**43.2**	**29.1**	**31.5**
Local	25.8	16.2	19.6	41.2	28.3	30.7
Non-Local National	49.0	22.8	32.9	45.1	29.7	31.9
Non-Local International	19.7	11.3	14.8	35.4	23.3	29.6
Avg. of nDegree	**0.10**	**0.20**	**0.14**	**0.03**	**0.07**	**0.04**
Local	0.09	0.17	0.11	0.02	0.07	0.04
Non-Local National	0.16	0.25	0.19	0.03	0.08	0.04
Non-Local International	0.07	0.12	0.09	0.02	0.06	0.04
Avg. of Betweenness	**145.9**	**41.1**	**83.9**	**1469.16**	**276.23**	**682.23**
Local	65.8	10.2	43.9	1012.07	30.61	666.02
Non-Local National	364.6	68.6	169.8	1815.46	340.69	740.86
Non-Local International	15.2	2.2	9.5	245.85	16.57	245.44
Avg. of nBetweenness	**0.33**	**0.96**	**0.56**	**0.11**	**0.36**	**0.26**
Local	0.15	0.24	0.29	0.07	0.04	0.25
Non-Local National	0.81	1.60	1.13	0.13	0.44	0.28
Non-Local International	0.03	0.05	0.06	0.02	0.02	0.09
Avg. effective size	**13.7**	**6.3**	**9.5**	**12.86**	**5.98**	**5.37**
Local	9.2	2.0	6.1	8.56	2.66	4.49
Non-Local National	28.0	9.2	16.9	15.43	6.80	5.92
Non-Local International	4.5	3.0	3.0	6.33	3.20	2.89
Avg. Efficiency	**0.26**	**0.24**	**0.26**	**0.18**	**0.14**	**0.12**
Local	0.23	0.16	0.22	0.14	0.08	0.11
Non-Local National	0.36	0.30	0.35	0.20	0.15	0.12
Non-Local International	0.18	0.16	0.18	0.13	0.12	0.09

** The complete network captures all possible networked connections.*

*** Analysis includes available data only; thus, data from 2017-18 & 2018-19 is not included.*

Public sector actors located in southern Canada (e.g., Canadian academic, federal, and provincial governments) represented the group of actors with the largest ego networks (Appendix 3D). Taking a longitudinal look at participation in ArcticNet, the total number of non-local public sector actors stayed relatively consistent over time. Over 60% of the Canadian academic organizations in ArcticNet participated in three or more phases (Appendix 3C), suggesting that these organizations were central to the ongoing existence of the network. Data for individual participants corroborates this trend, with 18% of Canadian Academic individuals participating in three or more phases. Approximately 20% of individuals from provincial governments also had continued participation (more than 3 phases), which is high when compared individuals in each of the other categories, which had less than 10% participation in three or more phases.

When considering changes from Phase 1 to Phase 4, there were small increases in degree centralization for Canadian academic, Northern international, and private sector organizational and individual actors (Appendix 3D). While provincial governments increased their organizational degree centralization, there was a decrease in degree centralization for individual provincial actors. Conversely, while federal government organizational actors became less central, there were individuals from the federal government who became more central. However, although some individual actors may have increased their degree centrality, the change was not large enough to account for the increased network size resulting in a decrease in average normalized degree centrality. Overall, decreases to normalized average degree were seen for individual and organizational actors from all locations and from all sectors.

Although non-local academic actors from Canada are among the most central actors in ArcticNet, it is important to note an increasing presence of local actors (see Figure 3.1, Table 3.4, Appendix 3B). While local actors have a smaller average degree compared to non-local Canadian actors, there was an increase over time. However, these increases did not necessarily result in relative increases in degree centralization when compared to non-local actors. Individual actors from international locations and organizations from southern Canada (i.e., non-local) saw the largest average increase in degree of centralization over time.

An investigation of ArcticNet's identified project leaders (n=91) illustrates that the majority of project leaders were males (86%) from academic organizations: Canadian Academic (91%), Northern (5%), Government (2%), Non-profit (1%), International (0%) and Private Sector (0%). The limited gender diversity among ArcticNet's academic leadership is elaborated on elsewhere (Natcher et al., 2020) and the association between project leaders and academic institutions was expected given that at least one project leader per project was required to have a university affiliation. Node-level analysis suggest that project leaders were much more central to the network than non-project leaders (average normalized degree project lead/non leader: Whole network 0.06/0.02; Phase 1 0.10/0.07; Phase 2 0.09/0.05; Phase 3 0.08/0.05; Phase 4 0.07/0.04) and that they were more likely to be in boundary spanning positions (average normalized betweenness project lead / non leader: Whole network 0.99/0.06; Phase 1 1.7/0.17; Phase 2 1.32/0.11; Phase 3 1.35/0.10; Phase 4 1.33/0.15) suggesting that these individuals are in relative positions of power within the network.

3.3.4 Cross-sector collaboration patterns and boundary spanning

Evidence presented above suggests that ArcticNet was successful in recruiting actors from several sectors and geographic locations (local and non-local actors). Cross-sector relations largely took place between non-local Canadian public sector actors (universities, government) and local/Northern actors. Actors from international locations, Canadian non-profits and the private sector had relatively low average degree centralization when it comes to the overall network for both organizational and individual relationships.

Project-level relationships (individuals connected through projects) across themes suggests that actors collaborated differently based on project theme (Figure 3.3). In the context of boundary spanning, projects with high betweenness centrality could serve as a platform to facilitate collaborations across the entire network or they could disseminate information across the network more easily. Projects funded under Themes 4 and 5 (Northern policy/development; Knowledge transfer) scored among the projects that had the most diverse sectoral representation, while Theme 1 (Marine systems) had the lowest likelihood of cross-organization collaboration. Projects linked to Marine and Terrestrial Systems (Themes 1 and 2) were the least likely to facilitate boundary spanning (avg. betweenness; Theme 1(62), 2(62), 3(111), 4(105), 5(116)).

Figure 3.4 expands this discussion to consider the configuration of sector-based organizational collaborations by Theme. Based on these findings, it can be determined that there are different collaboration patterns within the network depending on the topic of focus. For example, projects focused on Theme 3 (Health, education and adaptation) included organizations from all sectors, with local/Northern innovation actors constituting the largest organizational sector, compared to projects on marine systems (Theme 1) which included the highest proportion of international organizations and the lowest proportion of local/Northern organizations. Based on the different configurations of actors, it can be argued that each theme reflects a different collaboration pattern, thus potentially different innovation outcomes. It is particularly interesting

Figure 3.3 Boundary spanning projects and complete network collaboration patterns by project

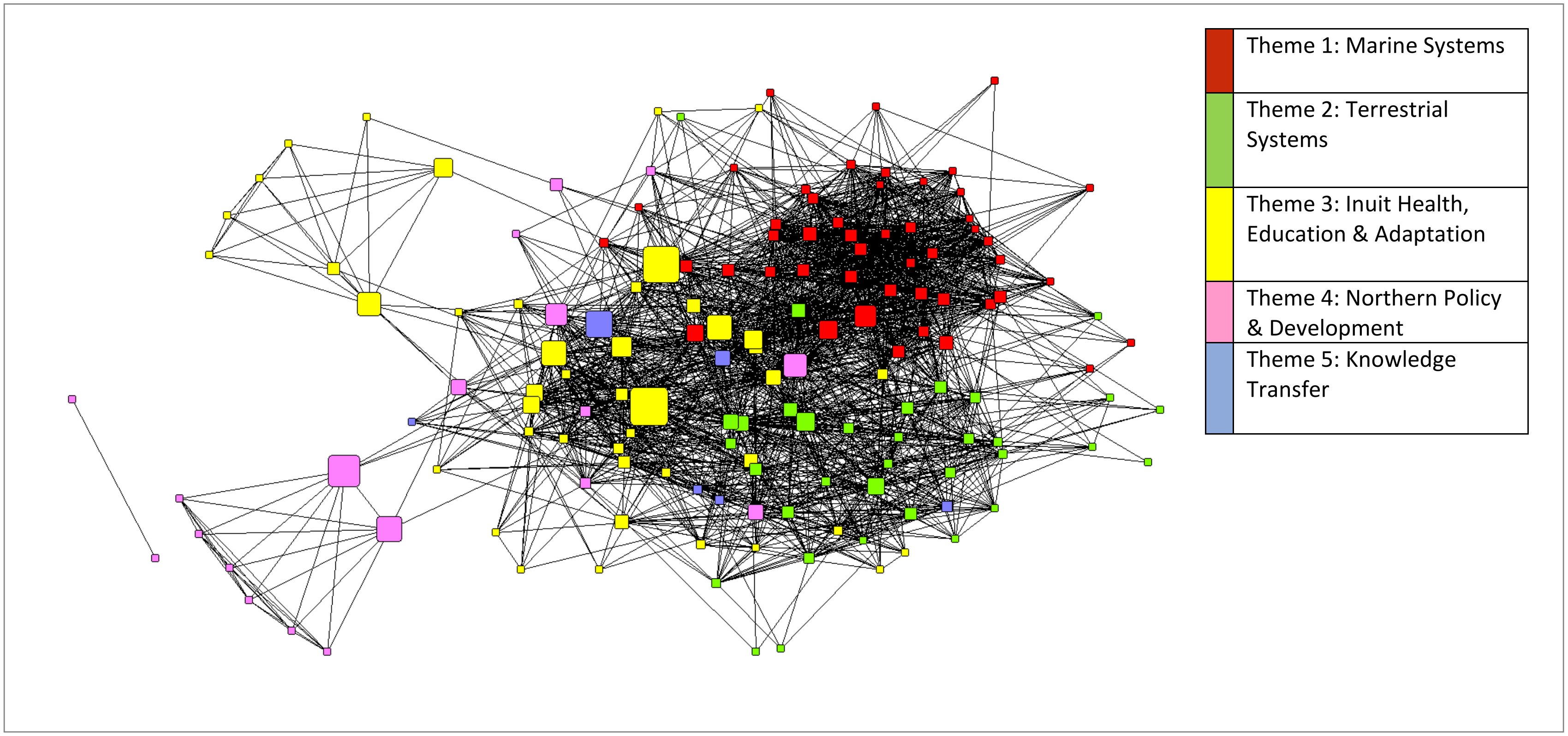


Figure 3.3 illustrates the complete ArcticNet network of individual actors connected through projects with the nodes (squares) representing projects and the lines representing the relationships between individual actors. Nodes colors reflect each project's theme and the size of nodes corresponds to betweenness centrality scores, which indicates the extent that a project served as a bridge between actors on other projects.

Figure 3.4 Topic-specific collaborations: Type of organizational actors by theme

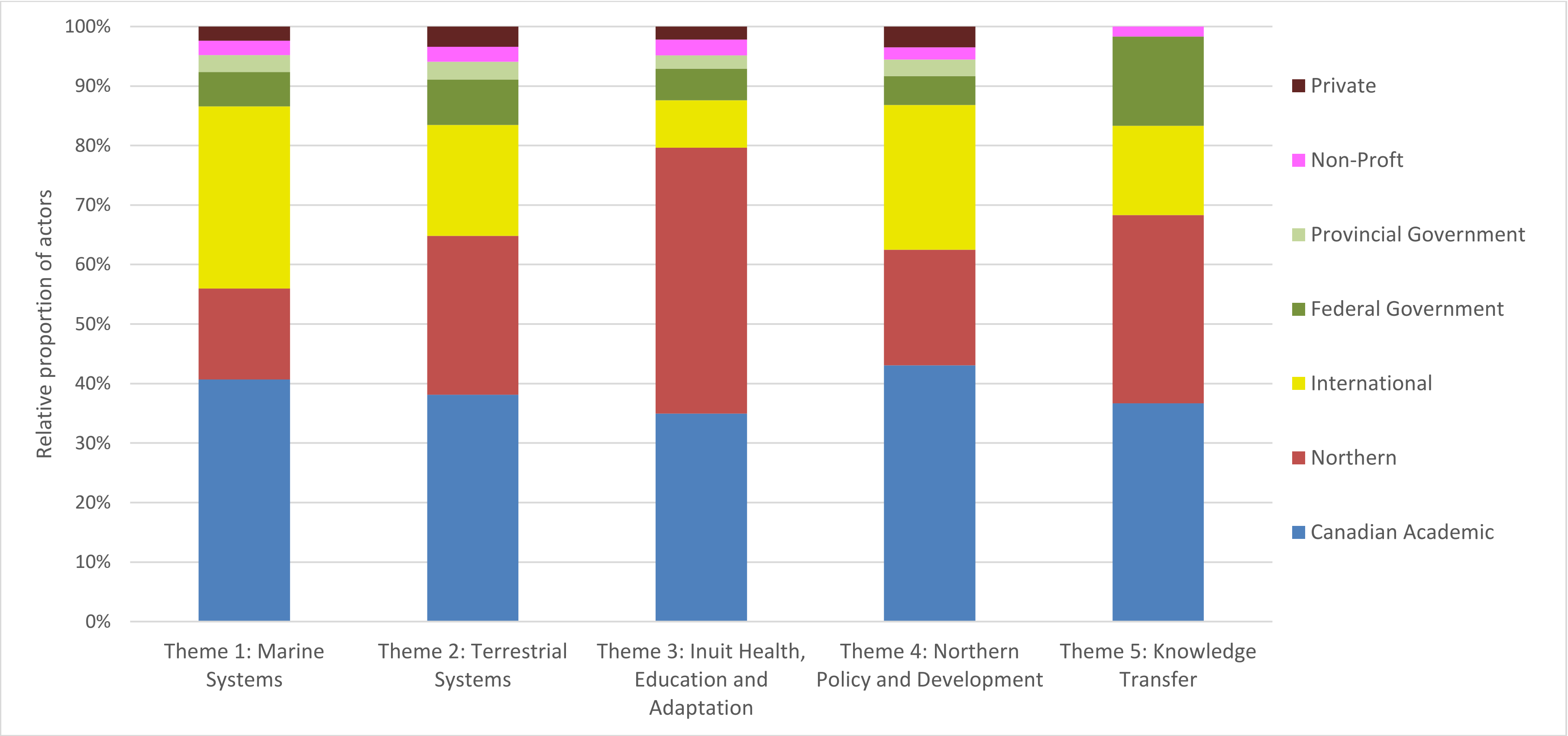


Figure 3.4 captures the breakdown of sector-based organizational collaborations by theme. Data include all phases and each color represents a different sector.

that Theme 5: Knowledge Transfer, a topic that in the broad literature is closely associated with the private sector has engaged virtually no private sector organizational or individual actors.

Overall, Canadian academic organizations and individual actors are the sector with the highest average betweenness centrality suggesting that they are most likely to act as boundary spanners, followed by the federal government. These patterns were found in the complete network and in each phase for organizational actors. For individual actors Canadian academics consistently had the highest average betweenness scores, but actors with affiliations based in Northern Canada (i.e., local actors) saw the largest increase in average betweenness from Phase 1 to Phase 4, implying an increased likelihood to carry out boundary spanning roles. The same pattern is revealed with local individuals in terms of structural holes. (Table 3.4). With respect to individual actors, the overall impact (average effective size) saw a slight decrease and the proportion of non-redundant ties (average efficiency) decreased. Interestingly, local (individual) actors did not follow this trend and had the greatest relative increase over time for both impact (average effective size) and non-redundant ties (average efficiency). Overall, the impact of organizational actors increased with time, especially for non-local Canadian organizations (average effective size) and the proportion of non-redundant ties also increased over time for organizational actors (average efficiency).

3.5 Discussion

This study reveals the dynamic structural profile of a Canadian Arctic scientific network created to promote science-informed innovation in the Arctic. It provides a useful example of how a systematic examination of network collaboration patterns a can yield insight into the broader organization, evolution, and boundary spanning practices in Arctic science. Contributing to the literature on Arctic science for innovation and impact, the findings characterize science-based innovation actors, their configurations over time and their potential roles within the network. We now reflect on the collaboration patterns among networked Arctic science actors to consider the position and role of central actors and present insights that may help to inform policies designed to better serve Arctic innovation needs.

3.5.1 Evidence of a dynamic collaboration network

While effective collaboration is known to define the quality and effectiveness of a regional innovation initiative (Markkula & Kune, 2015), it has generally been assumed that peripheral regions will have less established networks and connections than more central economic regions (De Noni et al., 2018). The results from our structural network analysis of ArcticNet illustrates the potential for non-local research networks to facilitate connections across a large and geographically isolated region of Canada, spanning sectors, disciplines/themes and geography (e.g., local/non-local). This finding corroborates evidence from other Canadian studies suggesting that formal Canadian scientific research network have been successful in fostering multidisciplinary and multi-sectoral research collaborations (Clark, 1998; Coutinho & Young, 2016). ArcticNet's collaboration network grew over time, becoming more decentralized as new individuals joined. However, despite a reduced focus on some individuals, key organizations played an ongoing central role suggesting that science-based innovation in the Arctic may be reliant on somewhat entrenched organizational actors.

3.5.2 Unique position of non-local public sector actors in networked Arctic science

ArcticNet's structure reflects the innovation actor profile of a peripheral region, with limited participation from private sector actors and a high emphasis on Canadian public sector institutions (e.g., governments, academic organizations) (Coates et al., 2014; Doloreux & Dionne, 2008;

Pierrakis & Saridakis, 2019). More than half of all ArcticNet actors were affiliated with Canadian academic institutions, representing the most central actors (reflected by average degree) reflecting expectations for universities to play a central role in regional innovation processes (Benneworth & Fitjar, 2019). Academic actors were also the most likely to act as boundary spanners (high degree betweenness), suggesting that academic entrepreneurship was important for realizing ArcticNet's innovation outcomes (Etzkowitz & Zhou, 2017; Fischer et al., 2018; Schaeffer et al., 2018) and that academic actors are adopting boundary spanning roles in the Arctic (Pigford et al., 2018). This echoes a general trend towards academic actors adopting boundary spanning roles in the context of complex challenges (Schut et al., 2013; Turnhout et al., 2013; Atta-Owusu, 2019) implying that non-local academic actors play a supportive role in facilitating Arctic science and innovation efforts.

The central network position occupied by non-local Canadian academic actors (average centrality, average betweenness, average effective size) is an interesting finding because universities are often restricted to having local innovation spillover effects suggesting that local universities would have a more direct impact on local innovation outcomes (Schaeffer et al., 2018). While it may be true that local universities are known to have a positive impact on innovation in peripheral regions at a macro-level (Grillitsch & Nilsson, 2015; Kempton, 2015; Brown, 2016), we see that the more micro-level activities undertaken by individual academic actors who adopt entrepreneurial roles in support of network building and cross-boundary linkages can also support innovation (Atta-Owusu, 2019; van den Broek et al., 2019). Given that regional innovation efforts are known to draw upon actors from various locations (e.g., local, cross-regional or cross-country) depending on the availability of local actors (Clarysse et al., 2014), the predominant position and boundary spanning roles occupied by non-local Canadian academic actors in ArcticNet is likely due in part to the lack of a university in the Canadian Arctic during the time period examined (2003-2017) and policies that have directed research funding to university institutions located outside of the region (Abele, 2015; ITK, 2016; Obed, 2018).

3.5.3 The increasingly important role of local actors

While non-local academic actors played a major role in facilitating collaboration in ArcticNet, local actors also filled key roles. Over the 13-year period, there was an increasing tendency for local actor participation in the network (number of nodes and ties doubled from Phase 1 to 4; represent one quarter of all individuals). The need for time to pass in order to see an increase in local participation implies that local engagement within Arctic science may take more time than is allocated within a single research project. Local actors had an increasing propensity for carrying out boundary spanning roles (increasing betweenness) and had increasing effective size and efficiency, indicating their role in facilitating knowledge flow and addressing structural holes. This finding supports the importance of situating Northern actors with local and Indigenous knowledge in central roles within Arctic science and innovation activities (GY, GNWT &, GN, 2016; ITK, 2018; Tysiachniouk & Petrov, 2018).

Our analysis also revealed that despite increasing participation and boundary spanning roles, local/Northern actors were less likely to be central to the network when compared to non-local Canadian actors. Local actors also had different levels of participation in projects funded under different focal themes. For example, projects funded under Theme 3 (Inuit Health, Education and Adaptation) and Theme 5 (Knowledge Transfer) had the highest levels of local participation, suggesting the areas of most community interest and regional relevance. In light of increasing Indigenous reconciliation efforts and calls for Northern actors to have self-determination in Arctic research (GY, GNWT &, GN, 2016; ITK, 2018; TRC, 2015), questions concerning who drives the research focus of regional scientific research network and innovation in the Arctic warrants further attention.

3.5.4 Implications for Policy

Recognizing that collaborative research networks emerge and grow under the influence of public policies for science and innovation, it is clearly important to consider their construction and evolution (Leite & Pinho, 2017). Based on our findings we can identify several considerations for policy makers involved in advancing Arctic science and innovation systems governance. Given that non-local academic actors constituted a central and sustained component of the ArcticNet network, it remains relevant that future Arctic innovation policies explicitly account for the wide range of roles that non-local academic organizations play in Canadian Arctic science research networks. ArcticNet also saw increasing participation by local actors, suggesting that future policies could focus on ways to better support the engagement of local innovation actors at the network's core (Oksanen & Hautamäki, 2015). Since the level of actor diversity can influence regional innovation outcomes (Tödtling & Trippl, 2005; Isaksen & Trippl, 2017), efforts to promote more diverse network leadership might also be beneficial, especially given the identified low gender diversity among academic Arctic science actors (Natcher et al., 2020). Arctic research and innovation policy should not lose sight of how long it can take for collaborative social network relationships to form, as well as their dynamic nature, as highlighted by ArcticNet's evolution towards more open and diverse collaborative relationships.

3.5.5 Future directions

Although only a single case, ArcticNet represents the largest continuous Arctic research network in Canada (13 years), presenting the opportunity for a considerable depth of analysis. The results of our network analysis offers novel insight to the structure and evolution of the collaborative relationships within ArcticNet over time; however it did not help us to answer questions related to network management, the quality of the collaborative relationships being examined, nor the innovation outcomes of the different collaborative structures observed. Further research that can address these types of questions is warranted, for example by examining the relationship between network structure and other innovation outputs (e.g., publications, patents, policies, spin offs, etc). We also recognize that a limitation of the analysis is that it did not disaggregate the diversity of Northern actors that participated in the network, which could have offered more nuanced insights on how Northern actors participated in the network. Additional Social Network Analysis research designed to map the various types of interactions and relationships that exist within the innovation system beyond ArcticNet, with a specific focus on the Northern actor participation, would be valuable.

3.6 Acknowledgements

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Preface to Chapter 4

Chapter 3 identified the organization and evolution of networked science-based innovation actors in a Canadian Arctic research network from 2004-2017. While the analysis provides a structural description of network attributes and identifies key boundary spanning actors, findings point to the need to also consider network-level relationships and outcomes. Building on the identification of science-based innovation actors (Chapter 3), Chapter 4 shifts the analytical focus towards the level of the network, examining the Network Administrative Organization (NAO) as a unit of analysis. Engaging the same Canadian Arctic research network, Chapter 4 employs Public Value Mapping (PVM) to identify network-level public values articulated by the network's NAO and discusses the implications of this approach for network-level evaluation efforts.

Chapter 4. Exploring the Articulation of Public Values in an Arctic Research Network: Identifying Considerations for Network-level Evaluation

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Abstract

Since the societal benefit of a research network is often assumed yet rarely assessed, we employed Public Value Mapping (PVM) to examine the articulation of network-level public values in a large Arctic scientific research network. Using the networks Network Administrative Organization (NAO) as the unit of analysis, the study aims to provide reflections for the design of network-level evaluation strategies. The analysis reveals that the NAO targeted a broad range of publics and six broad network-level value categories were identified (scientific excellence, useful information, collaboration and partnership, environmental change, network legacy, and nation building). Findings suggest that PVM is a promising approach for eliciting a deeper understanding of the multiple network-level public values associated with a large research network. In order for network-level public values to be reliably assessed, research networks need to ensure consistency in value articulation across public facing documents, articulate values and activities at the appropriate level of organizational, geographic or time scale and clearly identify network-level outcome attributes. Potential opportunities for developing more holistic network evaluation practices include establishing evaluation tools that better assess dynamic and emergent network-level public values, consulting multiple publics in evaluation efforts, defining how network boundaries are drawn for evaluation purposes and designing policies that support value articulation in complex networks.

4.1 Introduction

Publicly-funded scientific research is increasingly expected to address public policy objectives and contribute towards practical solutions for complex global problems (McNie, 2007; Potvin & Armstrong, 2013; Sivertsen & Meijer, 2020; Turnhout et al., 2013). Often seen as a tool for regional development, science has been enlisted in efforts to promote technological development, economic growth, capacity building, and provide evidence to inform policy and practice (Arocena et al., 2019; DFID, 2014; Hiruy et al., 2019; Pearson et al., 2012). This trend has been largely linked to a recognition that scientific endeavours have the potential to generate a range of public values[11] that extend beyond traditional academic and economic aims (i.e., scientific excellence, return on investment) (Bornmann, 2013; Bozeman & Sarewitz, 2011).

A commonly adopted strategy to support science-informed value creation has been to establish formal transboundary research networks (McNie et al., 2016; Wardenaar et al., 2014). By coordinating a variety of scientific and non-scientific actors, multi-actor research networks can offer opportunities for collaborative action, resource pooling, and collective innovation (Beebeejaun et al., 2015; de Raymond, 2018; Hessels, 2013; Joly et al., 2015; Roux et al., 2010). Such networks can foster public value creation by: overcoming the limitations of direct government intervention; recognizing the need for broad coalitions of interests to overcome political imperatives in order to solve problems; capturing second order effects that create interdependencies; and coping with layers of mandates and requirements (Agranoff' 2007;

[11] Bozeman (2007) defines the public values of a society as: "*those providing a normative consensus about (a) the rights, benefits, and prerogatives to which citizens should (and should not) be entitled; (b) the obligations of citizens to society, the state and one another; and (c) the principles on which governments and policies should be based*" (p 13). Scientific activities have the potential to generate a broad range of benefits and relevance for several public values (e.g., scientific, economic, social, political, cultural, political, health and environmental values) (Bozeman & Sarewitz 2011; Joly et al. 2015).

O'Toole, 1997). However, despite the potential for value creation through research networks, their inherent public value cannot be assumed, instead careful network-level evaluation approaches are required to ensure their performance (Bixler et al., 2019).

Given that the main benefit of a research network comes from the ‘network effects’ arising from collaborative activities, it is important that evaluation efforts reflect the impact of the whole network, and not only the individual components that make it up (e.g., researchers or projects) (Bercovitz & Feldman, 2011; Heimeriks et al., 2003; Leite & Pinho, 2017a; Newig et al., 2019; Noble et al., 2017; Wixted & Holbrook, 2012). This has been identified as a gap in existing research evaluation frameworks, with few tools available to assess the nature and breadth of public value impacts, particularly as they relate to the multi-dynamic nature of interacting actors, interests, institutions, and values associated with networked science (Budtz Pedersen et al., 2020; Wixted & Holbrook, 2008, 2012). To date, network-level attributes have been largely underused in research evaluation efforts (Lee & Bozeman, 2005; Leite & Pinho, 2017b; Rogers et al., 2001; Wixted & Holbrook, 2008, 2012), and although several assessment and evaluation frameworks have been developed to conceptualize and capture the societal impacts of research, as summarized in a recent review by (Budtz Pedersen et al., 2020), they have yet to focus on network-level attributes. Addressing this gap has the potential to help research networks since effective research evaluation can support improved social accountability, inform funding decisions, and identify management strategies for improved public value creation and delivery (Penfield et al., 2014).

Public Value Mapping (PVM) is an existing approach for identifying the public values created through scientific research. It provides a set of analytical tools which can help to elevate the deliberation of non-economic and scientific public values in order to offer more robust reflections on both policy problems and solutions (Welch et al., 2015). The foundations of PVM are rooted in the notion that the value generated by scientific knowledge is embedded within groups of users and producers of that knowledge, what Bozeman (2003) refers to as 'knowledge value collectives.' These collectives depend on collaborative interactions between diverse actors working together to transform scientific knowledge into something of value for the public (Bozeman, 2003). While PVM has been previously used to inform the development of evaluation standards for research impacts and outcomes (Bozeman & Johnson, 2015; Welch et al., 2015), it has yet to be applied at a network-level, offering an opportunity to garner new insights for research network evaluation.

Our objective in this paper is to assess the network-level public values associated with a publicly-funded research network in order to inform network-level evaluation approaches. Focusing on a research network operating in the Canadian Arctic as our case, and the Network Administrative Organization (NAO)[12] as the unit of analysis, we employ PVM to identify the target 'publics,' create an inventory of public values over a 14-year period and identify management considerations for capturing and evaluating network-level public values. Such longitudinal analysis has been previously identified as lacking in PVM scholarship (Fukumoto & Bozeman, 2019). In what follows we review the literature on network governance, network evaluation and mapping public value before presenting the case study.

[12] One way of organizing a formal network is to establish a *Network Administrative Organization (NAO)*, which is an organization that is responsible for facilitating, coordinating, supporting and serving network-related activities (Provan & Kenis, 2008)

4.2 Theoretical Background

4.2.1 Governing research networks: The NAO

Networks are inherently goal-directed and deal with complex problems that require coordinated, shared or centralized governance (Provan & Kenis, 2008). There are three common ways to coordinate and govern network relationships (i.e., shared governance, network led organization, and network administrative organization) (Provan & Kenis, 2008). In this paper we focus on *the Network Administrative Organizations (NAO),* which are organizations created specifically to administer, coordinate, govern and oversee all activities and decisions associated with a network (Braun, 2018; Provan & Kenis, 2008). While a NAO is an organization designed to serve its members, it does not participate as a member of the network and instead operates as a separate entity – either a non-profit or for-profit organization (Braun, 2018; Schuh & Woelk, 2015). NAOs can be organized around a single individual who acts as a network facilitator or they can have a formal organization consisting of a board of directors and staff (Braun, 2018). Common NAO tasks include: selecting membership by identifying new network members and removing members who are inactive or fail to meet network requirements, allocating and coordinating resources and tasks, regulating formal contracts and agreements as well as inter-organization cooperation, evaluating the effectiveness of joint activities, and supporting network members by fostering knowledge sharing processes (Sydow et al., 2015). Collectively the actions of the NAO are intended to achieve network goals and guide the future of the network (Schuh & Woelk, 2015), making it an important entity for creating network-level effects.

4.2.2 Evaluating public value in formal research networks

As scientific research transitions from an uncoordinated endeavor taken by independent actors towards more formalized, collaborative network structures there is an increased need to evaluate processes and outcomes (Trochim et al., 2008). Research evaluation includes *"any systematic, data based (including qualitative data) analysis that seeks as its objective to determine or to forecast the social or economic impacts of research and attendant technical activity"* (Bozeman & Sarewitz, 2011, p. 8). To date, evaluations of cross-sector research networks have largely targeted structural aspects of network-level collaboration, employing Social Network Analysis (Ginexi et al., 2017; Klenk et al., 2010), and collaborative configuration tracing techniques (Oancea et al., 2017). These efforts have mostly focused on economic-driven innovation networks, offering few insights into the design of formal research networks that aim to produce and support more policy relevant science (Klenk & Hickey, 2012).

From a design perspective, it is important that network-level assessments reflect 1) the purpose of the network and evaluation, 2) the scale and form of the network, and 3) outcome attributes associated with network effects (Wixted & Holbrook, 2012). Design should also include an explicit understanding of the 'publics' that the research network is responsive to (Klenk & Hickey' 2012; O'Toole, 1997). Clarifying these factors are important because there are often mismatches between the evaluation approach adopted and network-level aims (Wixted & Holbrook, 2012). Alignment is important since evaluation approaches are founded in different assumptions about the purpose and nature of knowledge production, definitions of relevance and value, and the mechanisms by which value creation is achieved, measured, and evaluated (Penfield et al., 2014). The effective design of research evaluation activities has the potential to subsequently impact research processes and public value outcomes (Molas-Gallart et al., 2016), in turn shaping the allocation of resources, the governance of the network as well as the effectiveness, lifecycle and sustainability of the network (Wixted & Holbrook, 2012).

Given the intricacies of evaluation design, it is important that network evaluation approaches adopt the network as a unit of analysis in order to adequately capture network-level effects. Introduced earlier, PVM is an approach that has been developed to encourage reflection on the range of public values created by scientific efforts (Bozeman, 2007a) and has potential utility for network-level evaluation. A key feature of thinking around public values is that they serve as a basis for collective action (Bozeman & Sarewitz, 2011). While PVM has typically focused on the outcomes of collective action as it relates to research, we reframe the approach to consider network-level impacts, focusing on the creation of network-level public values (See Figure 4.1).

4.2.3 Understanding public value failure through PVM

When applied to research evaluation, PVM directs the valuation of scientific research to include a range of scientific, economic, social, political, cultural, health, and environmental values (Bozeman & Sarewitz, 2011; Joly et al., 2015). A core rational for developing and applying PVM in the context of research evaluation is the notion that the focus of science policy should be on social goals and public values (Slade, 2010). However, despite increasing policy interest in science for public value, it has been argued that public value is often *"displaced, minimized, misrepresented or altogether missing"* in publicly-funded science programs (Bozeman & Sarewitz, 2011). Such *public value failure* often emerges when a community agrees on a shared value (e.g., that research should have societal impacts) and then that value is not achieved (Bozeman & Sarewitz, 2005, 2011; Welch et al., 2015). This tends to occur when the demand for scientific excellence (and economic value) takes priority over other goals that are more closely linked to societal outcomes (Bozeman & Sarewitz, 2011). Additionally, *public value failure* can occur when institutions and agencies lack the mechanisms for effective value articulation,

Figure 4.1 Model for conceptualizing network-level public values in research evaluation

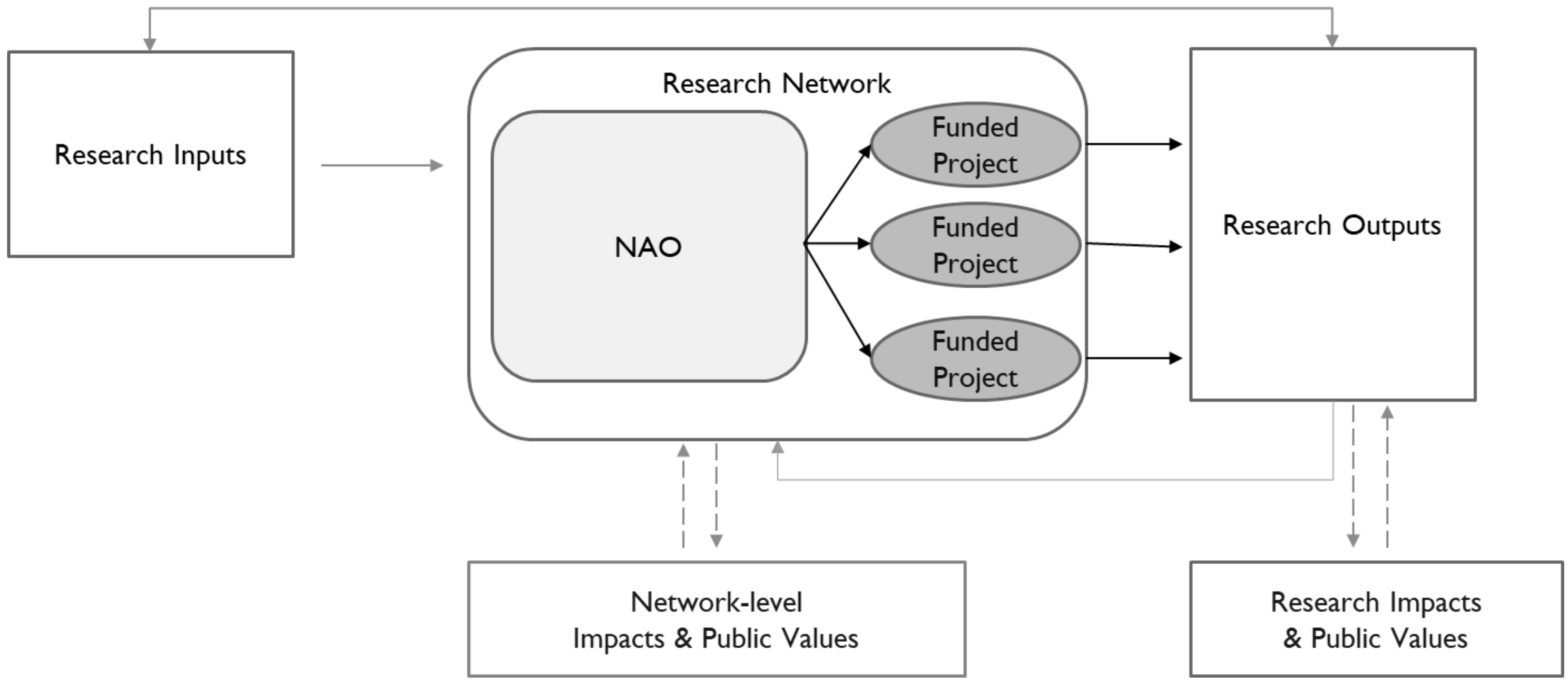


Figure 4.1 builds on Bozeman's (2003) model for conceptualizing public values in research evaluation to represent an adapted and expanded conceptualization for networked science. The figure has been interpreted to capture network-level impacts and public values resulting from a research network governed by a Network Administrative Organization (NAO). Solid lines capture resource and knowledge flows and dashed lines represent relationships with impacts. The processes identified are nested within unique institutional and public value contexts that are shaped by available capacity (scientific, technical, and human) and mediators of social change.

aggregation and communication (Bozeman, 2007a; Welch et al., 2015) or when there is incoherent public value logic within a program or an agency (Meyer, 2011). Failing to deliver and create public value can have negative implications for future research, partnerships, and societal outcomes (Beebeejaun et al., 2015).

The aim of PVM is therefore to facilitate reflection on the interplay between the variety of public values created (or not) (Bozeman, 2003; Welch et al., 2015). It can provide insight to the divergence between identified values and actual intent by examining connections between research goals and objectives (Meyer, 2011). It also encourages discussion around the 'publics' that the network is responsive to. The PVM heuristic can be used by public managers to determine what, how, where, when, and why public value should be created, and often by which organizations or institutions (Bryson et al., 2014). Since PVM is not prescriptive in the public values assigned to a specific program or organization, the values identified by PVM will reflect the goals of the project/ program/ organization under study as well as potential gaps in value creation and accountability practices (Bozeman, 2003; Joly et al., 2015; Welch et al., 2015). While PVM relies on publicly available claims of value that may be used for political gain or preserving the status quo, the identification of these values can help to identify discrepancies between articulated value and action, i.e., identify areas of potential public value failure (Meyer, 2011). PVM has been previously applied to understand publicly-funded science projects and programs in a variety of fields including, nanotechnology (Fisher et al., 2010; Slade, 2010, 2011), climate change (McLaren Meyer, 2010; Meyer, 2011), synthetic biology (Ribeiro & Shapira, 2020), breast cancer (Gaughan, 2003), bio-technology, and agriculture (Gupta, 2003; Joly et al., 2015; Matt et al., 2017; Quiedeville et al., 2017). In this paper we apply PVM to a publicly-funded Canadian research network focused on climate change in the Arctic.

4.3 Case Study

4.3.1 Research context: The Canadian Arctic

Arctic governments are faced with addressing substantial and complex challenges associated with concurrent social and environmental changes resulting in a high demand for socially and politically relevant scientific research (Ford et al., 2015; Huntington et al., 2019; Petrov et al., 2016; Wormbs & Sörlin, 2017). While a public value imperative for science exists, several reports have implied a high occurrence of *public value failure,* with Arctic scientific activities increasingly viewed as disconnected from political, social or economic priorities and outcomes (de la Barre, 1979; ITK, 2016, 2018; Simon, 2017). Evidence suggests that Arctic scientific research has been largely driven by the pursuit of scientific outcomes rather than the issues highlighted by northern communities (e.g., health, poverty, education, cultural vitality, equity, justice) (Brunet et al., 2016; Huntington et al., 2019; Ibarguchi et al., 2018; ITK, 2016, 2018; Ogden et al., 2016).

Attempts to design more socially responsive Arctic science have focused on adopting collaborative, transdisciplinary, and networked approaches (Brunet et al., 2014; Lee et al., 2015). For example, the Canadian government has funded several scientific research networks in efforts to support collaboration, promote nation building, foster development, and stimulate innovation in the Arctic (Bocking, 2007; England, 2010). Such approaches are inclusive of the diverse range of scientists, stakeholders, and rights-holders who need to come together to access information and make decisions on Arctic issues (Nilsson & Koivurova, 2016; Pigford et al., 2017; Wong et al. 2020). However, although research networks exist, the inherent networked nature of Arctic science has been largely overlooked in evaluation efforts (Pigford et al., *Submitted* – see Chapter 3), making this context an opportune setting in which to explore our research objectives.

4.3.2 The case: ArcticNet, An Arctic NAO

4.3.2.1 Overview

The Canadian government funded ArcticNet, a formal Arctic scientific research network, as part of large-scale Arctic science investment efforts in the early 2000's (England, 2010; Institute On Governance 2005). ArcticNet Inc. was incorporated as a not-for-profit corporation in December 2003 creating a formal Network Administrative Organization (NAO) to manage the network, as required by the Networks of Centres of Excellence (NCE) program (Wixted & Holbrook, 2012). The role of the NAO was to engage a variety of publics and bring organizational actors from various sectors together to examine the impacts of climate change in the coastal Canadian Arctic (ArcticNet, 2020). ArcticNet consists of actors from universities, northern and Indigenous communities, governments, non-profits, and private-sector firms (Pigford et al., *Submitted* – see Chapter 3). The network's core mandate is to create public value by translating science into impact assessments, national policies, and adaptation strategies (ArcticNet, 2020). ArcticNet Inc. is hosted at the Université Laval in Quebec City, Quebec, Canada.

4.3.2.2 Duration & funding

ArcticNet receives funding through the Canadian NCE program. Historically, each funded NCE was supported by the program for up to 14 years (two 7-year terms); however, in 2017 it was announced that the NCE program would be terminated and one final funding call was held, allowing existing networks to apply for an extension (Glauser, 2017). ArcticNet was successful in the renewal and has received $146.2 million (CAD) (2003-2025) from the NCE program and over $276.1 million (CAD) from partner organizations (GoC, 2020). A review of publicly available annual financial reports suggests that the majority of this funding has been directed towards supporting multidisciplinary, cross-sector Arctic research efforts.

4.3.2.3 Organizational structure

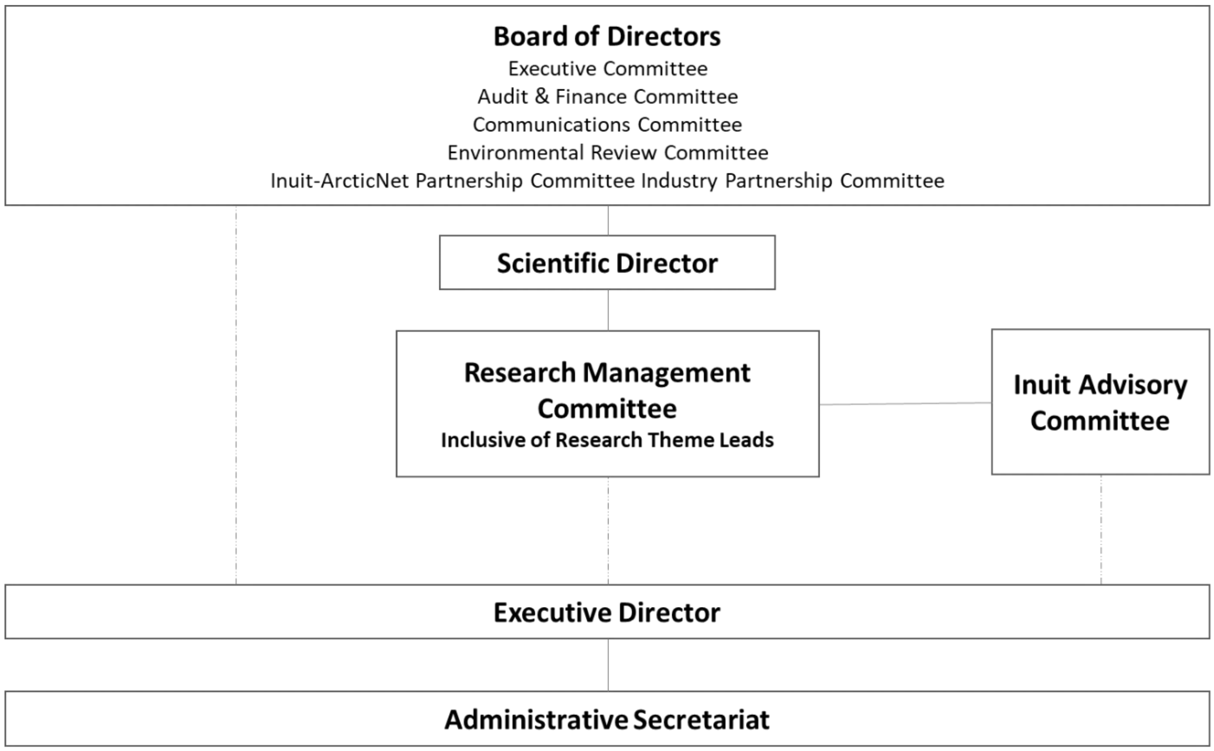
ArcticNet Inc. is governed by a Board of Directors (BoD) made up of senior officials from university, government, industry, and Inuit organizations (see Figure 4.2 for an Organizational Chart). The BoD is responsible for the overall governance of the network and is supported by several subcommittees. A Scientific Director appointed by the BoD provides scientific direction and strategic leadership to the network, participating on the BoD as an ex-officio, voting member and acts as the Chair of the Research Management Committee (RMC). The RMC is comprised of four Research Theme Leaders, the Executive Director (non-voting) and members from Inuit organizations, government, and industry. It manages the research program and assesses all research projects, providing recommendations to the BoD via the Scientific Director on research priorities and budget allocations. An Inuit Advisory Committee reports to the RMC providing guidance and recommendations to the RMC with respect to Inuit needs and priorities. The Network also includes an administrative centre known as the ArcticNet Secretariat, which is directed by an Executive Director who is supported by a team of staff who are responsible for the administration of the network (including reporting and evaluation). The Executive Director is also the Vice President and Chief Operating Officer and is an ex-officio non-voting member of the BoD and all sub-committees, the RMC, Communications Committee and the Inuit Advisory Committee. Parallel to ArcticNet Inc. was the establishment of the ArcticNet Student Association (ASA) which is governed by an Executive Committee. The ASA was created by graduate students to produce host national and regional meetings and opportunities for training.

4.3.2.4 Funding & evaluation practices

ArcticNet's cycle of operations and evaluation are organized around funding collaborative research projects, synthesizing research outcomes and then mobilizing and sharing new knowledge to benefit Canadians (NCE, 2016). ArcticNet organized its call for research proposals around strategic research themes and distinct research phases. While these themes changed over time, the call for proposal process remained the same. Project Leaders from academic institutions submitted proposals to ArcticNet and a peer review process engaging the RMC and IAC resulted in the awarding of funds to successful Project Leaders and their teams. As per NCE criteria, each collaborative research team funded by ArcticNet was required to leverage funding from other sources and illustrate connections, ideally from another sector in order to foster new relationships (Bramwell et al., 2012). Research projects were funded by ArcticNet in five distinct phases, with a call for proposals for each phase (Phase 1 2004-08; Phase 2 2008-11; Phase 3 2011-15; Phase 4 2015-18; Phase 5 2019-2022).

As a funded NCE ArcticNet is required to adhere to NCE reporting practices. Each year Project Leaders submit an activity report to ArcticNet and the Secretariat compiles this information to provide an annual comprehensive activity report to the NCE. The NAO is evaluated once mid-term (a term is 7 years) on its ability to meet the following criteria: management and governance; networking and partnership; excellence of the research; highly qualified personnel (HQP) development; knowledge and technology exchange and exploitation.

Figure 4.2 ArcticNet Inc. organizational chart*



Legend

Solid lines = direct relationship

Dashed lines = ex-officio, non-voting relationship

*Interpreted from information in ArcticNet Annual Reports from 2004-2017.

4.4 Methodology

4.4.1 Analytical approach

Informed by Public Value Mapping (PVM) (Bozeman, 2003; Bozeman & Sarewitz, 2011; Joly et al., 2015; Welch et al., 2015) and network evaluation design considerations (Wixted & Holbrook, 2012), a three-step analytical approach was adopted for this study. This involved 1) identifying the stakeholders/publics targeted by ArcticNet; 2) using PVM to articulate the network-level public values associated with ArcticNet; and 3) examining links between network-level public value articulation and core network evaluation design elements (purpose, scale, attributes). A detailed qualitative content analysis of the NAO's public facing documents informed each step (Hsieh & Shannon, 2005; Neuendorf, 2016). Since our focus is on the public values associated with the NAO, the analysis pays particular attention to the role of the network as a unit of analysis. Thus, an analysis of funded research projects was not included and was beyond the scope of this study.

Thirty-eight documents published between 2004-2019 were reviewed to document and describe ArcticNet's network-level public values (Table 4.1 and Appendix A for details). Data sources were identified through consultation with ArcticNet in the summer of 2018 and via key-informant interviews (McGill Research Ethics Board file 44-0618) and were obtained using an online search. While ArcticNet has funded 5 phases of research projects, the 5th phase is ongoing and documentation (annual reports and/or compendia) are unavailable. We therefore focused on the 14 years representing the four completed phases (ending in 2018) and associated publicly available documentation.

Table 4.1 Description of data sources

Report Type	**Number**
ArcticNet Newsletters	2
(Bi)annual Reports	10
Conference Proceedings	14
Research Compendia	8
Integrated Regional Impact Studies (full reports)	4
Total	38

4.4.2 Identifying target 'publics'

Since research networks are generally expected to be responsive to all stakeholders/publics invested in the network, the first step in our analysis was to identify the publics targeted by ArcticNet. The was done by reviewing documents to identify the groups and individuals (i.e., stakeholders or publics) targeted by the NAO in public value statements (Slade, 2011). Given that the potential breadth of publics targeted by network activities may differ from those at the project level, publics targeted by individual research projects were not considered.

4.4.3 Creating an inventory of network-level public values

Using tools from PVM, several steps were conducted to inventory ArcticNet′s network-level public values (Bozeman, 2003; Bozeman & Sarewitz, 2011; Joly et al., 2015; Welch et al., 2015). Network-level public values associated with ArcticNet were identified from several public sources (Table 4.1). To provide an impression of the scope of public values associated with networked Arctic science a survey of public documents was conducted to develop an inventory of public values, similar to the approach adopted by Jørgensen & Bozeman (2007) and Slade (2011). Given that few studies provide methods of classifying values, and no single approach or typology is accepted (Jørgensen & Bozeman, 2007), we adopted an iterative process to identify values whereby documents were reviewed, open coded and once codes were developed / values identified, previously coded sections were recoded with the updated value list. Both intrinsic values representing a desired end state and instrumental values adopted as a means to achieving intrinsic values were included in the set of values (Bozeman, 2007b). The identified values were then grouped under overarching themes / broad value categories to facilitate analysis and discussion.

A detailed qualitative content analysis was also conducted using the NAO's documentation to identify the actions articulated by the NAO in order to complement the inventory of public values generated. Since this analysis sought to capture the network-level public values rather than demonstrate *public value failure,* we did not generate hypothetical procedural and logical connections between values and outcomes. However, our efforts to identify the NAOs actions have the potential to form the foundation of logic models that could be used to assess public value failure in ArcticNet.

4.4.4 Interpreting network-level public values in the context of evaluation

To situate our analysis within the context of network evaluation, we also consider how the process of identifying publics and values relate to the core design elements of network evaluation (purpose, scale, attributes) (Wixted & Holbrook, 2012). The articulated purpose of the ArcticNet NAO is to support and manage a diverse network of actors with the goal of translating collaborative science into impact assessments, national policies, and adaptation strategies (i.e., create public value) (ArcticNet, 2020). To help unpack this purpose and how it might be evaluated from the perspective of the network, we first considered how ArcticNet has been evaluated and then how the public values identified at the level of the ArcticNet NAO may present further insight. We also consider the scale upon which network-level activities take place and explore the attributes upon which a network-level public value evaluation could be based. Findings are contextualized using information obtained through scoping interviews with ten key ArcticNet stakeholders (for methodological details see Section 1.5) as well as the broader Arctic research literature.

4.5 Findings

The review of NAO documentation between 2004 and 2019 revealed a wide breadth of intended publics and public value statements.

4.5.1 The publics targeted by ArcticNet

ArcticNet identifies a complex tapestry of potential publics that are assumed to benefit from network activities (Table 4.2). Most of the identified publics are intended end-users, which would benefit from the outcomes of network activities, such as the knowledge produced by network-funded research projects or subsequent adaptation strategies and policies. Since ArcticNet positions itself as the source of expertise and knowledge, end-users are an essential target public, assigned with responsibility for taking the knowledge generated by ArcticNet and transforming it into useful products such as strategies and policies. Rather than identifying specific actors, the target end-user publics identified in NAO documentation are commonly presented as lists of broad sectors or groups, inclusive of anyone with an interest in the Arctic. For example:

> *…ArcticNet will be the leading supplier of expertise (1) to prepare Northerners for the potential impacts and opportunities of climate change and modernization; (2) to inform decision in government and industry on Arctic issues and development; and (3) to help build capacity at all levels of northern societies. [Annual Report: 2009-2010]*

ArcticNet also identifies several publics that derive concrete or hypothetical benefit from involvement in network processes, participation, and engagement. These actors may be engaged by the NAO in short-term and/or long-term engagements, including funded researchers and a range of formal partnerships and agreements at the level of the NAO. For example, many scientists/researchers benefit from NAO activities that provide targeted funding, access to research infrastructure and opportunities to share their findings at conferences and meetings. Northern researchers were also targeted by NAO funding activities:

> *While Network Investigators actively address northern issues through their research initiatives, ArcticNet has gone one step further by funding northern partnership projects to directly engage northern communities or organizations in collaborative research efforts. As research for Northerners by Northerners, the three new Northern Partnership projects are co-led by Canadian academics and northern partners. [Annual Report: 2006-07]*

ArcticNet was awarded $815,000 in 2007 to facilitate the creation of an alliance of Arctic research networks (GoC, 2007) and also sought agreements and memoranda of understanding with other organizations (e.g., ArcticNet – SEARCH/Study of Environmental Arctic Change (USA), 2007/09; ArcticNet/Université Laval – ARCTOS Network/The Arctic University of Norway, 2014; ArcticNet – Centre national de la recherche scientifique (France), 2014). The NAO also established formal partnerships with several companies in the oil and gas sector (e.g., Imperial Oil, British Petroleum, ExxonMobil, Statoil Canada, Husky Energy). Several key publics represented in the network's governance structure are also assumed to benefit from their participation in network governance (see Case Study in Section 4.3 for details). Although a range of process-based publics are identified, public facing documents largely lack content from these publics, with the exception of a note from the Inuit Co-Chair in several ArcticNet Annual Reports (2004/05 to 2014/15).

Table 4.2 Sample of identified 'publics' targeted by ArcticNet

Targeted public	Illustrative Statement from Annual Reports [report details]
Canadian public	…focus its research efforts on priority issues for Canadians as they deal with the challenges and opportunities of climate change and modernization in the North. [2011-13] ArcticNet strives to translate our growing understanding of the Arctic into impact assessments, national policies and adaptation strategies for the Canadian public as well as government and industry stakeholders (oil and gas, navigation, mining, tourism, hydroelectric) whose mandate it is to manage a changing Arctic. [2014-15]
Global	As we have come to understand the important role the Arctic plays in global climate cycles and regulation, the work we do is of benefit to all of humanity. [2010-11] ArcticNet and its partners continue to work to enhance the development and direction of strategic Arctic research and work with international Arctic interests to develop innovative and global approaches to Arctic change [2011-13]
Governments, decision makers and policy makers	Key indicators of change and variability will provide the background necessary to make effective policy, management and governance decisions by all levels of government. [2005-06] Science results empower decision-makers at all levels with the information necessary for effective strategy and policy development to address climate change and modernization in the Canadian Arctic. [2007-09] ArcticNet's uniqueness in the world of Arctic research is expressed through its constant efforts to translate scientific knowledge into recommendations that inform policy and help decision-making. [2011-13] Communicating results to non-scientific audiences is central to the Network's mission and ArcticNet strives to provide information that will allow policy makers to make informed decisions. [2013-14] At the community level, access to results enables individuals to make informed decisions about their environment. It also helps decision makers in addressing the issues that Northerners deal with on a daily basis. [2011-13]
Industry	Other users of ArcticNet deliverables include industry (oil & gas, navigation, mining, hydroelectricity), and government departments with a mandate to manage a changing Arctic [2010-11] Through these [oil industry] collaborations and other ongoing network research activities, ArcticNet is now an important player in informing policy makers on the complex issues linked to oil and gas development in the Canadian Arctic. [2011-13]

Targeted public	Illustrative Statement from Annual Reports [report details]
Northerners and Inuit (national and international)	Helping Canadians, particularly Inuit and other Northerners living in the coastal communities of the Canadian Arctic, adapt to their changing environment is at the core of the Network's research program. [2011-13; 2013-14; 2014-15] …as we work towards the most effective utilization of the important knowledge gained from the hard work that has been done to make positive differences in the lives of Inuit, northerners, Canadians and others the world over. [2010-11] Over the life of the Network, we have observed the broadened scope, outreach and awareness to the other Inuit regions in Greenland, Alaska and Chukotka by ArcticNet [2013-14]
Scientists / Researchers	Addressing these cascading issues requires that researchers transcend the boundaries of scientific disciplines, share information and resources, and focus on effective management options. [2005-06] Disseminating the findings and the results of our research is a key component of ArcticNet's mission. We share our knowledge with an increasing number of stakeholders, from decision makers to fellow scientists and the general public. [2011-13; others]

4.5.2 An inventory of ArcticNet's public values

The public value inventory resulted in the identification of six broad categories of public values articulated in the documents assessed (Table 4.3, Figure 4.3). The broad value categories focus on the most common and consistently mentioned values in strategic documents throughout the lifespan of the network. While four of the six value categories were obvious from a review of high-level value signaling statements (e.g., mission and vision statements, articulated network objectives), the remaining two value categories emerged through a detailed review of the NAO documentation (Political values: Nation building and Network legacy). Value categories are interdependent with scientific values underpinning other values, priorities, and actions at the core of the NAO (Figure 4.3). Scientific values also had the most clearly articulated steps of how the NAO planned to achieve its desired values. Value categories are expanded on in the section below. Table 4.3 presents a list of intrinsic and instrumental value sets and associated value categories. A longitudinal sample of NAO actions identified in high-level network value statements (e.g., mission, vision, objectives) are also included to give a sample of how values changed over time. The values list is not hierarchical, and we do not draw linkages between different values, although there is overlap between categories. The list of values articulated by ArcticNet are varied and can be at times in conflict with one another; however, the goal of this analysis was to identify values rather than assess their relevance. The inventory of NAO public value statements used to create value categories and sets included value statements related to promoting cultural, technological and economic development; however, these statements were less common and typically implied as a downstream outcome from policies and strategies developed by end-users or activities carried out by partners. In some cases, intent for value creation was expressed without follow-up; for example, ArcticNet expressed intent for *"A new call for proposals will be issued in 2013 for* *research in the adaptation of technologies to northern conditions"* (Annual Report 2009/10), yet there is no future mention of such an activity. This finding suggests that some of the NAO values are in contrast with typical NCE rhetoric which generally focuses on economic values linked to technological innovation and the commercialization of research activities (NCE, 2016).

4.5.2.1 Scientific excellence

The need to support and maintain a successful interdisciplinary, cross-sectoral scientific program that produces high quality science is emphasized in all ArcticNet documents. This includes network-level values related to engaged scholarship, team science, and access to research infrastructure, among others (see Table 4.3). The majority of NAO activities are designed to support and promote high quality scientific research by funding scientific collaborative research projects, hosting scientific meetings, facilitating access to research infrastructure, recruiting excellent scientist, partnering to train future experts / highly qualified personnel, and establishing formal research partnerships with other sectors. Through its funded research the NAO supports research teams that cut across disciplinary boundaries (natural, health, and social sciences), and sectors in order to produce novel scientific findings.

> *The networking made possible by ArcticNet has tremendously leveraged the research conducted in the coastal Canadian Arctic by the best teams in Canada. [Annual Report 2005-06]*

Reports emphasize the excellence of funded projects and researcher teams, highlighting publications in top-quality academic journals and presentations at prestigious events. The NAO also acts as a platform to amplify and promote successful researchers and graduate students, publicly recognizing those who have received awards for their work on ArcticNet funded (or parallel) projects, also funding two Canada Excellence Research Chairs.

Figure 4.3 ArcticNet public value categories

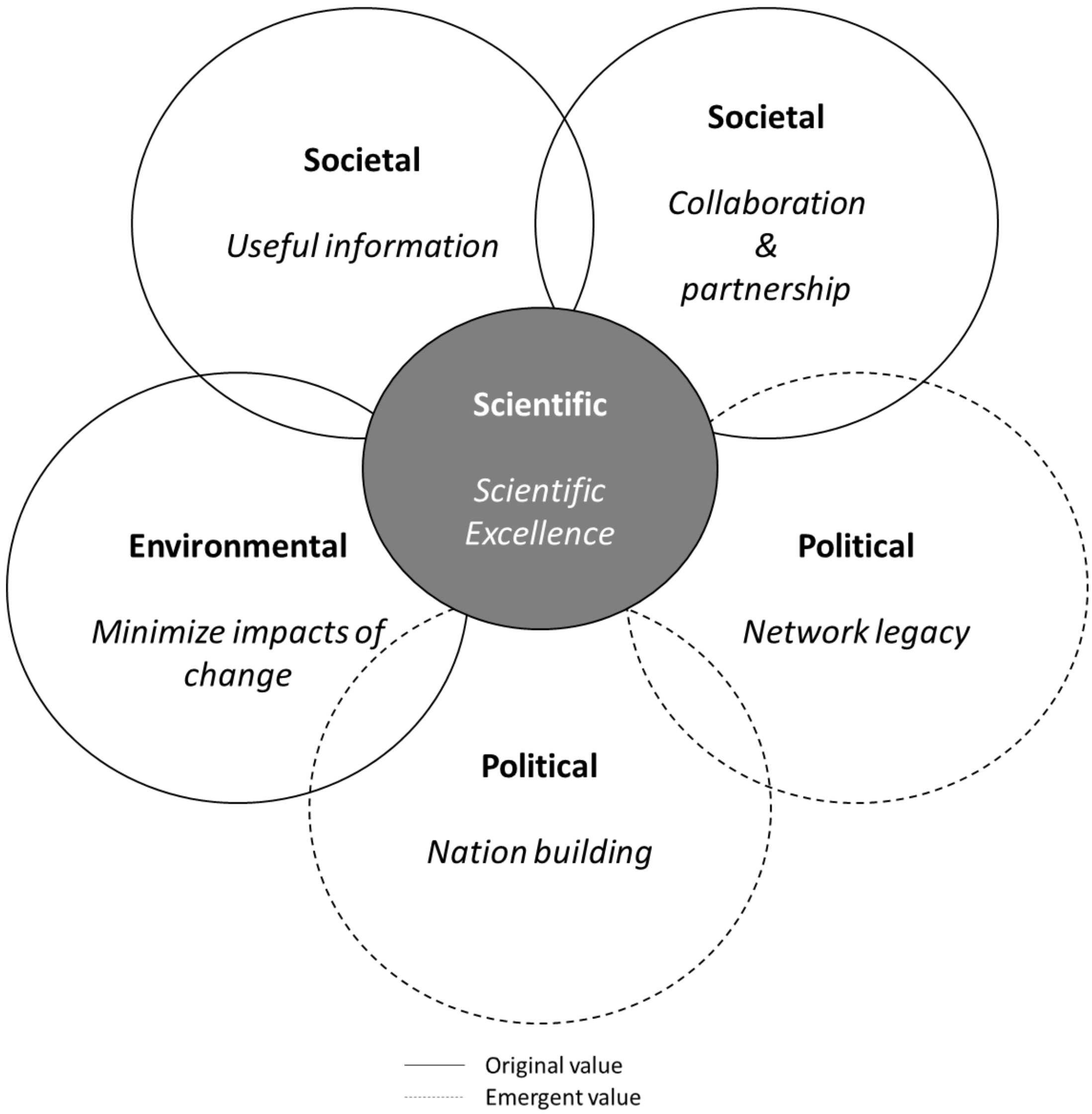


Figure 4.3 reflects the interdependence of the six network-level public value categories articulated in ArcticNet documentation. Solid lines indicate values that were explicitly mentioned in value signaling documentation, whereas dashed lines indicate emergent values. Scientific values are at the core of the NAO and underpin all values, priorities, and actions.

Table 4.3 Network-level public value articulation associated with ArcticNet over time

Value Category	Values	NAO goals outlined in high-level statements* [source]	Phase 1				Phase 2			Phase 3				Phase 4		
			04/ 05	05/ 06	06/ 07	07/ 08	08/ 09	09/ 10	10/ 11	11/ 12	12/ 13	13/ 14	14/ 15	15/ 16	16/ 17	17/ 18
Scientific: Scientific excellence	• Scientific excellence / high quality science • Access to infrastructure • Team science • Engaged scholarship • Researcher success • Capacity building • Education & training	Build synergy across disciplines [M]	x	x	x	x	x	x	x	x	x	x	x	x	x	
		Provide academics & collaborators with Arctic access [M]	x	x	x	x	x	x	x	x	x	x	x	x	x	
		Innovation in disseminating findings and research results [m]								x	x	x	x	x	x	
		Generate knowledge and assessments [CO]	C	C	C	C							C	C	C	C
		Knowledge exchange, monitoring, modeling and capacity building [V]		x	x	x	x	x	x	x	x	x	x	x	x	
		Train the next generation of experts, from north and south [M]	x	x	x	x	x	x		x	x	x	x	x	x	

Value Category	Values	NAO goals outlined in high-level statements* [source]	Phase 1				Phase 2			Phase 3				Phase 4		
			04/ 05	**05/ 06**	**06/ 07**	**07/ 08**	**08/ 09**	**09/ 10**	**10/ 11**	**11/ 12**	**12/ 13**	**13/ 14**	**14/ 15**	**15/ 16**	**16/ 17**	**17/ 18**
Societal: Produce useful information	• Useful information • Communication • Accessibility • Translational research • Knowledge translation • Responsiveness • Strategies • Policy interventions	Translate understanding into assessment, policies, strategies [M]	x	x	x	x	x	x	x	x	x	x	x	x	x	
		Conduct Integrated Regional Impact Studies (IRISes) [M]	C	C	C / x	C	x	x						C		
		Communicate to non-scientific audiences [m]								x	x	x	x			
Societal: Collaboration & Partnerships	• Representation • Collaboration • Partnership • Involvement of end-users • Leverage existing programs	Involve Northerners **[and Inuit]** in bi-lateral processes (governance & scientific) [M]	x	x	x	x	x	x	x	x	x	x	x	x **[x]**	x **[x]**	
		Involve government in bi-lateral processes (governance & scientific) [M]		x	x	x	x	x	x	x	x	x	x	x	x	
		Involve industry/ private sector in bi-lateral governance & scientific processes [M]		x	x	x	x	x	x	x	x	x	x	x	x	
		Consolidate international **[and national]** collab. [M]	x	x **[x]**	x **[x]**	x **[x]**	x **[x]**	x **[x]**	x **[x]**	x **[x]**	**x [x]**	x **[x]**	x **[x]**	x **[x]**	x **[x]**	

Value Category	Values	NAO goals outlined in high-level statements* [source]	Phase 1				Phase 2			Phase 3				Phase 4		
			04/05	05/06	06/07	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18
Environmental: Minimize the negative impacts of change	• Modernization • Globalization • Adaptation • Stewardship • Climate change	Ensure stewardship over the changing Arctic [M]	x	x	x	x	x	x	x	x	x	x	x	x	x	
		Observe ecosystem-level changes to address climate change & globalization [M]	x	x	x	x	x	x	x	x	x					
		Observe ecosystem-level changes to address climate change & modernization [M]										x	x	x	x	
		Prepare for the full impacts of environmental, economic and societal changes [CO]	C	C	C	C							C	C	C	C
Political: Nation building: Advancing the Canadian Arctic	• Arctic development • Sovereignty • Raising public awareness • Advocacy • Representation • Capacity building	N/A [emergent]														

Value Category	Values	NAO goals outlined in high-level statements* [source]	Phase 1				Phase 2			Phase 3				Phase 4		
			04/ 05	05/ 06	06/ 07	07/ 08	08/ 09	09/ 10	10/ 11	11/ 12	12/ 13	13/ 14	14/ 15	15/ 16	16/ 17	17/ 18
Political: Network legacy	• Voice of the future • Stability • Competitiveness • Adaptability • Continuity	N/A [emergent]														

Legend

X *= Annual Report*

C *= Compendia*

[M]= *Mission statement*

[V]*= Vision statement*

[CO] *= Central Objective*

[m] *= Mission stated in text, not in original mission statement*

[emergent] *= goals emerging from content analysis only*

** NAO actions are derived from high-level value statements and are not intended to be an exhaustive list of network actions.*

4.5.2.2 Useful information

In the context of networked Arctic science, the NAO emphasizes societal values related to producing ‘useful information’ that is capable of stimulating policy development and adaptation strategies:

> *ArcticNet’s research program continues to support a multidisciplinary approach to address the challenges facing the coastal Canadian Arctic, with the objective of filling identified knowledge gaps to help the formulation and implementation of policies and adaptation strategies. [Annual Report: 2014-15, 2015-17; Compendia: 2011-2012, 2012-13, 2013-14]*

Associated network values are linked to fostering translational research, responsiveness, knowledge translation, communication, data accessibility, strategies, and assessments. The NAO sought to create useful information for a variety of publics (see 5.1) and on a range of topics from industrialization to globalization, environmental change, economic opportunities, the health system, the education system and the culture of northern societies. Transforming scientific knowledge into useful information and then leveraging information into tangible societal outcomes relies on clearly articulated knowledge translation processes (McNie, 2007).

The main network-level mechanism employed by the NAO to support the production of useful information was four Integrated Regional Impact Studies (IRIS) which target resource managers and decision makers at all political levels:

> *An IRIS summarizes and combines knowledge and models of relevant aspects of the ecosystems of a region affected by change, with the objective of producing a prognosis of the magnitude and socio-economic costs of the impacts of change. The knowledge gained through this research process aids policy and decision makers in the development of policies and strategies for adapting to a changing Arctic environment. [Annual Report 2007-09]*

While overseen by the NAO, the IRIS process was delegated to four lead researchers who were each responsible for producing a comprehensive assessment for an assigned region. The IRIS process was dynamic and has been modified over time. In Phase 2, the network discontinued efforts for an IRIS that crossed the Canadian Arctic. Four IRIS Regional Impact Assessments were produced, with the final reports focusing on the Western and Central Canadian (2015); Eastern Arctic (2018); Hudson Bay (2018); and Eastern subarctic / Nunavik and Nunatsiavut (2012).

Other NAO mechanisms to promote useful information relate to communication and data management efforts. Several communication tools were developed to showcase the activities of the NAO. The ArcticNet website acts as a functional archive of network actions and related documents, including public facing reports produced throughout the duration of the network (e.g., (bi)Annual Reports, Newsletters, Research Compendia, Conference Proceedings). The NAO provided assistance in Canada's Arctic exhibit at the Vancouver Aquarium in 2009/10 and the ArcticNet Photo Gallery was formally launched in 2012 as Polar Photography. The collection of photographs capture ArcticNet funded research and have been used in a variety of promotional materials as well as print and electronic media and reports. NAO leadership also engaged with the media and attended political events to promote the network and share findings.

> *Long-term stewardship and accessibility of all data were priorities from the very beginning of ArcticNet, and the critical importance of these objectives was stressed numerous times by evaluators, partners and end-users of ArcticNet research, including Inuit community representatives. [Compendium: Phase 1 V1]*

Between 2007-2009 the NAO supported the creation of the Polar Data Catalogue along with the Canadian Cryospheric Information Network and the Department of Fisheries and Oceans Canada and in 2010/11 the ArcticNet Publications Database was established in partnership with Arctic Science and Technology Information System (ASTIS).

4.5.2.3 Collaboration & partnership

Collaboration and partnership represent strongly held societal values promoted by the NAO. Related network-level values included representation, inclusivity, partnership, consolidation, leveraging existing programs and relationships, and stakeholder/end-user engagement in research and governance processes. The NAO encouraged relationships that cross disciplines, sectors, and geographies to bring several initiatives together under one umbrella while also fostering new linkages. Annual meetings were hosted by the NAO to bring partners together in all years except 2011. Early in the network's lifespan the NAO placed emphasis on consolidating collaborations with international networks and researchers, supported in part by funds from the NCE's International Partnership Initiative. In later years, the NAO emphasized efforts to promote collaboration within Canada to consolidate research led by ArcticNet researchers (for example, see Annual Report 2014/15).

Stakeholder engagement was also seen as an important value and avenue to transform the scientific landscape, evidenced by NAO actions to engage Inuit, Northerners, industry and governments in research and governance processes (for target publics see 5.1). Collaborative partnerships were viewed as a mechanism to advance knowledge production:

> *Through collaborative partnerships, researchers also have access to the expertise of northern communities, regional authorities and governments across the four Inuit regions of Canada. [Annual Report: 2011-13]*

Access to research infrastructure was facilitated by partnerships between the NAO and the CCGS Amundsen, Québec-Océan, the Polar Continental Shelf Project, the Centre d'études Nordiques (CEN), the Nunavik Research Centre, the Churchill Northern Studies Centre, the Aurora Research Institute and the Nunavut Research Institute, among others. From a governance perspective, particular emphasis was placed on engaging Inuit at the beginning of the network, with the Inuit co-Chair of the Board noting:

> *The three Inuit members of the ArcticNet Board of Directors, along with a Science Management Committee, adopted a new Inuit model of scientific collaboration, laying out how ArcticNet will conduct research in the Arctic. We have ensured that each of the four Inuit regions in Canada hired an Inuit Research Advisor, to help coordinate the scientific work and to improve connections between scientists and communities. ArcticNet, after our first targeted call for new research proposals, contributed to the funding of four northern-led research project partnerships. [Annual Report 2004-2005]*

4.5.2.4 Nation building (Advancing and enhancing the Canadian Arctic)

Nation building is an emergent network-level political value category not identified in mission statements. Investment in ArcticNet by the federal government is a political act that sends clear signals about the priorities of the government. The creation of ArcticNet responded to the identified need to 'revitalize' Canadian Arctic science:

> *The year 2004–2005 will be remembered as a pivotal time in the revitalization of the Canadian effort in Arctic research. The rapid development of ArcticNet has triggered a significant and much-awaited revolution in the way northern research is conducted in Canada. [Annual Report: 2004/05]*

Establishing a 'new model' for Arctic science, the NAO promotes a networked approach that aims to work across disciplines and sectors as an avenue for consolidating efforts, bringing actors together while also acting as a model for stakeholder engagement and inclusion. By training students within this model, ArcticNet aims to

…train the next generation of Arctic specialists and to help establish new researchers in Canadian universities, federal departments and northern organisations. [Annual report 2007/09]

The nation building narrative extends beyond transforming the scientific landscape, linking to broader value sets associated with Arctic development, sovereignty, capacity building, advocacy, raising public awareness, giving voice to Canadian Arctic issues, and Canadian representation on the international Arctic stage. The NAO presents itself as an international leader on Canadian Arctic, bringing key issues to the forefront of national and international political agendas, while also aligning its strategic directions with broader Canadian political narratives:

The Network has also helped push Arctic issues to the forefront of the political agenda, stimulating the formulation of Canada's long-awaited Northern Strategy which will be ArcticNet's strategic roadmap during its next cycle of funding. [Annual Report: 2009/10]

Representatives from the NAO took an active role in several national and international forum including political and diplomatic venues, in order to advocate for the advancement of the Canadian Arctic through ArcticNet-related efforts (e.g., advocating for the CCGS Amundsen, developing international partnerships). Partnerships between the NAO and oil industry led to claims that ArcticNet is a major player for informing issues linked to oil and gas development in the Canadian Arctic, lending legitimacy to industry-sponsored scientific research. Key actors from the NAO (e.g., Scientific Director) also regularly spoke to the media in an attempt to raise awareness of Arctic issues among the general public. Ultimately, the NAO notes that as a result of ArticNet's efforts:

Canada is now leading the modern exploration of the Arctic and the global quest to understand the fate of this last frontier and its communities under the triple pressure of climate change, development, and modernization [Compendium: 2014-15]

4.5.2.5 Network legacy

Similar to nation building, network legacy reflects a political value category that emerged within network documentation. The NAO conveys values related to self-promotion, continuity, adaptability, stability, and a voice for the future. The majority of the NAO's efforts to establish a legacy focused on developing new models of partnership in the region and supporting projects that led to the development of models and best practices. Examples include, the ArcticNet co-funded 2004 Nunavik Health Survey, which informed the International Polar Year funded Inuit Health Survey in the late 2000's, or the adoption of the ArcticNet IRIS model by the Arctic Council *Adaptation for a Changing Arctic Assessment*. In their contributions to the annual reports, Inuit co-chairs speak of a potential long-term Network legacy, viewing ArcticNet as an avenue to support Inuit to adopt more direct roles in the acquisition and use of knowledge and promote capacity building in order to enable Inuit to flourish beyond the lifespan of the network.

ArcticNet boasts national and international recognition as *"Canada's premiere Arctic science network"* and the NAO raises concern over the future of the network and Arctic science when the time limited NCE funding is completed:

> *As the NCE funding of ArcticNet ends in March 2018, many fear the fast erosion of the remarkable coherence the Network has created among Arctic specialists in academia, the government, the North and internationally, as well as with the users of research results in Canada and abroad. [Annual Report 2015/17]*

NAO leadership adopted an active role in advocating for the future of the network, promoting the network and related initiatives through various lobbying and advocacy efforts, arguing that

> *…there is increasing pressure to consolidate the spectacular advances made by ArcticNet by morphing the Network into a stronger and permanent alliance encompassing Canada's northern expertise. [Annual Report 2013/14]*

As part of the projections about ArcticNet's legacy, the NAO provides several proposals for what

ArcticNet could become, from aspiring to consolidate ArcticNet and other initiatives into a CFI-Funded National Polar Research Platform (Annual Report: 2009/2010) to evolving from ArcticNet into a Canadian Arctic Research Institute responsible for coordinating Arctic research activities and infrastructure upon the completion of NCE funding (Annual Report: 2013/14). Although neither initiative came to fruition, ArcticNet was presented with the opportunity to temporarily continue under the NCE umbrella and proposed *"continued vision of an integrated field of Canadian Arctic Sciences for the sustainable development of Canada's North"* (Annual Report: 2015/17; Compendium: 2017/18).

4.5.2.6 Environmental: Minimize the impacts of change

A focus on environmental change is an essential network-level value which drives most NAO actions. All mission and vision statements reference environmental change in some way, linking to value sets around climate change, modernization, globalization, adaptation, and environmental stewardship. Since environmental change triggers a range of associated transformations, network-level public values are often linked to broader impacts of change. The NAO articulates two concrete actions related to addressing environmental changes: observe ecosystem-level changes in the Arctic and train the next generation of experts to ensure stewardship over the changing Arctic.

4.5.3 Network evaluation design: Reflections for evaluating network-level public values

To understand if ArcticNet has formally assessed network-level public values we reviewed ArcticNet's past evaluation practices. Document review and scoping interviews indicate that ArcticNet did not undergo any additional evaluations beyond those required by the NCE program (annual reports and mid-term reviews in 2007/08, 2015/16). Therefore, the NCE evaluation tools represent the core research evaluation approach employed to characterize and capture the public values associated with the network. While the NCE literature includes a strong rhetoric around transformationalist ideals such as public value creation, NCE evaluation practices are known to be inconsistent and confusing when it comes to the level of implementing and assessing these type of outcomes (Coutinho & Young, 2016). A detailed study on how ‘societal relevance’ is captured within the Canadian NCE program concluded that evaluation practices do not adequately capture societal relevance and instead focus on easily quantifiable outputs over softer qualitative outcomes, such as public engagement and knowledge sharing (Coutinho & Young, 2016). Given that ArcticNet has had limited formal evaluation of their network-level public values, in what follows we consider how identifying an inventory of key network publics and values using PVM may help to enhance the design of value-based network evaluation.

4.5.4 Clarifying Purpose: Consistency in network-level value articulation

Capturing ArcticNet’s network-level purpose and public values presented several challenges related to consistency in value articulation. High-level public value signaling statements were an important starting point for PVM and included mission and vision statements, as well as articulated network objectives. ArcticNet’s stated mission and vision varied depending on the type of public facing document (e.g., compendia vs annual report) and the date of the document. While the network’s vision remained relatively consistent despite some nuanced changes between document type and elaborations over time, the stated mission varied substantially between type of document. Most Annual Reports included a network mission that consists of up to eight distinct bullet points, whereas compendia documents often summarized the mission of ArcticNet in a single sentence:

The ArcticNet mission is defined as: "to bring together Canadian and foreign Arctic expertise to conduct Integrated Regional Impact Studies (IRIS) of the consequences of climate warming, environmental changes and societal changes in key areas of the coastal Canadian Arctic". [Compendia: Phase 1 V1 & V2, 2015-16]

The single sentence mission omits a range of identified values captured by the longer mission statement, only focusing on values related scientific, collaboration & partnerships.

The identification of network objectives was also variable. The eight strategic objectives of the Phase 1 research strategy are identified in one document (Compendium: Phase 1 V1), yet not mentioned again, although future network objectives are explicitly stated in the 2017-18 Compendium and in the 2015-17 Annual Report. There are also several references to ArcticNet's 'central objective' which varies depending on the document it appears in (Newsletter 1; IRIS 1,2,3,4; Compendia: Phase 1 V1 & V2, 2014-15, 2015-16, 2016-17, 2017-18; Annual Reports: 2011-13, 2013-14, 2015-17). Most expressions of the 'central objective' point to a purpose based in knowledge production, however despite some overlap it remains unclear which elements of knowledge production the NAO is responsible for supporting. References to the 'central objective' of the network range from: 'study the impacts of climate change and modernization', to 'develop and disseminate knowledge', to 'provide scientific information', to 'generate knowledge and assessments', to 'generate the knowledge and expertise required to document and evaluate the changes taking place and their consequences for the Arctic environment and its peoples' to 'the formulation of adaptation strategies'. It is generally implied that the knowledge produced is intended to inform (adaptation) strategies and (national) policies, although the scope of the strategies and policies is not always identified. Key issues targeted by these strategies and policies include the impacts and opportunities of 'climate change and globalization', 'climate change/warming and modernization', and 'environmental, economic and societal changes'.

Intended publics vary from Canadians, to northern societies and industries, to Inuit and other Northerners depending on the document. Further, the geographic focus of the 'central objective' includes the 'coastal Canadian Arctic', 'the Arctic', and 'the coastal Arctic' all of which are on slightly different scales.

4.5.5 Scale: The dynamic characteristics of network-level public values

While ArcticNet's strategic focus appears to be on a localized Canadian context (climate change research occurring in the coastal Canadian Arctic), the inventory of public values illustrates that the NAO intended public value impacts across several geographic scales. Network-level public values were tied to the range of responsibilities attributed to the NAO, which was responsible for coordinating and managing all activities linked to all ArcticNet research projects and outreach activities. The NAO engaged in activities to create public values for a variety of publics (see 5.1), providing funding and logistical support to a range of local, regional, national and international cross-sector research actors (for description of ArcticNet actors see Chapter 3 – Pigford, Hickey, Klerkx *Submitted)*. Although the NAO frequently articulated value creation aspirations at different geographic scales (local, national, and international), related statements of action were generally vague, target audiences were not always evident and anticipated timelines were often missing.

Since network-level public values were interpreted over a 14-year period, this presented the opportunity to explore potential longitudinal effects. Results suggest that while scientific excellence was emphasized in the earlier phases of the research and remained consistent throughout the duration of the network, additional emphasis was placed on other public values (e.g., useful science, collaboration, and network legacy) as the network matured. Qualitative data generated from the PVM process helped to contextualize observed changes in the network's public values over time, suggesting that shifts in network-level public value focus paralleled broader social events and movements, including the International Polar Year and an increasing demand for northern organizations to participate in research processes. Repositioning of network values and changes in NAO efforts were observed between each phase (e.g., revising IRIS and theme structure in Phase 2) and following mid-term reviews (2007/09, 2015/16), suggesting that the NAO was responsive and that network learning was present. To illustrate examples of change over time, Table 4.3 provides a longitudinal sample of NAO actions linked to network-level values identified from high-level value statements.

4.5.6 Discerning network-level attributes

In applying PVM to capture network-level values it was necessary to discern the difference between activities and outcomes produced by different actors (a partner organization, a funded research project, or by an individual actor) or through the NAO. This was challenging at times because the ArcticNet documentation often did not specify whether an action or outcome was the direct result of NAO activities or independent efforts made by network affiliates, conflating core NAO actions with peripheral actions taken by network partners. NAO documents often highlighted the successes of individual network members or their organizations, even on projects and initiatives that were not directly related to ArcticNet activities. This trend was seen frequently with academic and Inuit actors, but less often with industry partners.

The existing NCE reporting structure followed by ArcticNet largely focuses on capturing project-level outputs (Coutinho & Young, 2016), making it important to develop and implement relevant performance measures that better align with network-level attributes. Since inventoried public values were both intrinsic and instrumental, the PVM process presents an opportunity to reflect on the inherent complexity in accommodating and capturing network-level outcomes and the mechanisms employed to achieve those outcomes. Many of ArcticNet's values were associated with partnerships and collaborations, making it important that network-level outcome attributes capture both partnership outcomes and processes. For example, the NAO's collaborative Inuit Research Advisor (IRA) program, will require outcome attributes that capture and assess (1) the network-level impact of the IRAs on the evolution of research design, community engagement and the production of scientific knowledge, as well as (2) partnership activities between ArcticNet, the Northern Contaminants Program (NCP), the Nasivvik Centre for Inuit Health and Changing Environments, and the Regional Inuit Land Claim organizations, which work together to support the IRAs. Clearly outlined network-level outcome attributes incorporating both intrinsic and instrumental values are needed to effectively inform network-level public value failure assessments, which then depend on the development of logic models with hypothetical linkages between values and outcomes (Bozeman & Sarewitz, 2011).

4.6 Discussion & Conclusion

Since the societal benefit of a research network is often assumed yet rarely assessed, we employed PVM to examine the articulation of network-level public values in a research network designed to create and deliver public value. In what follows, we present the lessons learned and identify potential opportunities and constraints for articulating network-level values in the context of research evaluation before identifying areas for future exploration.

4.6.1 Diverse and emergent network-level values

Our results suggest that PVM is a promising approach for eliciting a deeper understanding of the multiple network-level public values associated with a large scientific research network. Despite inconsistencies in value articulation across NAO documents, the application of PVM allowed us to navigate through the lack of clarity by focusing on commonly mentioned network-level public values. Diverse network-level public values were identified, with the NAO adopting strong values on issues related to scientific excellence, useful information, collaboration and partnership, environmental change, network legacy, and nation building. By unpacking the range of network-level values targeted by the NAO we were able to achieve a broad understanding of the network's purpose and core values, several of which were less immediately obvious and embedded within network rhetoric. For example, emergent values (nation building and network legacy) revealed ArcticNet's political positioning as a temporary research network developed to target strategic issues and fill knowledge gaps. Our findings suggest that evaluation criteria should be carefully designed to capture the evolving, emergent, and dynamic nature of network-level public values, recognizing that public values are not static and change over time (Bozeman & Sarewitz, 2011).

4.6.2 Inclusive network-level evaluation tools: Consulting multiple publics

Although there is considerable opportunity for public values to enter into assessment cycles (Budtz Pedersen et al., 2020), there remains a need to develop research evaluation tools that better assess how collaborative dimensions are considered and evaluated in network settings. Our analysis suggests that such tools will need to clarify the purpose and scale of collaborative activities, who is/are the targeted public(s) and how this will this be achieved through collaborative action. Recognizing that the NAO is theoretically accountable to all publics targeted by NAO actions (Klijn & Koppenjan, 2015), it has been argued that evaluation perspectives from non-research stakeholders should be included in research evaluations to provide broader perspectives on collaborative outcomes and to help overcome potential bias issues associated with self-report data (Wixted & Holbrook, 2012). Given that the majority of ArcticNet's articulated public values can only be achieved in partnership with other entities, it is noteworthy that the voice of stakeholders and end-users is largely underrepresented in public facing documents. Further, the NCE evaluation approach used by the NAO largely focuses on capturing project-level bureaucratic units (e.g., does this project funded by that agency yield value?), failing to evaluate important contributions related to networking activities (Coutinho & Young, 2016). Thus, there is a need for evaluation approaches that better account for network complexity and capture partner perspectives on key network evaluation items such as: the quality of partnerships, sustainability of partnerships, cross-sectoral cooperation, academic leadership, recruitment policies, access to knowledge, intellectual coherence, learning mechanisms, multidisciplinary collaboration, and intellectual synergies (Klerkx & Guimón, 2017).

4.6.3 Public value attribution in networks: Defining network boundaries

While research networks are often a mechanism to foster development, collaboration and deliver public value, our case study presents one of the first attempts to examine public values at the network level. Adopting the NAO as our unit of analysis (versus a research project) offered several important insights into evaluating networked value creation. The focus on the NAO introduced questions about how network dimensions are considered and where/how network boundaries are drawn for reporting and evaluation purposes, in addition to the common questions associated with linking activities to societal impacts (e.g., How is causality ascribed for nonlinear impacts? How are impacts attributed to specific inputs or activities? How is internationality captured? What is the time scale?) (Penfield et al., 2014; Sivertsen & Meijer, 2020).

We found that the way in which ArcticNet reported activities presented challenges when attempting to attribute activities to the NAO instead of those carried out by teams and individuals. This ambiguity brought attention to the importance of considering the scope of network boundaries, the inclusion / exclusion criteria applied to the network, the communities/publics included in the network, and which actions are considered reflective of network values. Thus, funders and managers need to determine and communicate how the network is bounded in advance of beginning an assessment in order to facilitate network-level evaluation (Wixted & Holbrook, 2012). While this step need not be prescriptive, it will be important for clarifying the scope of the potential network impacts being evaluated. Given that networks include a variety of actors, efforts should be made to set boundaries early, engaging actors in participatory practices (Wixted & Holbrook, 2012). Further research is needed to provide insight on how to conceptualize boundaries for the evaluation of network-level impacts.

4.6.4 Implications for network evaluation policy: Improving value articulation

From a policy perspective, our result support calls for an improved articulation of network-level public values by large research networks where value is implied by a strategic focus. Situated in the context of increasing demands for science to articulate its broader value, our analysis suggests that research networks may face challenges with consistent value articulation within and across public facing documents. Improved value articulation, inclusive of target publics and value creation mechanisms may help to facilitate the evaluation of research network activities in support of responsible decision making based on achieving specific public values (McNie et al., 2016). Efforts to define network boundaries, improve the communication of non-scientific outcomes and clarify who is targeted by network activities (and on what scale) are required to inform the design of scientific networks that better embed public values. Ultimately, with more clarity around the aforementioned items funding efforts can better respond to and target research networks that seek to creates specific public values. Seen through this lens, this research may have important implications for funding bodies and research councils that aim to move beyond assessments dominated by knowledge creation outcomes to reflect the summative, network-level public value impacts of a research network. Specific suggestions for improved network-level evaluation policy include the development of evaluation tools that better assess dynamic network-level public values, promote explicit articulation network boundaries for evaluation purposes and clarify value articulation across scale in complex networks, all of which may improve public value creation.

4.6.5 Uncovering public values in networked Arctic science

As a secondary objective, this research also provides novel insight into the public values associated with networked Arctic science, which is expected to serve multiple publics and have both global and local relevance. Given that the Arctic is often treated as a single unit under pressure from a variety of global forces (Martello, 2004), a public value approach helps to draw attention to the variety of publics that are both influenced and impacted by Arctic change. Improved characterization of the range of publics and public values associated with Arctic scientific networks may provide a baseline of values to consider when evaluating research networks for the potential of public value failure. Based on our findings, we hypothesize that reports of implied public value failure in networked Arctic science (see Case Study in Section 4.3) may be linked to the poor articulation of non-scientific values and related actions. Establishing clearly articulated logic models for achieving and evaluating public values may garner more nuanced assessments of information that are capable of supporting the design of efficient value creation systems.

4.6.6 Limitations & future directions

This exploratory study employs PVM to provide reflections on how generating a public value inventory may help in the creation of more effective network-level evaluations. We recognize that a known limitation of PVM is that the sincerity of the social benefits expressed in the documents reviewed are not questioned, although the identified public values are considered to be reflective of the network's policy goals (Meyer, 2011). Future research could be undertaken to assess the accuracy and sincerity of network-level public values and actions identified through PVM from the perspective of target publics. Such a study could also examine the institutional pathways designed to deliver public value, considering how well the existing evaluation tools employed by research networks align with and capture network-level public values. Detailed studies could help to assess if strategies are place for linking and mobilizing institutions to achieve articulated values, or if the human, organizational, and financial resources are in place to achieve articulated public values (Wagner, 2020). From an Arctic perspective, these kinds of studies could present insights into claims that the entrenched institutions – 'rules of the game' – associated with Arctic science may be contributing to a range of undesired direct and indirect effects (Burn, 2008; ITK, 2018).

There remains a need for a more substantial understanding of the nature and breadth of science's public value impacts as they relate to networks (Budtz Pedersen et al., 2020). While our project aimed to capture network-level effects, we recognize there are potential limitations associated with drawing an arbitrary boundary around the NAO. For this reason, we encourage further inquiry into potential links between NAO activities and the outcomes from funded collaborative research projects. Future research to better understand the cumulative impact of network effects could also examine the interplay between network-level public values created at different levels (e.g., NAO, collaborative research project, individuals). This could include a detailed assessment of the publics targeted and the values created at the project-level, followed by a comparison to see how they align with the inventory of network-level public values identified in this study. Since network-level effects are inherently linked to all collaborative actions, we also encourage future studies to examine the interplay between public value creation, and existing management, partnership and delegation practices.

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Preface to Chapter 5

Chapter 4 describes a diverse array of public values associated with the ArcticNet NAO and provides considerations in support of improved network-level public value evaluation. Recognizing that network-level public values are created within broader systems of rules and norms, it is important to unpack the institutional arrangements that shape public value creation. Therefore, focus is shifted away from the level of the network (Chapter 4) towards the institutions that shape how networked Arctic science is organized and governed. Chapter 5 uses principal-agent theory to examine the delegation dynamics associated with overlapping, multi-level contracts for public value creation and management as mediated through a NAO. The public value Strategic Triangle is used to interpret the findings and identify implications for Arctic scientific governance and associated public value creation processes.

Chapter 5. Delegating Public Value Management Responsibilities: Principal-Agent Relationships in the Public Administration of Networked Science

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Abstract

The trend towards network delegation in science systems implies a shift in responsibility for public value management away from governments towards networked science actors. In this paper, a principal-agent lens is applied to unpack who is assigned public value management roles in a large Canadian Arctic research network. The exploratory case study illustrates a chain of principal-agent contracts that are guided by the goal of using public funds to conduct Arctic scientific research on a large-scale. Many of the public value management tasks associated with the Strategic Triangle (value identification, legitimacy, and operational capacities) were delegated to the N*etwork Administrative Organization* (NAO), which acted on behalf of the government. The NAO reported common principal-agent challenges with respect to identifying public value when working with scientists (adverse selection and moral hazard), yet not for management roles related to seeking legitimacy and coordinating resources. Findings reveal that while public value management roles were delegated to the NAO and subsequently passed on to researchers and other partners, these management expectations were largely implied, but not explicitly addressed.

5.1 Introduction

Governments are generally expected to use policy instruments to formally oversee, define and implement science and innovation agendas in order to help address complex societal challenges

(Borrás & Edquist, 2013; Hessels et al., 2009; Martin, 2016; Potvin & Armstrong, 2013). Since governments often lack the scientific expertise needed to produce useful science for society, they often contract out the task of conducting research by establishing a principal-agent contract between the government (principal) and scientific actors (agents) (Braun & Guston, 2003; Caswill, 2003; Guston, 1996; Hessels et al., 2009). Principal-agent contracts are intended to help bridge the strategic gaps between science and society (Braun & Guston, 2003; Hessels et al., 2009) and are often facilitated by a number of mediating organizations (Braun, 1993; Caswill, 2003; Klerkx & Leeuwis, 2008; Shove, 2003; Slipersæter et al., 2007). For example, granting councils often act as intermediaries, whereby a government delegates authority to the council to execute an agreement with universities and researchers (Braun, 1993; Caswill, 2003; Slipersæter et al., 2007; Van der Meulen, 2003). Engaging intermediaries is believed to reduce the potential for overburdening governments, while also improving productivity and efficiency (Braun, 1993). Although enacting this kind of government-intermediary-researcher principal-agent contract may seem straightforward, the act of producing useful scientific research is complex and shaped by many processes that need to be carefully considered (McNie, 2007). For example, society can only reap the benefits of scientific research when it has been transformed by a collection of actors into accessible products, services or processes (Bornmann, 2013).

Contemporary scientific research systems have entered a phase where multi-actor network models have become the norm, driven largely by efforts to collaboratively produce relevant knowledge in the context of application (Etzkowitz & Leydesdorff, 2000; Gibbons et al., 1994; Hessels et al., 2009). As a result, many large-scale research and innovation initiatives are focused on building network capacities (Hessels et al., 2014; Ojo & Mellouli, 2018; Wardenaar et al., 2014). From a principal-agent perspective, these approaches often delegate a large amount of authority and responsibility to multi-actor networks to carry out activities on behalf of the public (Klerkx & Leeuwis, 2008; Shove, 2003). Given that research networks need to be created and governed it is important to consider how networks are organized and managed, which can have significant impacts on subsequent relationships and outcomes (Giest & Howlett, 2014; Provan & Kenis, 2008).

Formally constructed, publicly-funded networks are often led by, coordinated, and governed by a central administrative entity known as a Network Administrative Organization (NAO) (Provan & Milward, 2001). NAOs are created specifically to deal with complex problems and associated coordination issues requiring shared or centralized management, and often play important roles in disseminating resources and administering the network (Braun, 2018; Provan & Kenis, 2008). In the context of delegated research networks, a NAO may operate in both principal and agent roles, acting as a principal in relation to the researchers and an agent in their relationship to the government. Such 'intermediary' roles are not passive, rather they are often associated with mobilizing, reframing, and structuring expertise (Meyer & Kearnes, 2013). Thus, the adoption of intermediary roles by the NAO implies that they have the potential to play an active and important management role in creating public value through scientific research.

Recognizing that networked scientific research efforts are most commonly funded using public resources, it is important to understand how resources and responsibilities are assigned to networked science actors, including NAOs. Here, public value[13] thinking may offer some insight. Public value contends that value can be created in many different ways and emphasizes the importance of 'public managers' who have a role in helping to create and guide public efforts,

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[13] Public value is a public administration approach that primarily focuses on the value added by public managers (Moore 1995). It inherently considers (1) what the public values - the nature of public issues and (2) what is good for or enhances the public sphere- the strategies employed to tackle them (Alford and O'Flynn 2009; Benington & Moore 2011a, 2011b; Moore 1995).

while also leveraging existing resources to enhance the overall effectiveness, capacity, and accountability of the system (Bryson et al., 2014; Moore, 1995). They do this by coordinating resources from various sources (e.g., private sector, civil society, and the state) to find a common purpose and priorities, while also maintaining trust and legitimacy (Ballintyne & Mintrom, 2018; Benington, 2011; Benington & Moore, 2011a; Moore, 1995; Stoker, 2006). While historically governments were seen as the central actor responsible for public value creation, there has been a shift towards delegating these responsibilities to other public organizations, including networks, suggesting that the actors who occupy 'public manager' roles has changed (Bryson et al., 2017; Stoker, 2006). Since formal research networks are created by governments to produce, create and deliver public value (Isett et al., 2011), there is a need to better understand how public value management roles are translated and re-assigned in these delegated principal-agent relationships. This paper considers who is responsible for the public value management of networked scientific research in a chain of delegated principal-agent relationships being mediated by a NAO, using a case study from the Canadian Arctic.

5.1.1 Research Context & Objective

Arctic governments are facing new demands to engage in and support scientific and technological developments that can address the substantial and transformative changes facing Arctic social-ecological systems (Kofinas et al., 2020; Nilsson & Koivurova, 2016; Tesar et al., 2016). Increasingly, they aim to fulfill this societal responsibility by engaging in delegated principal-agent relationships with scientific researchers via research networks. As a result, the Arctic scientific community is increasingly assigned the responsibility for helping to address 'real world' interests and complex challenges (Wormbs & Sörlin, 2017). The efficacy of this approach, however, remains unclear and there have been repeated calls for improved alignment between

Arctic science investments and local Arctic priorities and needs (Ibarguchi et al., 2018; ITK, 2016, 2018; Ogden et al., 2016). Further, although delegated and networked approaches for Arctic scientific research are increasingly being promoted, there has been limited systematic investigation into how these approaches are governed and managed (Kofinas et al., 2020; Pigford et al., 2018). Recognizing this gap, and the increasing expectation that Arctic research networks will create public value on behalf of governments and the public tax payers who fund them, we present a case study from the Canadian Arctic to investigate who is assigned public value management roles in a large research network.

5.2 Analytical Approach

To analyze the responsibility for public value management in networked science, we sequentially apply principal-agent theory (Braun & Guston, 2003) and the public value Strategic Triangle (Moore, 1995). This is done to capture and unpack the core principal-agent contracts being mediated by an Arctic research NAO and explore how role assignment for different aspects of public value management (value identification, legitimacy, and operational capacities) flow through these contracts.

5.2.1 Principal-Agent contracts in networked science

Principal-agent theory is a well-established approach for examining delegation in research funding relationships (Braun, 1993; Braun & Guston, 2003; Caswill, 1998, 2003; Guston, 1996). Much like granting agencies, networks can play mediating roles in principal-agent contracts in support of producing 'useful science.' Delegating decision making authority to strategic research networks can act as an avenue to promote coordinated action (Braun, 2003; Shove, 2003; Wardenaar et al., 2014) and reduce the potential for transaction costs (Braun, 2003; Hessels et al., 2014). This is commonly associated with a greater distance from the government, resulting in higher levels of self-organization and an informal governance style that requires participants to rely on shared interests (Wardenaar et al., 2014). However, principal-agent relationships become increasingly complex in networked scientific research, with resulting projects and programs likely to face challenges in considering all potential principal-agent relationships (Shove, 2003).

Associated with the increased number of contracts when adopting networked approaches is the potential for challenges to arise with transaction costs (including monitoring), which becomes particularly apparent when the goals of the principal and agent differ. It is therefore common to see conflict between the relative independence of scientific researchers and a government's desire to demonstrate accountability and the usefulness of the research it funds (Doern & Stoney, 2009). Scientists have been found to have more freedom when they work with multiple principals (Morris, 2003), with conflicts tending to arise when agents push to advance their own specializations while principals advocate for transferring results into practical solutions beyond academia (Sen, 2017). Generally, principal-agent relationships in scientific research work in both directions, with high levels of feedback between principals and agents (Braun & Guston, 2003; Doern & Stoney, 2009).

Principal-agent theory highlights a number of potential challenges that may emerge in delegated science-society relationships: 1) getting scientists to do what political actors contracted them to do (responsiveness); 2) ensuring that the best scientists are selected (adverse selection); 3) ensuring that scientists do their best to carry out the tasks delegated to them (moral hazard); and 4) knowing what is the best path forward (decision-making and priority-setting problem) (Braun, 2003). Intermediaries may play an important role in helping to reduce these concerns (Caswill, 2003; Van der Meulen, 2003); however, asymmetrical relationships can still exist when intermediaries are used (e.g., between governments and granting councils, and granting councils and scientists) (Slipersæter et al., 2007). Despite the potential for transaction costs and asymmetrical relationships in delegated research relationships, previous work has shown that networked approaches with multiple principal-agent relationships may be able to effectively leverage existing relationships, expertise and self-interest in the research community to instill improved interactions, better responsiveness and innovative outcomes (Braun, 2003; Hessles, 2014; Klerkx and Leeuwis, 2008). However, recognizing that principal-agent theory is an analytical approach for understanding delegation relationships, it should be complemented by appropriate approaches that better capture and explain collaborative action (Klerkx & Leeuwis, 2008). Therefore, we employ principal-agent theory to identify delegated research relationships in a large research network, but also draw on the public value 'Strategic Triangle' to interpret our findings to better understand how public value management expectations are re-assigned in delegated research network relationships (Moore, 1995).

5.2.2 Managing for public value: The Strategic Triangle

As a paradigm for managing public resources, public value highlights the underlying assumption that public interventions are defined by the search for public value (Stoker, 2006). Three distinct yet interdependent processes have been identified as being necessary for creating public value: 1) defining public value by clarifying and specifying strategic goals (*identifying public value*); 2) creating the authorizing environment necessary to achieve the desired public value outcomes, which can include building and sustaining multi-actor networks (*authorizing environment / political legitimacy*); and 3) building operational capacity to mobilize resources (e.g., finance, staff, technology) (*operational capacity*) (Alford & O'Flynn, 2009; Ballintyne & Mintrom, 2018; Moore, 1995). Together these facets form what is referred to as the Strategic Triangle (Ballintyne

& Mintrom, 2018; Moore, 1995). It is considered the responsibility of public managers to bring these facets together, and thus, the Strategic Triangle offers a pragmatic heuristic for conceptualizing key aspects of public value management (Hartley et al., 2017).

While there has been relatively limited empirical investigation into how the Strategic Triangle works in practice (Hartley et al., 2017), it can be used to help diagnose existing situations, structure thinking about what the ideal or desirable process is, and offer categories to analyze public sector service delivery (Alford & O'Flynn, 2009). At the core of the Strategic Triangle is an attempt to understand what is expected of public managers and how value creation is incorporated in public management activities (Liddle, 2018). Since networked science actors inherently assume delegated responsibilities when they accept public funds to execute science on behalf of society (via the government), the Strategic Triangle may illustrate who these actors are, and what is expected of them. In this paper we consider each of the three Strategic Triangle elements as they apply to the delegated principal-agent contracts for the production of Arctic scientific research (Figure 5.1).

5.3 Context and Research Methods

We employed an exploratory case study approach (Yin, 2013) to retroactively examine the delegation of responsibility for public value management in a Canadian Arctic research network.

Figure 5.1 The public value *Strategic Triangle* as it relates to principal-agent relationships

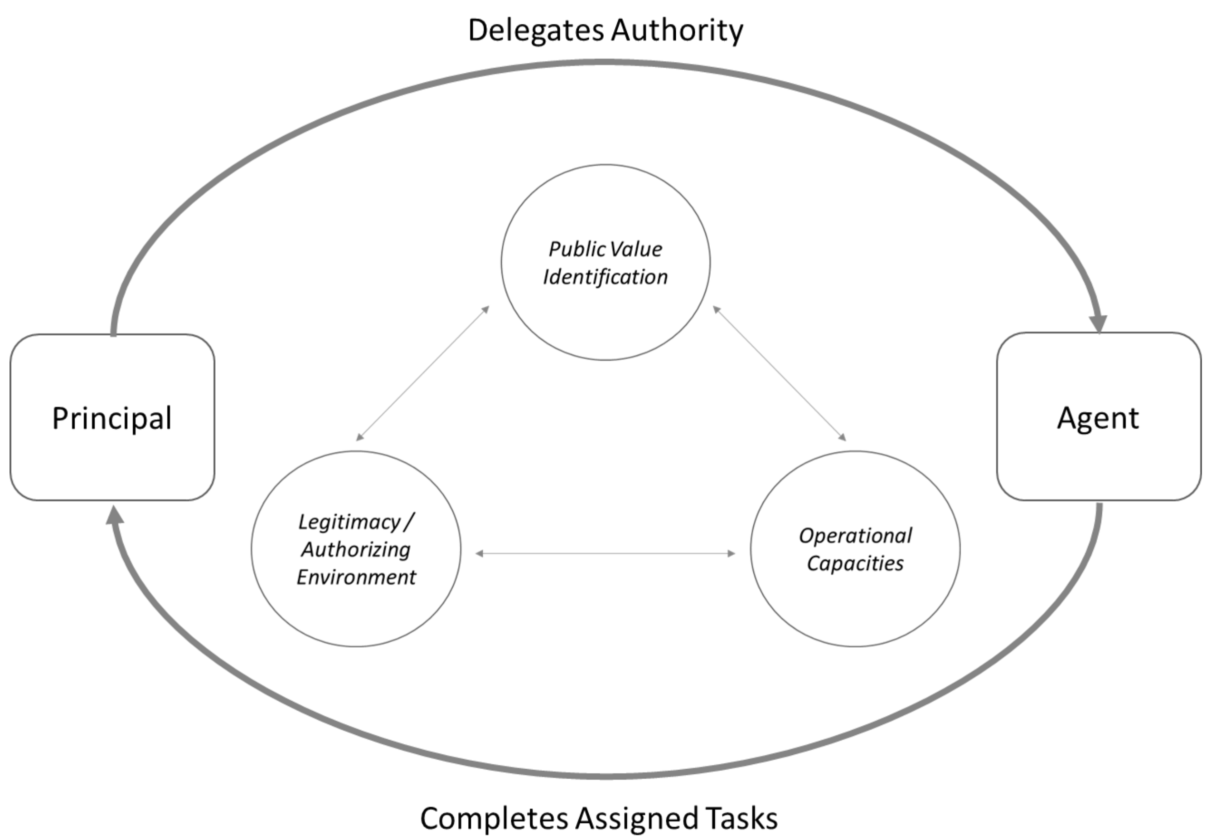


Figure 5.1 presents a principal-agent relationship with key public value management responsibilities captured by the Strategic Triangle. The Strategic triangle has been adapted from Moore, 1995 and Bryson, 2014.

5.3.1 Case study

The Canadian federal government has been supporting Arctic research and encouraging the creation of northern research networks since the 1960's to improve the flow of scientists, theories and data (Bocking, 2007). Following growing concern that the state of Canadian Arctic science was in crisis in the late 1990's (Task Force on Northern Research, 2000) and repeated calls to improved alignment between Arctic science investments and local Arctic priorities (Ibarguchi et al., 2018; ITK, 2016, 2018; Ogden et al., 2016) the Canadian government has been steadily increasing investments in scientific research designed to promote evidence-based decision-making for sustainable northern development (Carr et al., 2013; ITK, 2018; Pigford et al., 2018). One of Canada's most predominant Arctic investments has been over $146.2 million (CAD) to support ArcticNet, a large Canadian Network of Centers of Excellence (NCE)[14] (GoC, 2020).

Established in 2003, ArcticNet is the largest cross-sector research network of its kind in Canada. We describe the organization and governance structure of ArcticNet elsewhere (*see Chapter 4)*. While ArcticNet aims to understand the impacts of climate change and modernization in the coastal Canadian Arctic, the network also seeks to create a range of scientific, environmental, political, and societal public values (*see Chapter 4).* ArcticNet's stated societal contributions have been linked to industrial development; environmental assessments, policies, and strategies; knowledge sharing and engagement; as well as economic and social development (Coutinho & Young, 2016). It therefore offers a unique and ideal reflective case study because of its implied role in facilitating improved linkages between scientific research and meaningful Arctic outcomes.

[14] In the 1980's Canada's NCE funding program emerged as a way of networking different 'Centres of Excellence' together to address strategic areas of focus while urging researchers to think about the economic and social impact of their work (Atkinson-Grosjean, 2006).

5.3.2 Data collection and analysis

The analysis relies on a combination of secondary source data (including official network documents and websites) and a set of semi-structured interviews with key informants on their perceptions of, and experiences with, the ArcticNet NAO. Document analysis (Bowen, 2009) included an extensive review of ArcticNet's public facing documents. Data sources included: annual reports inclusive of budgets, research compendia, newsletters, the ArcticNet website, and information available through the federal government's NCE website and annual reports. Data sources were identified through consultation with ArcticNet in the summer of 2018 and via online searches. Of note, ArcticNet documentation (annual reports and/or compendia) beyond 2018 was limited, therefore this research largely focuses on material covering activities between 2004 and 2018.

Ten key-informant scoping interviews were conducted in late 2018 (McGill Research Ethics Board file 44-0618). Interviews focused on key individuals who worked closely on the design and implementation of ArcticNet programming (i.e. past and current staff and committee members). Participants were recruited using convenience and snowball sampling, allowing for the recommendation of further participants (Creswell & Clark, 2007). Semi-structured scoping interviews (~1.5 hours) followed a broad interview guide that was designed to capture general information about ArcticNet, focusing on core institutional and operational mechanisms associated with centers of excellence schemes – design; application, selection and funding; implementation and governance; monitoring and evaluation (Klerkx & Guimón, 2017) (Appendix 1A). Informed consent was obtained, and interviews took place at the informant's office or by telephone/Skype based on the informant's preference. All interviews were recorded, transcribed, and rendered anonymous during the transcription process. Transcripts were imported into qualitative data analysis software (Nvivo, QSR International, Doncaster, Australia) and then analyzed inductively to identify common themes among participant responses (Neuendorf, 2016; Vaismoradi et al., 2013). Despite attempts to anonymize transcripts, all findings are presented as summary statements to ensure the anonymity of key informants given the relatively small sample size (n=10) and the closeness of the group of key informants interviewed.

An important limitation of using documents and key-informants that are closely associated with the NAO to assess network-level public value is that we are missing the perspectives of other actors in the chain of principal-agent relationships, which may have resulted in an incomplete picture of the delegated public value management relationships. To reduce the potential for gaps in our analysis we focused on well-established, high-level funding and reporting relationships that were easy to trace through publicly available documents. Efforts were also made to situate the findings within the broader institutional context, drawing on available literature on Arctic science.

5.4 Results

The following section identifies the principal-agent contracts evident in ArcticNet and then explores how different aspects of public value management (value identification, legitimacy, and operational capacities) flow through these relationships to identify who is assigned responsibility for public value management.

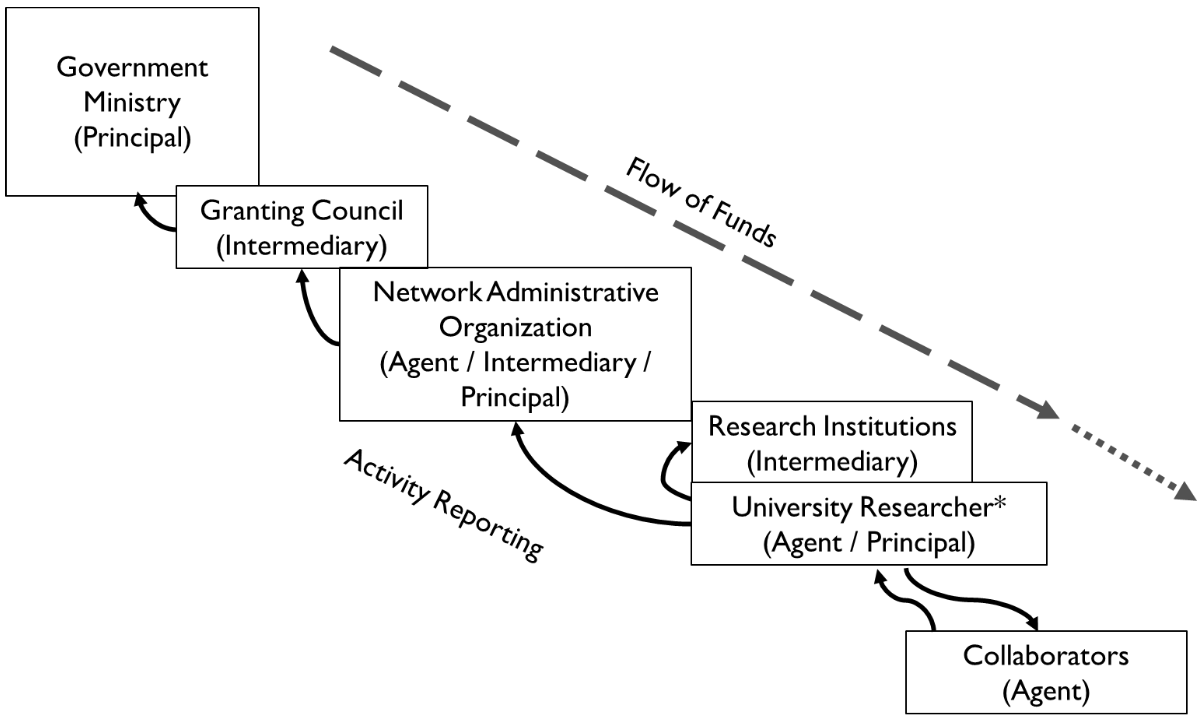
5.4.1 Overlapping, multi-level principal-agent contracts

Principal-agent analysis revealed the existence of many principal-agent contracts associated with ArcticNet, each being affected and affected by its relationship with the others. Recognizing that there are several potential principal-agent relationships that could be investigated, we focused on the higher-level science-society contract whereby public funds are provided to research actors to conduct Arctic science. This contract is dependent on several preliminary steps, including the establishment of a NAO capable of generating public value. A detailed network timeline illustrates core activities carried out by the NAO in the pursuit of carrying out the contract to produce useful science (Appendix 5A). In what follows, we summarize a chain of principal-agent contracts related to research grants and identify how each relationship may shape the delegation of public value management roles.

5.4.2 The science-society contract to conduct Arctic scientific research

Recognizing that grants (i.e. the flow of funds) are not the only type of principal-agent contract, we explore these relationships as a starting point to understand the delegated relationships in ArcticNet. Enlisting researchers in a contract to conduct Arctic scientific research on behalf of the government required a broad chain of overlapping, multi-level principal-agent-agent relationships. The Canadian federal government (the ultimate principal in our case) acted through a series of intermediaries to fund research actors who were considered capable of conducting Arctic scientific research (Figure 5.2). First, the Canadian federal government contracted a granting agency (agent) to identify a strategic network with the potential to address key issues. Following a formal competition, the granting agency (principal) contracted the ArcticNet NAO (agent) to create a cross-sector Arctic scientific research network. The ArcticNet NAO (principal) then held a formal competition to identify collaborative research teams (agent) capable of conducting Arctic science. As part of the ArcticNet competition lead researchers (principal) were responsible for assembling a team of cross-sector collaborators (agents), who, with the lead researcher formed the collaborative research teams (ultimate agent) to conduct Arctic science on behalf of the government. All awarded projects received funds from ArcticNet through the researcher's home institution (principal), which then administers funds to the researcher (agent) and potentially on to collaborators (agent). In alignment with reports of increasing community-based research mechanisms in Arctic science (Brunet et al., 2014), some informants noted that the chain of funds did not end with researchers or research collaborators, rather funds were also used to engage with and support interested community partners. However, for the purposes of our analysis we end the chain at the research collaborators. At the center of the chain (Figure 5.2) is the ArcticNet NAO which plays a principal-(agent/principal)-agent role, representing the double roles of principal and agent as it mediates the flow of funds as an intermediary in the government – science contract.

Figure 5.2 Simplified view of principal-agent contract(s) for funding ArcticNet



Legend

Dashed lines: Show the flow of financial resources; short dashed lines indicated potential flow of funds.

Solid lines: Show the flow of activity reporting for research activities

** There is often is an additional principal-agent relationship from researchers to trainees (e.g., postdoctoral fellow, graduate students), which is not included in this figure.*

Figure 5.2 expands on concepts presented in Caswill (2003) on principal-agent relationships in science, to reflect principal-agent relationships in a chain of relationships including a research NAO. To communicate the most obvious chain of delegation contracts, we focus on the flow of funds to conduct scientific research and the reporting activities associated with this funding.

5.4.3 Delegated responsibility for public value management

Next, we examine the responsibilities for public value management (captured by the facets of the Strategic Triangle) from the perspective of the NAO to see how delegated public value management tasks are to be carried out, by who and how.

5.4.3.1 Role: Identifying public value

Public managers are expected to support strategies that are aimed at achieving something that is substantively valuable (i.e., it must constitute public value) (Alford & O'Flynn, 2009). In principal , they do this by clarifying and specifying strategic goals (Moore, 1995). In our case, public managers within the Canadian federal government (ultimate principal) identified the need: 1) for large cross-sector networked science initiatives that bring together academia, government, and industry to solve strategic problems (Atkinson-Grosjean, 2006); and 2) to address the perceived inadequate state of Arctic science in Canada (Task Force on Northern Research, 2000). Together these goals informed the establishment of the delegated principal-(agent/principal)-agent relationship with the ArcticNet NAO at the center.

Following a formal open competition, the granting agency (intermediary) contracted by the government (principal) awarded ArcticNet (agent) funding to establish a cross-sectoral network designed to promote innovation. Once funded, the ArcticNet NAO, inclusive of the administrative team, board of directors and research management committee, adopted the responsibility of defining public value as it related to establishing the Canadian Arctic science research agenda. Once funded, the NAO worked collaboratively with other NAO partners to set priorities for research funding calls, thus articulating strategic directions on behalf of the government. In this way it assumed responsibility for identifying priorities for value creation; however, whether or not these priorities are associated with public value is debatable since the mechanisms to ensure that these priorities align with the values identified in the original contract between the NAO-government are unclear. Following the call for proposals, researchers submitted funding applications to ArcticNet, communicating the research areas that they thought to be of value. Using their established funding priorities, the NAO then selected and funded collaborative research projects for a 3-4 year period.

Throughout this extended process of awarding funding to researchers, the NAO ultimately played a mediating role whereby public value outputs are identified and generated at two levels: the first being at the level of the network captured by the principal-agent relationships between the government and ArcticNet; and the second being at the level of funded research, with ArcticNet articulating public value and then delegating responsibility for achieving that value to researchers. Although strategic goals (assumed to reflect public value needs) are defined and identified by the principal in the case of both relationships, informants suggested that it was generally accepted that the agent (either the NAO or the researchers) would assume all value creation responsibility and deliver the expected outcomes once the funding contract was established. The delegation of funds was therefore associated with the delegation of responsibility for executing public value management tasks.

Principals in this case used relatively simple tools to evaluate if the identified strategic goals (i.e. public value) were being realized. The government-ArcticNet contract was monitored through annual reports, in which the NAO relied heavily on annual reports provided by researchers to the NAO to populate their activity reports for the government. Given that ArcticNet was funded through block funding, they also underwent two mid-term evaluations throughout the duration of the network as a way of allowing the principal/government to determine if the government-ArcticNet contract was being satisfied.

Informants noted several delegation tensions related to the NAO role as principal with researchers as agents, reflecting challenges that have been reported in other contexts (Braun, 2003). These included issues with responsiveness, as some researchers did not conduct the research they were contracted to, despite agreeing to a defined contract and value proposition associated upon the receipt of funding. Additionally, moral hazard presented a challenge with respect to ensuring compliance with network reporting requirements, as some researchers did not submit annual reports. Informants also noted that the potential for adverse selection was largely mitigated by the NAO's funding review process and problems with decision-making and priority-setting were not broached by our study participants. Further, in the government-NAO contract, the NAO did not report any tensions related to value articulation in the delegated relationships; however, as the agent in the relationship, the NAO may have been unaware of, or unwilling to, identify the tensions associated with that contract.

5.4.3.2 Role: Establish Legitimacy / Authorizing Environment

Public managers need to mobilize authorization to ensure that their efforts are perceived as legitimate and politically sustainable for ongoing support (i.e., they must attract sufficient ongoing support and committed resources from the broader authorizing environment) (Alford & O'Flynn, 2009). To create the authorizing environment necessary to achieve the desired public value outcomes and achieve political legitimacy, public managers need to leverage their power to influence and negotiate with authority figures, stakeholders and legislators for continued support (Ballintyne & Mintrom, 2018).

As part of the first relationship in the principal-(agent/principal)-agent relationship, the ArcticNet NAO received a contract and associated funds from the government (via a granting agency) to establish and support both a network and an enabling environment for Arctic science.

While the initial award and funding from the government meant that ArcticNet had the political legitimacy (via the grant) to begin its efforts to support Arctic science, actors within the NAO spent substantial resources (e.g., time, intellectual, human, financial) to lobby potential partners and establish relationships. The goals of this part of the science-society contract were distinct from those related to conducting Arctic science, reflecting several ambitious network-level public values related to scientific excellence, useful information, collaboration and partnership, environmental change, network legacy, and nation building (see Chapter 4). Importantly the network-level values articulated by ArcticNet in the pursuit of a network legacy aligned closely with public manager tasks associated with mobilizing the authorizing environment (e.g., self-promotion, continuity, adaptability, stability, and a voice for the future). Findings suggest that public managers within the ArcticNet NAO illustrated significant levels of political savvy, which is required to ensure ongoing network support from political leaders, senior public managers, relevant interest groups, and other stakeholders (e.g., the media, engaged citizens, users of the public services in question and their advocates) (Ballintyne & Mintrom, 2018). For example, public managers associated with the NAO adopted an active role in national and international political venues, advocating for the advancement ArcticNet and Canadian Arctic science.

Other efforts to establish legitimacy were related to the latter half of the observed principal-(agent/principal)-agent relationship, where researchers were awarded grants from ArcticNet, which acted as a granting agency. To be eligible for funds, researchers had to convey their legitimacy by establishing their authority as an expert in the field and proposing a collaborative research project with cross-boundary actors that would be administered through a legitimate academic institution. It is important to note that the flow of financial resources needed to pass through a university in order to reach researchers, affecting who was eligible. We found few other pathways that ArcticNet researchers use to seek political legitimacy with the NAO. Common principal-agent problems were not noted by informants in the case of seeking political legitimacy.

5.4.3.3 Role: Operational Capacity

Public value management efforts need to be operationally and administratively feasible (Alford & O'Flynn, 2009). Substantial financial resources supported ArcticNet-funded research and network activities. Financial capacities were passed along the principal-(agent/principal)-agent chain from the government, through the granting agency (NCE program) to ArcticNet, which held its own call for proposals and then passed financial support to researchers and their teams through research awards. Similar to other principal-agent studies (Caswill, 2003), research awards were viewed as contracts, and in the case of ArcticNet, this contract involved financial support for research and training activities in exchange for expectations of public value creation. As delegated agents in the delivery of public value, awardees were expected to produce reports on their activities to the NAO annually, which compiled reports and shared summary results with the NCE funding program.

Public managers, in this case the NAO and researchers, had control over how to allocate the resources assigned to them in their attempts to create public value (Ballintyne & Mintrom, 2018). By partnering with a wide range of partners, these public managers can seek to harness the resources from other organizations that share a common mission (Liddle, 2018) in order to improve access to additional resources (Ballintyne & Mintrom, 2018). The ArcticNet NAO sought to create public value through a suite of partnerships and delegated activities, ultimately creating a secondary and equally complex web of principal-agent relationships (Table 5.1, Figure 5.3). Additionally, the network benefited from several parallel initiatives that sought to create similar public value(s) through scientific research. The expressed motivations for partnering with other Arctic science initiatives, networks and governments were to gain political legitimacy as

"Canada's premier northern research network" (2014-15 Annual Report) or to gain access to resources that would otherwise be unavailable. Although the staff, committees, and board members associated with the NAO held significant experience and expertise in carrying out Arctic science, there were several cases where they partnered with other organizations to fill knowledge and resource gaps. Key examples include:

- *Research infrastructure partnerships:* ArcticNet placed emphasis on supporting coastal Arctic access through annual expeditions on the CCGS Amundsen, a Canadian ice breaker with scientific research capacity. ArcticNet refers to the Amundsen as ArcticNet's central/principal infrastructure and elaborates on the value of having access to a mobile research platform. Several other ships were also engaged; however, not to the same extent as the Amundsen. With respect to non-marine research, researchers in the ArcticNet network were able to take advantage of infrastructure support from several other initiatives – referred to as partner institutions by ArcticNet (Québec-Océan, Polar Continental Shelf Project, the Centre d'études nordiques (CEN), the Nunavik Research Center, the Churchill Northern Studies Center, the Aurora Research Institute and the Nunavut Research Institute). Other partners include the Government of Canada, Inuit organizations and private sector partners. Partners provided cash and in-kind contributions that provided logistical support, access to infrastructure and expertise.
- Data management partnerships: Between 2007-2009 the NAO supported the creation of the Polar Data Catalogue along with the Canadian Cryospheric Information Network and the Canadian Department of Fisheries and Oceans and in 2010/11 the ArcticNet Publications Database was established in partnership with Arctic Science and Technology Information System (ASTIS).

- Research training partnerships: Direct training opportunities provided by ArcticNet include the ArcticNet training fund intended to provide student members with access to high-quality Arctic training opportunities (established in 2004) and the ArcticNet Fieldwork Safety Training Fund (created in 2014-2015). Collaborative training efforts include: Schools on Board, an education outreach program that takes place on the CCGS Amundsen and is a result of a partnership between the University of Manitoba and ArcticNet; the ArcticNet Students Association, created and led by graduate students, it hosts national and regional meetings and provides opportunities for training; and finally, funds allocated to researchers through their collaborative projects are intended to support trainees.
- The Inuit Research Advisors: Collaboratively supported with the Nasivvik Center for Inuit Health and Changing Environments, the Northern Contaminants Program and the four Inuit land claim organizations, ArcticNet supported an Inuit Research Advisor (IRA) position in each of the four Inuit regions of Canada. *"The mandate of the IRAs includes the facilitation of community visits and consultations to present research projects to northern communities and research licensing bodies and the collection of input by Northerners into specific projects and the overall research program of ArcticNet. IRAs act as a liaison between Inuit and researchers, whereby they play an important role for both the research community and their regions." (Annual Report 2013-2014).*

Common delegation challenges associated with principal-agent contracts were not discussed by informants when seeking improved operational capacities through delegated partnerships.

Table 5.1 Summary of principal-agent contracts related with ArcticNet

Principal	Intermediary (Agent/Principal)	Agent(s)*	Contract Goal
Government	Granting Council (NCE)	ArcticNet NAO	Create an NCE to achieve core values: ArcticNet's values include: ensure scientific excellence, produce useful information, promote collaboration and partnership, address environmental change, ensure network legacy and support nation building (see Chapter 4 for more details)
	ArcticNet NAO	Researchers** (via research institutions)	Conduct Arctic science: Financial resources from the government (principal), are mediated through ArcticNet (intermediary), and provided to researchers to develop new knowledge on behalf of society. Target stakeholders & communities: Researchers are responsible for building cross-sector relationships and legitimacy through research that engages potential end-users.
		Research infrastructure	Facilitate research access through partnerships with existing research platforms, infrastructure, and programs.
		ArcticNet Students Association School on Board Non-profit	Provide training and outreach for secondary and post-secondary students.
		Polar Data Catalogue Committee Arctic Science and Technology Information System (ASTIS)	Manage and organize ArcticNet research data and publications.
		Inuit Research Advisors	To provide ArcticNet with assistance and guidance in engaging Inuit, and to support research coordination by improving connections between Inuit and ArcticNet researchers.

**Many of these agents also receive support through public resources through alternative mechanisms.*

*** There is often is an additional principal-agent relationship from researchers to trainees (e.g., postdoctoral fellow, graduate students) to execute these contracts.*

Figure 5.3 Sample web of principal-agent relationships related to the NAO

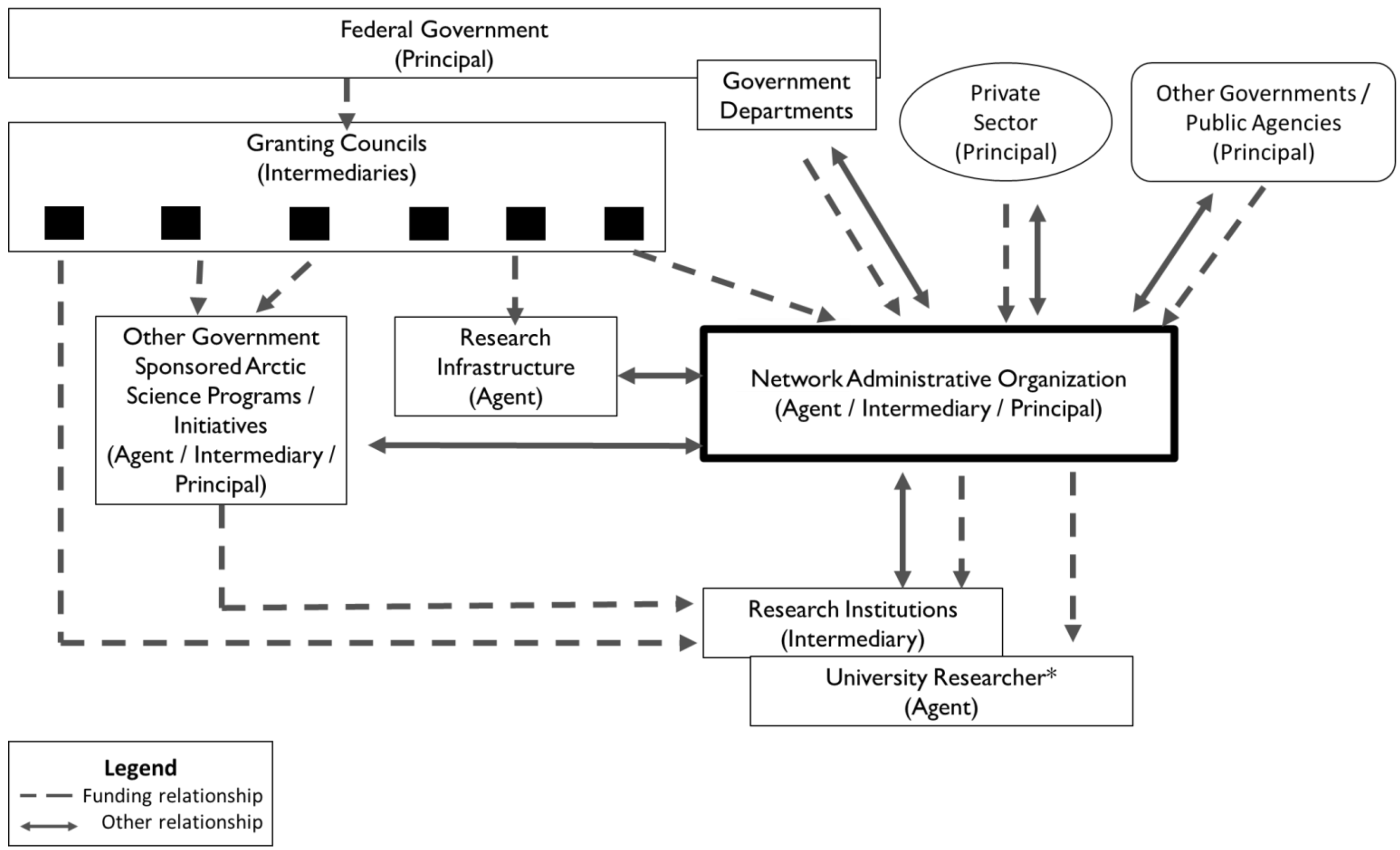


Figure 5.3 illustrates funding-related relationships and partnerships associated with the ArcticNet NAO. Explicit funding relationships are captured by dashed lines. Solid lines reflect the establishment of partnerships to leverage operational capacities, which often included the exchange of cash and in-kind contributions linked to providing logistical support, access to infrastructure and expertise.

With respect to operation capacities linked to research projects, once funding was awarded, researchers were given relative autonomy to execute their contract so long as they followed general guidelines. The funding competition process and annual reporting were the main venues in which researchers illustrated their operational needs to the NAO. We observed a reliance on prescriptive reporting frameworks from the NAO, which took priority over political and democratic forms of accountability and reporting (Coutinho & Young, 2016; Liddle, 2018).

5.4.3.4 Role: Aligning the three facets of the Strategic Triangle

As previously mentioned, an effective public manager theoretically seeks to align the three facets of value management identified in the Strategic Triangle (Ballintyne & Mintrom, 2018; Moore, 1995). A collective examination of the identified principal-(agent/principal)-agent chain, with the NAO at the center highlights the active public value management roles adopted by the NAO as an agent of the government (see Table 5.1). However, when it comes to public value management roles as a principal, the NAO delegated many of the public value creation responsibilities to the researchers or other partners. For example, when it came to facilitating, coordinating, or communicating across funded projects, the NAO adopted a passive approach, leaving researchers to self-organize except for projects taking place on the CCGS Amundsen, which the NAO supported directly. Most NAO value management efforts focused on creating and supporting network-level public values (see Chapter 4). In this case, the NAO leveraged existing resources to create new or modified institutions, ultimately acting as a catalyst to create and transform public value (Hartley, 2011). In this way, public managers can be seen as playing an important role in helping governments decide what can be done and then facilitating institutional change in order to improve outcomes for the public (Benington & Moore, 2011b; Moore, 1995).

While governments are typically responsible for coordinating public value management tasks, we found that through delegated principal-agent relationships, the agent largely assumed responsibility for aligning and executing public value management. For example, responsibilities linked to conducting and managing Arctic science were largely delegated from the NAO to the researchers. Informants suggested that the project-level coordinative requirements of the NAO were met by funding projects that meet several criteria for collaboration.

5.5 Discussion

The ArcticNet NAO offers a useful case to examine delegated public value management roles in the context of a large scientific research initiative. Since relatively little is known about the public value management dynamics within delegated research networks, we engaged two complementary concepts (principal-agent theory and the public value management Strategic Triangle) to explore who is responsible for public value management in networked science. Together the concepts enabled us to identify new insights to how scientific research networks are managed with respect to delegated responsibility (Braun, 1993; Moore, 1995).

The findings suggest that although public value management roles were not often explicitly assigned to delegated actors, there were overall expectations that these roles will be adopted by agents in principal-agent relationships. The actors along the identified principal-agent chain engage in delegating public value management roles, often contracting management responsibilities and expectations along the chain. In general, the management role for identifying public value (and its related monitoring) was transferred from principal to agent along the chain of relationships, implying a hierarchical (top-down) relationship with respect to managing public value identification through delegated contracts. This pattern corresponded with concerns from informants about common principal-agent problems related to responsiveness and moral hazard when managing for public value identification. While our findings suggest that responsibility for the other two facets (establishing legitimacy, and operational capacity) tends to fall on the agent in principal-agent relationships, informants did not identify traditional principal-agent concerns with these delegated relationships.

Interestingly, although public value identification is occurring at the level of the principals, it is the agents who are ultimately responsible for creating public value. Additionally, the NAO enlisted in a range of parallel partnership activities to bolster their operational capacities. This raises important questions about how values and expectations are communicated to the agents who assume responsibility for executing them, and how prepared actors are to adopt public management roles. These questions are particularly important given that there is very little data about how public managers and other stakeholders perceive and make sense of the key facets of the Strategic Triangle (Hartley et al., 2017). It has been argued that although the concepts and relationships of public value management have relevance for people who adopt these roles, they may lack an explicit language to capture them (Hartley et al., 2017). This suggests that principals have some responsibility in 'training' agents to be able to take on new value management roles.

As with public value management thinking more broadly (Liddle, 2018), our findings point to concerns that those who are assigned 'public manager' roles may be working in constrained and siloed environments that do not enable them to fully comprehend and identify with their assigned roles. For example, by accepting public grant money, academic researchers become implicated in the science-society contract. While individual scientists are increasingly urged to take greater interest in policy issues and directly engage with policy makers when designing Arctic research (Fleming & Pyenson, 2017), it has been suggested that many researchers are unaware of the embedded challenges they face when executing research intended for value creation (Kofinas et al., 2020). Further, it is unclear if they have the necessary skills and are prepared to do so. If academic research actors are expected to occupy public management roles, there needs to be opportunities for training to help them prepare for these responsibilities. Within ArcticNet, several general training opportunities were provided for secondary and university-level students, but not for more senior academics. This is an area that warrants further attention. There also needs to be clearer pathways of communication to trainees involved in research networks, who are often placed in delegated public management positions within research projects and commonly interface with local communities. Several recent Arctic-based studies suggest that early-career researchers and trainees feel that there is a lack of training for adopting public value management roles as they relate to engaging local communities (MacMillan et al., 2019; Sjöberg et al., 2018; Tondu et al., 2014). Future studies could build on the results of our analysis to examine how knowledgeable academic researchers (and trainees) are about the responsibilities associated with being a delegated public value manager and their perceptions of their role.

5.5.1 Limitations and Future Directions

We recognize that this research focuses largely on the perspectives of the NAO and would benefit from complementary analysis that garnered perspectives from other actors involved in the delegated chain. Future research could consult government actors, funding agencies, researchers, and community members to help identify gaps in our understanding of public value management delegation practices in networked scientific research governance. The inclusion of community member perspectives in future research is important and aligns with increasing community-based research in Arctic science (Brunet et al., 2014) and the need for improved understanding about the various capacities that communities are expected to possess when it comes to supporting scientific and development activities (Darling et al., 2018). Further, a more granular principal-agent analysis examining NAO partnerships with other entities to create and deliver public value would likely present meaningful insight into organizational resource flows (e.g., capital, human resources) as well potential barriers to coordination. To better understand how these relationships create public value it may also be worthwhile to examine key evaluative dimensions as they relate to each partnership: outcome achievement, trust and legitimacy, service delivery quality, and efficiency (Faulkner & Kaufman, 2018). Given that few studies have examined how the Strategic Triangle works in practice (Hartley et al., 2017), further efforts to link it to principal-agent theory may help to increase understanding about how public value management responsibilities are delegated across a governance network.

5.6 Conclusion

This exploratory study raises questions linked to the delegation of public value management roles for publicly-funded scientific research through formal networks. Our case study focused primarily on the NAO of a large Canadian Arctic research network, revealing that while public value management roles were delegated to the NAO and subsequently passed on to researchers and other partners, these management expectations were implied, but not explicitly addressed. By accepting public funds to conduct Arctic science, researchers and their collaborators were expected to bring together the three aspects of the public value Strategic Triangle, reporting their public value outcomes to the NAO, who would then report to the government. Results suggest that more explicit articulation of the delegation of public value management roles in the chain of contracts from governments to scientists may be central to the improved success of efforts to enhance the public value outcomes tied to publicly-funded scientific research. Key-informants also indicated that improved training for delegated actors to be better prepared to adopt public value management roles could be an important strategy in supporting value creation efforts. This suggests the need for a more detailed understanding of how different actors implicated in principal-agent relationships through scientific research networks view their public value management responsibilities.

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Chapter 6. General Discussion & Conclusion

6.1 Introduction

This dissertation considers the question: *how does networked scientific research designed to support innovation shape public value creation in the Arctic?* A systems approach informed by scholarship on innovation ecosystems, public value, and network governance was adopted to facilitate the research. This allowed an examination of the ways that networked Arctic scientific research is organized, evaluated, and managed in support of innovation and public value creation. Given that relatively little is known about the underlying scientific research governance systems that support science-informed innovation in the Canadian Arctic (Chapter 2), the results presented in this dissertation offer novel insights. This chapter presents an integrated synthesis of findings to help answer the main research question and offer directions for future inquiry. In what follows, I summarize the cross-cutting findings, outline the scholarly and practical contributions of the research, and suggest future directions to continue and expand on this work. While the insights presented in this section are framed in the context of the Canadian Arctic, they also have relevance for networked science policy and science-informed public value creation more broadly.

6.2 Cross-Cutting Observations & Major Findings

The thesis employed an exploratory case study approach using a mixed methods research design, wherein both qualitative and quantitative data from primary and secondary sources were collected and analyzed. Each chapter builds on, and complements, the chapters that preceded it in order to answer a specific research question. Given that this section aims to summarize observations, more specific policy directions are presented in Section 6.4 and specific research directions are provided in Section 6.5.

6.2.1 An improved understanding of Arctic innovation ecosystems

Research Question: *What is known about the systems that support or inhibit science-informed innovation in the Canadian Arctic and how can innovation ecosystems thinking enhance understanding about the public value of Arctic scientific research?*

Chapter 2 presents a literature review on science and innovation governance in the Canadian Arctic to identify opportunities for, and challenges to, creating public value. The review provides insight into Canada's efforts to promote scientific research in support of Arctic innovation, highlighting coordination issues and a general lack of knowledge about the systems that enable the development of northern-specific science-informed innovations. Recognizing that the Arctic is a complex policy environment and relies heavily on multi-stakeholder frameworks, the review finds evidence in support of innovation approaches that engage diverse Arctic governance structures, stakeholders, and rights-holders. This evidence, combined with the dominance of more linear views of knowledge flow in public policy, suggest that the Arctic would benefit from a systems approach to garner more complete understandings of the dynamic relationships that promote science-informed innovation and value creation processes. Thus, Chapter 2 establishes the groundwork to explore the public value of Arctic science by identifying several directions and research questions that require further investigation, while also proposing innovation ecosystems thinking as a conceptual framework to help approach these questions.

Building on the recommendations presented in Chapter 2, this dissertation operationalizes aspects of innovation ecosystem thinking to help consider the complexity of public value creation through scientific research by focusing on the case of ArcticNet, Canada's largest Arctic research network (Chapters 3-5). The decision to explore a single instrumental case study and approach it from different levels of organization (actors, networks, institutions) was informed by the recognition that innovation ecosystems are complex and that a single study alone would not garner adequate insight. As a result, a more comprehensive case study was completed involving three sub-studies, each looking at different factors shaping innovation ecosystem structure and function as it relates to scientific research governance (Chapters 3-5). First, collaborative relationships between individual and organizational research actors were assessed to characterize the collaborative network structure of science-based innovation actors in the Canadian Arctic, inclusive of boundary spanning patterns (Chapter 3). Second, the network-level public values articulated by the ArcticNet Network Administrative Organization (NAO) were identified, presenting new insights for network-level evaluation (Chapter 4). Third, the contract between Arctic science and society was examined, highlighting delegation practices for public value management in networked Arctic science (Chapter 5).

When considered together, the evidence suggests that large research networks like ArcticNet may possess the basic attributes necessary to act as a catalyst or 'proto-institution' in the formation of an innovation ecosystem focused on creating public value through science-informed innovation (see Table 6.1). That said, ArcticNet's focus on generating scientific knowledge via the academic enterprise implies that it likely reflects only one aspect of the Canadian Arctic innovation ecosystem. Further research is needed to understand the extent to which research networks can consciously contribute to the construction of Arctic innovation ecosystems. Insights presented in this thesis apply to different aspects of innovation ecosystems (e.g., innovation community dynamics, value articulation, management responsibilities). Further details about the potential theoretical implications that arose from framing this dissertation within innovation ecosystems thinking can be found in Sections 6.3.

Table 6.1: Core characteristics of innovation ecosystems compared to ArcticNet attributes

	Innovation Ecosystem*	**ArcticNet**	**Thesis Chapter**
Issues addressed	Value creation: socio-technological innovation, business development, management, sustainable regional development	Creating value: Generating scientific knowledge, using science to inform strategies and strategies, building a network, nation building, minimizing the impacts of climate change	Ch. 4
Focus	Problem-focused: Multi-stakeholder processes for value co-creation	Strategic-focused: Multi-stakeholder processes for addressing environment-related changes in the Canadian Arctic	Ch. 3-5
Groups of actors	Innovation communities: Multi-organizational networks; Multiple actors in co-operation and competition; Co-evolution	Research teams: A network of diverse stakeholders and rights-holders spanning multiple geographic, administrative and cultural boundaries; Co-evolution	Ch. 3
Actors	Participants that produce and use the innovation: Private-sector firms, entrepreneurs, financial markets, venture capitalists, universities, non-profits, decision makers, government institutions, end-users	Participants that produce and use science: Scientists, science program managers, Indigenous organizations, northern communities, governments, non-profits, private-sector firms	Ch. 3
Organizing force	Focal firm or platform	ArcticNet as a platform to fund collaborative Arctic science	Ch. 4, 5
Scale	Local to global: Cut across multiple organizations, functions and industries	Local to global: Relevant to Arctic communities, various policy communities and the international science community	Ch. 3, 4

**Summary interpreted from content provided in: Autio and Thomas 2014, de Vasconcelos Gomes et al. 2016, Jackson 2011, Oh et al. 2015, and Oksanen and Hautamäki, 2015.*

6.2.2 Arctic innovation community dynamics

Research Question: *How do diverse science-based innovation actors interact and foster boundary spanning within a large Arctic scientific research network?*

Networked innovation communities are an essential component of an innovation ecosystem since they foster the multi-actor collaboration required to advance fundamental scientific knowledge while also supporting public value creation through seeking innovative solutions (Chapter 2). Chapter 3 maps the configuration of science-based innovation actors in ArcticNet from 2004-2017, demonstrating that an increasing number of actors joined the network and crossed sectoral, geographic, and thematic boundaries to participate in collaborative research projects. Such findings are promising because effective collaborative networks can be used to help reduce the cost of what are often expensive Arctic research endeavours (Mallory et al. 2018), support knowledge flows between diverse actors (Task Force on Northern Research, 2000; Brunet et al. 2014), and promote coordination across large geographic and remote areas (Lee et al. 2015). However, a heavy reliance on collaboration may implicitly increase the potential for higher transaction costs to be incurred by team members (Pigford et al. 2018), which can be further amplified by the high number of principal-agent contracts in Arctic research networks (Chapter 5). To help reduce potential transaction costs and address many of the coordination issues inherent to collaborative Arctic science (Chapter 2), strategies designed to target centrally networked actors with high boundary spanning performance (e.g. non-local public sector actors and increasingly local actors) are needed (Chapter 3). Further, since non-local public-sector actors (mainly Canadian academics) represent the most central actors in the innovation community examined, it will be important to elicit their perceptions and understandings about key ecosystem structures and functions.

6.2.3 Articulating network-level public values within an innovation ecosystem

Research Question: *What are the network-level public values associated with networked Arctic science and how does adopting the network as a fundamental unit of assessment impact opportunities for network evaluation?*

Well-articulated public values are important in helping to realize a healthy innovation ecosystem by ensuring that networked innovation community actors are operating from a shared understanding of common objectives (Jackson, 2011; Jucevičius & Grumadaitė, 2014). After identifying ArcticNet's network of science-based innovation actors in Chapter 3, Chapter 4 uses the Network Administrative Organization (NAO) as the unit of analysis to identify the network-level public value propositions associated with ArcticNet using Public Value Mapping (PVM). ArcticNet targeted a broad range of publics and six broad network-level value categories were identified: scientific excellence, useful information, collaboration and partnership, environmental change, network legacy, and nation building. The implications of pursuing each value category could be further unpacked.

Since efforts to evaluate the public value impacts of collaborative research networks have been relatively limited (Budtz Pedersen et al., 2020), Chapter 4 also provides reflections for the design of network-level evaluation strategies. For example, it suggests that network managers should pay close attention the unit of assessment when articulating public value, since the values associated with individual research projects may not well-reflect broad network-level values. To reliably assess network-level public values it is recommended that research networks ensure consistency in value articulation across public facing documents and clearly identify network-level outcome attributes and articulate value creation goals at the appropriate level of scale. Findings imply that the Canadian Arctic innovation ecosystem would benefit from more inclusive evaluation tools that consult the range of publics targeted by activities (Chapter 4), the agents contracted to help achieve tasks (Chapter 5) and the collaborative actors involved in the innovation community, as identified in Chapter 3. Further, improved definition of network boundaries (i.e., who and what is included in the network) may facilitate improved understanding of what Arctic science-informed innovation efforts hope to achieve.

6.2.4 Delegated responsibility for public value management roles across the ecosystem

Research Question: *Who is responsible for public value management in a large Arctic scientific research network mediated by a NAO?*

Given that Arctic innovation ecosystems are nested within dynamic and multi-layered institutional landscapes (detailed in Chapter 2), it is important to have a foundational understanding of who is responsible for creating public value through science-informed innovation. Turning to the contract between science and society, Chapter 5 explores principal-agent contracts for delegating core public value management responsibilities associated with ArcticNet. Overlapping, multi-level principal-agent contracts for public value creation were identified, suggesting a shift from government as the agent responsible for creating public value to an expectation that many different science-based actors will adopt public value management roles.

Despite this trend, it remains unclear how core elements of public value management (i.e., identifying public value, political legitimacy, and operational capacity) are realized and communicated in the Arctic innovation ecosystem. While Chapter 3 characterizes the networks of actors that come together with the goal of creating socially-relevant science, Chapter 5 moves beyond the level of the project to raise important questions about hierarchical delegation processes that may complicate scientific research governance, increase transaction costs and impede effective public value management. Chapter 4 also speaks to this, raising important questions about who is responsible for creating public values for a range of diverse publics, and if NAO's may have a role in this. Given these unanswered questions, it is possible that current responsibilities and delegation practices may be associated with prohibitive institutional structures, making it necessary to identify concrete examples of past efforts and attempts to revise existing institutional arrangements to improve Arctic scientific research governance.

6.3 Contributions to Theory

This dissertation contributes towards an expanded understanding of Arctic innovation ecosystems by exploring networked science intended to promote public value creation in the Canadian context. Each chapter investigated different aspects of the Arctic innovation ecosystem (see Figure 1.3 page 26), coming together to illustrate the potential utility of linking innovation ecosystems and public value thinking to better understand Canadian scientific research governance. More specifically, theoretical contributions relate to 1) the relationship between innovation ecosystems and public value, and 2) opportunities for an expanded conceptualization of Arctic science-informed innovation ecosystems.

6.3.1 Innovation ecosystems for public value creation

In general, public value thinking is informed by the network governance literature associated with co-production, collaboration, and innovation (Liddle, 2018), suggesting that there is substantial overlap with the rhetoric driving innovation ecosystems thinking. However, despite the mutual reliance on network governance approaches and the potential for conceptual overlap, there have been limited attempts to bridge the two concepts. To date, the public value literature has largely focused on framing an approach for the administration of public systems and there has been limited empirical research on public value and innovation systems (Hartley et al., 2017). Further, the innovation literature has largely focused on private sector outcomes even though the value created through innovation ecosystems can be of a public or private nature (Hartley, 2011, 2015). The use of both concepts in this dissertation presents an opportunity to consider innovation ecosystems as they relate to public value creation, moving both concepts beyond their traditional applications in an effort to identify novel ways of re-thinking governance and institutions for improved innovation outcomes in the Arctic context.

By merging the two concepts to enhance understanding of Arctic scientific research governance, this dissertation illustrates that innovation ecosystems thinking has the potential to support and guide the design of science-informed innovation efforts for public value creation (Chapter 2). In general, this type of approach is needed because although several different types of large scientific research initiatives exist, most have been driven by values related to technological and economic innovation (Hessels et al., 2009). With a shift towards expectations that scientific research facilitates other forms of value creation, the ArcticNet case illustrates an intent for network-level public value creation (Chapter 4) and the adoption of public value management roles by the NAO (Chapter 5), calling attention to the need to better capture and understand the societal value and relevance of publicly supported networked research (Adam et al., 2018; Budtz Pedersen et al., 2020; Hellström, 2011).

6.3.2 An expanded conceptualization of Arctic science-informed innovation

While the dissertation does not empirically test theoretical assumptions related to innovation ecosystems, it makes important contributions for expanding notions about science-informed innovation in the Arctic and presents several opportunities for future theoretical exploration. More specifically, the use of innovation ecosystems thinking, as framed in this dissertation, calls for 1) improved appreciation of the multifunctionality of Arctic science-informed innovation, 2) more inclusive conceptualizations of Arctic innovation communities and power dynamics, and 3) an expanded view of the potential for supporting boundary spanning.

Innovation ecosystems thinking may offer a useful umbrella concept that is appropriate to account for the wide multifunctionality (i.e., many functions at many levels) of Arctic systems. Focusing on scientific research governance, there are several process-based and human functions carried out by Arctic scientific research (e.g., communication, knowledge translation, partnership, education, training) that are key to achieving desired outcomes in addition to traditional knowledge production expectations (Henri et al., 2020; Pigford et al., 2018; Tondu et al., 2014; Wong et al., 2020). Findings suggest that the effectiveness of these process-based functions may be shaped by the boundary spanning practices enacted by collaborative actors (Chapter 3), the clear articulation of public values (Chapter 4), and how well publicly funded science resources are managed (Chapter 5). The dissertation suggests that a lack of attention to these issues could hinder conscious adoption of multifunctional approaches.

Since the production (and use) of scientific research is only one of many enabling factors for promoting value creation (Wieczorek & Hekkert, 2012), by enacting innovation ecosystems thinking the thesis calls attention to the complementary systems and innovation communities that also exist support innovation in the Arctic. By promoting inclusive conceptualizations of innovation communities, innovation ecosystems may better reflect the diverse actors and multiple economies present in the Canadian Arctic, while also accounting for alternative forms of innovation that co-occur within a shared environment, each with their own related innovation community (which may be more or less developed and resourced). For example, an innovation ecosystem could be conceptualized to simultaneously support innovations emerging from Western science and Indigenous science, as well as emergent (and different) interactions that combine alternative approaches. It could also highlight diverse Indigenous voices that are not traditionally engaged by Arctic science actors (Hitomi & Loring, 2018).

Although the thesis was not designed to examine the challenges with bridging across different types of innovation communities and knowledge cultures, by promoting innovation ecosystems thinking (Chapter 2), examining boundary spanning within science-based innovation communities (Chapter 3), considering target publics (Chapter 4), and public value management responsibilities (Chapter 5) it highlights the potential importance of power and negotiation at the level of the innovation community, which is key to effective public value creation. The pluralism that is inherent in innovation ecosystems requires explicit acknowledgment of deep interdependent multi-dimensional relational linkages between communities (Jackson, 2011; Jucevičius & Grumadaitė, 2014; Oksanen & Hautamäki, 2015). For example, existing Arctic innovation approaches largely emphasize Western science without fully opening to lessons from Indigenous knowledge, which may contribute to lock-in and other self-reinforcing processes that exclude the introduction potentially innovative knowledge (Bocking, 2008; Archie & Bolduc, 2017; Lam et al., 2020). Thus, there is an opportunity to better consider the socio-political power dynamics that shape actor inclusion and diversity in scientific research networks to counter potential lock-in and to support sustainable Arctic development (Nilsson & Koivurova, 2016; Oksanen & Hautamäki, 2015; Rachold, 2018).

Recognizing that multiple and at times contradictory goals may exist within the ecosystem (Nambisan & Baron, 2013) ongoing efforts are required to clarify, communicate, and evaluate the achievement of public values by and for different actors within Arctic innovation ecosystems (Chapter 4). Further understanding of the challenges associated with role delineation in Arctic systems is also needed (Chapter 5). Similarly, there is a need to understand cross-boundary interactions that adaptively engage with actors at different scales to consider emergent effects due to concurrent processes (e.g., feedbacks, flows, interactions) (Walrave et al., 2018), which if left unaddressed can have an impact on the development and scaling of science-informed innovations in terms of gaining critical mass or possibly losing momentum.

Although innovation ecosystems thinking appears to offer new insights for designing cross-sectoral science-informed innovation in the Arctic, action is needed by those designing to systematically operationalize and use innovation ecosystems thinking in the Arctic. By broadening the change agents considered for Arctic innovation to include all actors operating in different innovation communities, innovation ecosystems thinking raises new questions about the potential need to reconceptualize important relationships and interactions between actors to better support innovation. Future investigations into Arctic innovation ecosystems may thus seek an improved understanding about multifunctionality, transboundary relationships, and the role of power within and between different, yet interdependent, innovation communities each seeking to create different public values through different public value management approaches (see Section 6.5 for more explicit research directions).

6.4 Insights for Policy & Practice

Arctic governments regularly turn to scientific research for answers about how to best foster innovation, development, and value creation in the Arctic (Arctic Council, 2017; Coates, 2020; Eerkes-Medrano et al., 2019; Hall, 2020; Kettle et al., 2019; Pigford et al., 2017). Despite ongoing attempts to address key Arctic issues by bringing researchers and other expertise together from across the globe, reports suggest that research investments are often tailored to support scientific pursuits rather than addressing community needs or fostering local innovation (Eerkes-Medrano et al., 2019; GY, GNWT &, GN, 2016; Healy, 2017; ITK, 2016, 2018). This gap raises key questions about how scientific research designed to support innovation contributes to public value creation in the region.

6.4.1 Adopting innovation ecosystems thinking

Evidenced by the exploratory research presented in this dissertation, a more inclusive conceptualization of the Arctic innovation landscape is required to fully comprehend the systems that shape public value creation. This includes the way that research and innovation processes are organized, structured, funded, and governed. Findings suggest that policymakers need to focus efforts on overcoming challenges related to coordinating across complex jurisdictional boundaries and multiple innovation communities (Chapter 2), a reliance on non-local innovation actors to support science-informed innovation (Chapter 3), ambiguous value articulation (Chapter 4), and overlapping yet unclear contracts for public value management (Chapter 5). Developing and support innovation governance models that are based on innovation ecosystems thinking may help to more equitably incorporate various innovation communities, support boundary spanning, consider scale and promote delegated public value management that is anchored in well-articulated value propositions for creating Arctic innovation. Ultimately, these kinds of interventions have the potential to enhance the public value of Arctic scientific research investments. The practical implications of adopting innovation ecosystems thinking and how it may help address existing issues and enhance the creation of public value are further elaborated on below.

6.4.2 Reflexive research management, coordination and design

Arctic science systems that promote greater reflexivity and responsiveness may ultimately produce more robust public value outcomes. Given recent calls to action and efforts to decolonize science and promote self-determination approaches (e.g., Truth and Reconciliation Commission in 2015, National Inuit Strategy on Research in 2018, the territorial Pan-northern Approach to Science in 2016), it is increasingly important for Arctic governments to consider how they approach and evaluate Arctic science and innovation activities. Efforts need to move beyond baseline assessments and a focus on project-level outcomes to more effectively capture longitudinal change and public value outcomes at other levels, while also considering interactivity between outcomes (Chapter 4). There is also evidence to suggest that poorly communicated public value management expectations accompanied the potential for high transaction costs may exist within current institutional delegation practices, a situation that would benefit from greater policy attention (Chapter 5). Management approaches that leverage existing knowledge brokers and boundary organizations may help to minimize some of the transaction costs associated with Arctic scientific research governance and facilitate more effective, systematic, and reflexive northern research policy (Pigford et al., 2018).

It is now widely accepted that Arctic stakeholders and rights-holders rely on collaborative networks and knowledge exchanges to arrive at decisions in support of improved collective outcomes. Based on our findings we identify several considerations for policy actors to target in their efforts to promote increased collaboration:

- Circumpolar Arctic governments, including the Arctic Council may benefit from an inventory and synthesis of current science and innovation activities to provide a more complete understanding of the range of science and innovation activities happening in the region so that interventional policies to direct action can be designed to guide policy action.
- The Canadian federal government could further address the fragmented Canadian Arctic scientific research governance landscape by creating and resourcing an intra-governmental

Arctic science coordinating entity to help synthesize and promote more coordinated action across the various federally-funded Arctic science and innovation initiatives occurring at multiple levels (e.g., projects, programs, networks, departments and agencies, intramural, and extramural research funding).

- In response to recent calls to decolonize Canadian Arctic science and promote Indigenous self-determination in research, there is a need to review Canadian scientific research governance policies that target traditional innovation ecosystem actors (e.g., private sector and southern academics) and consider how future policies may be designed to better support the engagement of local innovation actors, who show the potential to drive sustainable innovation efforts in other Arctic contexts.
- Until the Canadian Arctic develops new institutions for Arctic scientific research governance Arctic innovation policies may need to more explicitly account for the wide range of roles that non-local academic organizations play in networked Canadian Arctic science.
- Given the need to address cross-cutting Arctic issues with impacts on local to global scales, circumpolar governments and funding bodies would benefit from adopting a public value framing that more clearly considers the scale of intended impact and better articulates the intended publics, public values, and assigned responsibilities for public value management.

6.5 Future directions

The research presented here was exploratory in nature and provides initial insight into several factors that influence the creation of public value in networked Arctic scientific research. However, the adoption of an exploratory research design, which is considered appropriate for topics and issues with limited existing knowledge about the processes being studied (Babbie, 2015; Stebbins, 2001), presented several challenges. While the flexibility and broad research questions inherent in this approach allowed for an investigation of contemporary phenomena at different levels of the innovation ecosystem (actors, networks, institutions), it did not allow for a comprehensive analysis targeted at specific aspects of the innovation ecosystem. Further, the cursory nature of exploratory research meant that each study could not engage all potential actors with insights on these topics, especially actors from Arctic communities. The dissertation therefore often raises more questions than answers, laying the foundation for future research. More specifically, findings from this dissertation confirm the need for additional studies to help improve the understanding of the underlying systems that shape science-informed innovation and public value creation in the Arctic. Future directions are directly associated with identified theoretical and practical implications are identified in earlier sections. Here, I identify broad directions that would benefit from future research:

- Ongoing efforts to conceptualize and provide critical analysis of the actors, networks, and institutions that shape Arctic scientific research governance would be valuable in helping to provide directions for interventional research that can improve coordination and knowledge integration within complex science and policy networks designed to support public value creation.
- Recognizing that the research presented in this dissertation focuses explicitly on the scientific enterprise and how it is embedded within Arctic innovation ecosystems, there is a need for complementary studies that examine how other knowledge systems are situated within Arctic innovation ecosystems. For example, future studies could link to Indigenous methodologies and approaches to science or draw on theories of Indigenous

innovation (Archie & Bolduc, 2017), grassroots innovation (Hermans, Roep, & Klerkx, 2016) or inclusive innovation (Foster & Heeks, 2013).

- Further exploratory studies are required to help uncover how elements of innovation ecosystems thinking are expressed in the Arctic (both through formal and informal institutional structures) and how they may come together to influence innovation dynamics and potential.
- Given that the Arctic is a large, circumpolar region and many of my research findings are based on case study research conducted in Canada, efforts to conduct similar analyses in other Arctic regions at multiple scales (local to circumpolar) would be valuable in order to support the generalizability of findings and further develop region-specific theories.

6.6 Conclusion

This dissertation represents one of few detailed examinations into the relationship between public value creation and Arctic scientific research governance in Canada. It explores the diverse linkages and intersections that exist among scientific research actors, networks, and institutions operating in a prominent Canadian Arctic innovation ecosystem, offering novel insight to the public value creation processes associated with science-informed innovation efforts. Amidst increasing investment in Arctic scientific research designed to foster sustainable development and address transformational change, this dissertation presents an opportunity to reflect on and potentially reassess Arctic scientific research governance structures and their positioning within innovation narratives. The adoption of innovation ecosystems thinking facilitated an expanded approach for conceptualizing the processes involved in creating public value through scientific research and enabled the identification of areas for future inquiry. The need to design and promote more inclusive and reflexive Arctic science and innovation systems that better account for the complex, fragmented, evolving, nested, and transboundary nature of Arctic governance is pressing. Collectively, the findings and ideas presented in this dissertation add to a growing body of literature designed to support scientific research governance strategies that are capable of delivering public value in the form of economic, social, political, cultural, health and/or environmental benefits, through science-informed innovation in the Arctic and beyond.

6.7 References

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Appendices

McGill

Appendix 1A: Interview guide for key-informant scoping interviews

Title of Research: Creating Public Value Through Arctic Scientific Research

Researcher: Ashlee-Ann Pigford, Ph.D. Candidate, Natural Resource Sciences
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Student Supervisor: Gordon Hickey PhD., Associate Professor, Natural Resource Sciences
Contact Information: Tel: (514) 398-7214 Email: gordon.hickey@mcgill.ca

Location: To be determined by the participant
Duration: Up to 1.5hrs

Introduction

This is an interview-based study that explores issues that are relevant to the ongoing development and evaluation of ArcticNet. We are recording scoping interviews with key-stakeholders associated with ArcticNet. Interviews will be transcribed and de-identified - no one you mention will be identifiable by their names in the transcripts. These transcripts will then be qualitatively analyzed, looking for both common themes among participants as well as examples of disagreement in order to better understand how public value is created by ArcticNet. We intend to disseminate the findings as abstracts at academic conferences and to publish our analysis in the peer-reviewed literature. Written quotations of comments will be used but de-identified.

The interview will be expected to take no more than 1.5 hours. Before we begin, I would like to remind you that there are no correct answers. Your participation is **voluntary**. You do not have to answer any questions that make you feel uncomfortable. You can choose to end the interview at any point.

Do you have any questions about the study and the use of data before we begin recording?

Questions (boxes are context for interviewer)

1. Introduction
    a. Please tell me a little about your experience working with ArcticNet?
        i. How long have you been with the network?

2. Public Value, Design and Governance
    a. What are the goals of the organization?
        i. Can you tell me about the rational for ArcticNet?
        ii. Who are the target groups? (e.g., which scientists, fields of study?)
        iii. How does ArcticNet align more broadly with other initiatives?
        iv. Which sources fund ArcticNet?

Design

- *Rationale*
- *Target groups (e.g., which scientists; which fields of science and technology?)*
- *Focus and scope (e.g., focus on education or research; applied or basic research?)*
- *Alignment with innovation policy mix (how does it relate to other innovation policy instruments?)*
- *Funding (from which sources will it be funded? for how many years?)*

    b. How does ArcticNet work as a funder of scientific research?
        i. What is the process for approving projects?
        ii. What evaluation criteria are used?
            1. Has this changed over time?
        iii. How are priority areas defined?

Application, Selection and Funding

- *Two- or three-stage selection processes including pre-proposals. An international panel makes final selection, sometimes with participation of private sector representatives*
- *Evaluation criteria include scientific worth, structural potential and organizational viability, impact and fit with host institution(s), innovation capacity and contribution to competitiveness of national industries*
- *5–10 year funding timelines, where the funder provides 40–100% of total funding and the remainder is matched by host institutions and external stakeholders/partners, often with a gradual decrease in base funding*
- *In some cases, no requirements to attract matching funding although industry cooperation may be a funding condition*

    c. Please describe the governance of the organization?
        i. How has this changed over time?
        ii. What types of resources are used to support the governance? (financial, human)
    d. What do you think ArcticNet does well?
    e. What do you think ArcticNet can improve on?

Implementation and Governance

- *Governance involves steering committees, an international advisory board, and/or combination of ministerial oversight and local leadership groups. There may be mixed governance boards including business partners, sometimes with a requirement that the board has a majority of external partners and reflects the stakeholders involved*
- *Demands for specific organizational forms may include coherent milieus (under one roof), unitary leadership, multidisciplinary teams, and integration with the host institution(s), with different degrees of integration between host institutions and foreign partners*
- *The structure must be able to manage complex research and commercialization activities. Often the structure may be flexible, consisting of several smaller research groups*
- *Centres often have to plan, and use part of their budget, for cooperation*

3. Reporting
    a. Can you tell me about monitoring and evaluation processes?
        i. Scientific outputs – publications, patents
        ii. Innovation outputs – contracts with industry, patents, spinoffs
    b. Who in the network is responsible for reporting?
    c. What internal practices are in place?
    d. Have there been any external evaluations of ArcticNet commissioned?
        i. What have they found?
        ii. How has ArcticNet responded

Monitoring and Evaluation (M&E)

- *Mid-term and final evaluations as well as annual reviews focusing on financial and operational monitoring*

M&E topics:

- *Scientific outputs (patents, publications, etc.)*
- *Innovation outputs (contracts with industry, patent licensing, creation of spinoffs, etc.)*

M&E organization:

- *Ongoing monitoring by commissioner and centres themselves*
- *Commissioned evaluations to assess progress*

4. Coordination & Organizational capabilities
    a. In what ways has ArcticNet promoted scientific coordination/collaboration?
    b. Can you tell me about ArcticNet's management structure?
    c. Has ArcticNet faced challenges in terms of coordinating individual researchers? If so, what?
    d. Has ArcticNet faced challenges in terms of coordinating the network broadly? If so, what?
    e. What mechanisms are in place to foster communication across the network?

M&E topics:

- *Organizational capabilities (internal collaboration, management structure)*
- *Strategic capacity (situational awareness and clear vision, executive capacity)*
- *Resource strategies (external acquisition and internal allocation)*
- *External cooperation and networking (quality of partners, sustainability of partnerships, crosssectoral cooperation)*
- *Human capital base (academic leadership, recruitment policy)*
- *Epistemic capability (access to knowledge, intellectual coherence, learning mechanisms, multidisciplinary collaboration, intellectual synergies)*

5. Boundaries & Policy
    a. What kinds of barriers does ArcticNet face as a network?
    b. Can you think of any examples of how public policy has inhibited the functioning of ArcticNet?
        i. E.g., selection criteria requirements, funding timelines, leveraging requirements
    c. Can you think of any examples of how public policy has supported the functioning of ArcticNet?
    d. Can you think of any examples of how ArcticNet has influenced policy decisions?

That's the end of my formal questions, is there anything else you'd like to add or comment on?

Do you have any other key-informants that you recommend we contact?

At this time, I would like to thank you for your participation. As we start to better understand this topic area, we may contact you for some follow up interviews. Your contribution to this study has been beneficial and insightful. If you have any further comments or questions please contact me. My contact information is included on your copy of the consent form.

Appendix 3A: Supplemental Analysis: ArcticNet structure

Purpose

A supplemental Social Network Analysis was conducted to present further insight into the network's evolution over time by exploring networked relationships between individual actors that were eligible to receive direct funding from ArcticNet via funded projects (i.e., Project Leaders (PL) and Network Investigators (NI)). Specifically, we aim to map changes to the network of individuals over time to generate insight into changing network structure.

Methods

Using the longitudinal data described in Section 3.3.2, data were extracted for PLs and NIs to create a subset of individual actors. This included information on individual actors connected through project relationships. Individual attributes were not considered, and project attributes included phase and thematic funding stream only.

Social network analysis techniques (Scott 2012) were employed to explore changes in individual network structure by Phase. Data transformations and network metrics were calculated using UCINET 6 software for Windows and visualizations were prepared using NetDraw 2.164 software (Borgatti, Everett et al. 2002). Data were analyzed by examining collaborative relationships (binary, undirected relationships) between individuals receiving funding by ArcticNet actors to garner a general description of the network. If individuals participated in at least one project together a relationship was seen to occur. Data are presented by Phase, with each Phase including only the relationship that occurred during that phase (i.e., the data are not cumulative).

Two-mode matrices were created for each Phase to examine how individual actors collaborated across projects (individual × project). Network visualizations were generated to identify changes in relationships between ArcticNet actors. These were then converted into one-mode adjacency matrices to represent the relationships between the individuals connected through ArcticNet funded projects (individual × individual) to generate network metrics. Network cohesion measures (density, number of ties and components) and average individual metrics (average degree centrality) were assessed using one-mode adjacency matrices (individual × individual) for each phase. Four additional that were not defined in Section 3.3 measures are added: number of components, component ratio, principal component size and number of isolates. The number of components reflects groups of connected actors that are not connected to other groups/components. Individuals are part of the same component if there is a path connecting them, it does not need to be a direct connection. The component ratio is a measure of network fragmentation. The closer the ratio is to 1 the more fragmented, suggesting that every node is an isolate; the closer the ratio is to 0 the more connected the network, suggesting that every node belongs to the same component. The size of the principal component provides insight into network integration. We also calculate the percentage of NI/PLs included in the principal component to garner understanding about the percentage of individuals connected directly or indirectly. The number of isolates presents insight into the number of NI/PLs that have no connection to any other NI/PL in the network.

Results

Over a 13-year period (2004-2017) 152 multidisciplinary research projects were funded, with over 100 individuals positioned to receive funding from the network in each phase. The Table below outlines key network attributes. The total number of NI/PLs in the network increased over time, but the increases were relatively proportionate to the increase in number of funded projects, suggesting that the increases in network size witnessed in Chapter 3 were likely due to an influx of other collaborators who were ineligible to directly receive project funds. The network funded and average of 3.5-4.1 NI/PLs per project. NI/PLs were more likely to be connected to other NI/PLs in Phase 1 (average degree) compared to subsequent phases and the number of isolates increased slightly over time. As the number of components increased the network moved away from a large, highly integrated principal component connecting more than 90% of NI/PLs towards less connected network structures. From a network structure perspective, the network became less centralized and more fragmented over time (decreased degree centralization, more components, lower higher component ratios and more isolates).

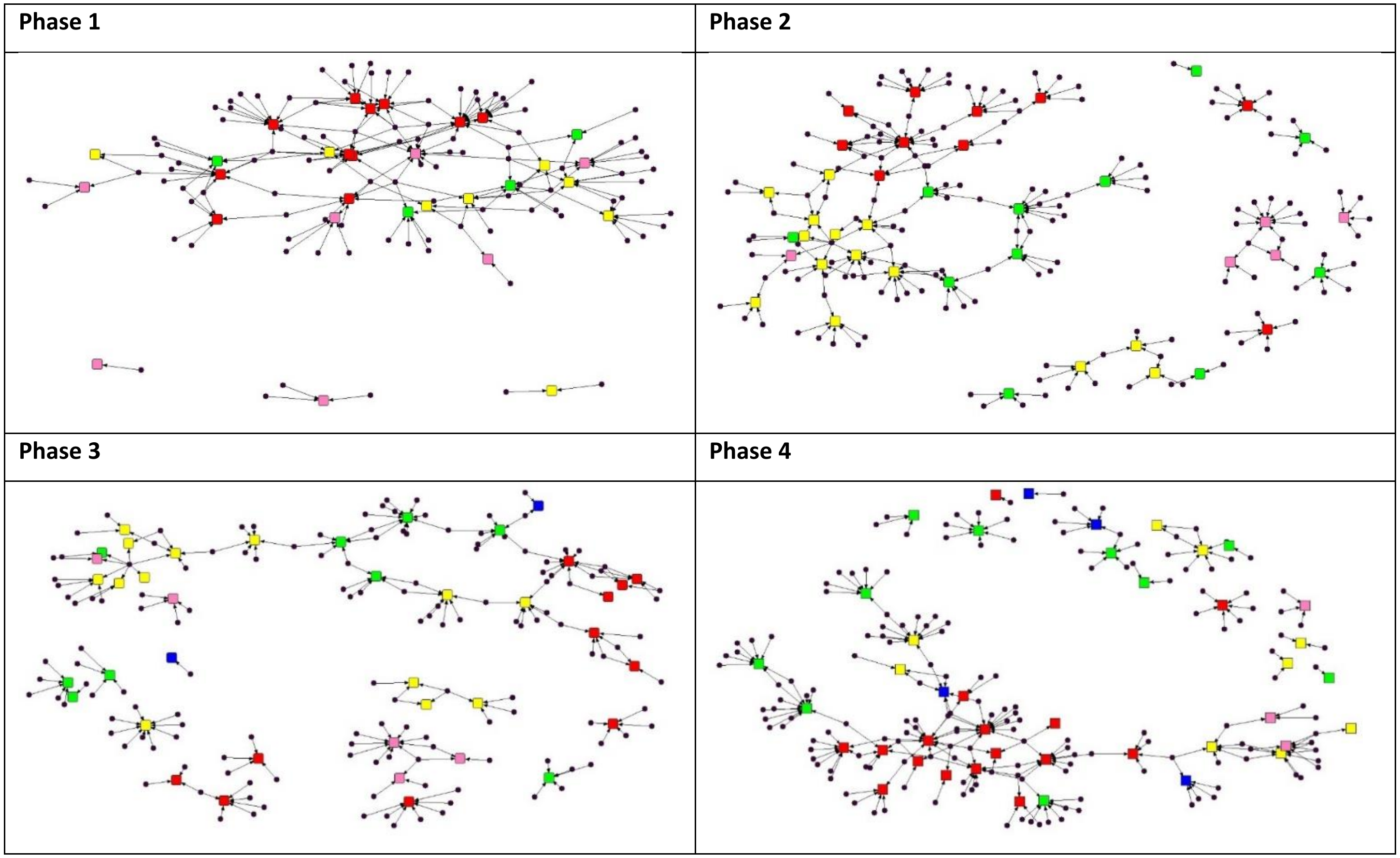
This supplemental analysis points to the NI/PL network becoming less cohesive over time, moving away from a network with extensive project-based connections towards a network with fewer cross-project linkages. The movement away from a more cohesive, integrated network with a large principal component illustrates a reduction in the direct and indirect collaborative paths between ArcticNet funded researchers. The trend suggests that over time the network may have had fewer opportunities to leverage network ties (both direct and indirect) to diffuse information and innovations between funded researchers (NI/PLs).

Appendix 3A Table: ArcticNet network characteristics for funded individuals*

	Phase 1	Phase 2	Phase 3	Phase 4**
# Projects	30	40	40	42
# Individuals	104	155	147	171
Average # Individuals / Project	3.5	3.9	3.7	4.1
Individual – Individual Connections				
Degree centralization	0.23	0.11	0.08	0.13
Density	0.10	0.04	0.04	0.05
# Ties	1058	1048	920	1484
# Components	4	11	14	14
Component ratio	0.03	0.06	0.09	0.08
Principal component size (% of network)	98 (94%)	102 (66%)	75 (51%)	126 (74%)
# Isolates (% of individuals)	1 (1.0%)	1 (0.6%)	2 (1.4%)	4 (2.3%)
Average degree	10.2	6.8	6.2	8.7

**Includes Network Investigators and Project Leaders only.*

Appendix 3A Figure: Network structure over time: Collaborations between funded academics through projects



	Theme 1: Marine Systems		Theme 2: Terrestrial Systems		Theme 3: Inuit Health, Education & Adaptation	●	Individual
	Theme 4: Northern Policy & Development		Theme 5: Knowledge Transfer			□	Project

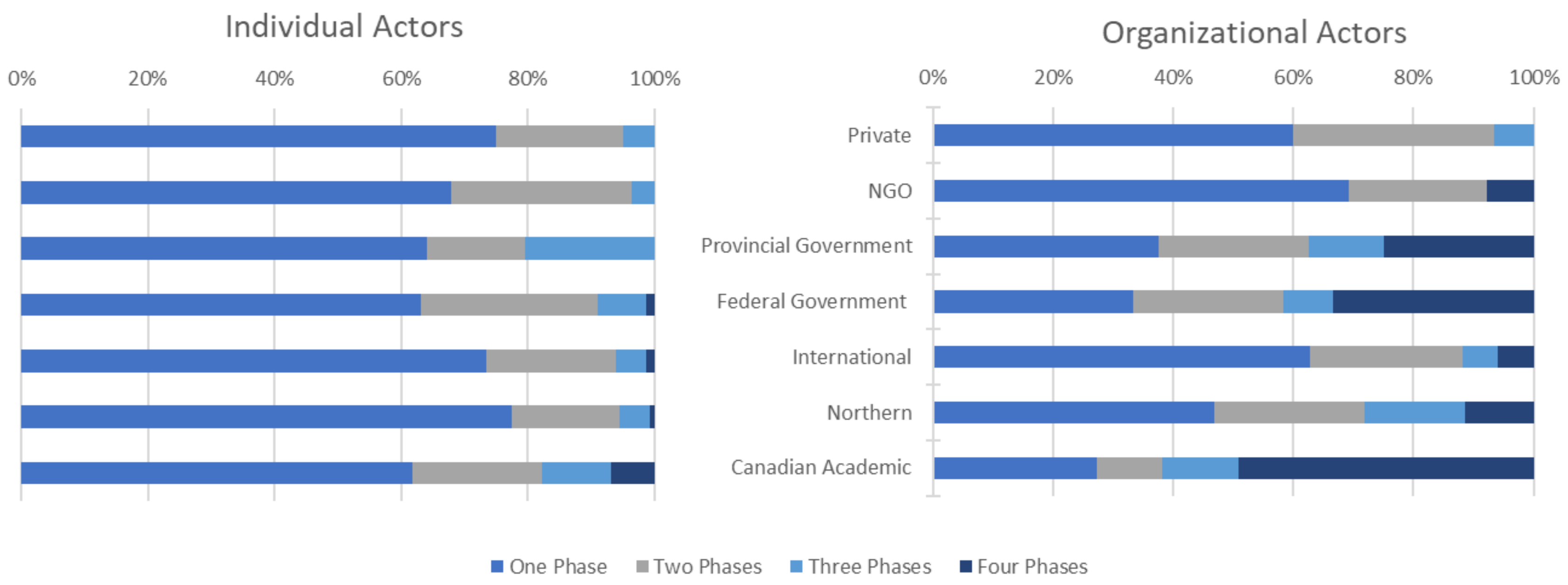
Visualizations represent network of individual actors connected through projects with the nodes (squares) representing projects, circles representing individual actors and the lines representing the relationships between individual actors. Nodes colors reflect each project's theme.

Appendix 3B: Detailed breakdown of ArcticNet actors by sector

	Complete Network*	Phase 1	Phase 2	Phase 3	Phase 4**
	N [% actors]				
# Unique Organizations	**301**	**94**	**151**	**167**	**175**
Canadian Academic	55 [18]	36 [38]	38 [25]	40 [24]	42 [24]
Northern	96 [32]	25 [27]	52 [34]	53 [32]	55 [31]
International	102 [34]	16 [17]	40 [26]	52 [31]	50 [29]
Federal Government	12 [4]	8 [9]	6 [4]	6 [4]	9 [5]
Provincial Government	8 [3]	5 [5]	4 [3]	5 [3]	4 [2]
Non-profit	13 [4]	2 [2]	5 [3]	5 [3]	7 [4]
Private Sector	15 [5]	2 [2]	6 [4]	6 [4]	8 [5]
# Individuals	**1659**	**394**	**622**	**732**	**728**
Canadian Academic	862 [52]	246 [62]	332 [53]	371 [51]	419 [58]
Northern	416 [25]	60 [15]	143 [23]	194 [27]	138 [19]
International	147 [9]	20 [5]	47 [8]	66 [9]	64 [9]
Federal Government	146 [9]	50 [13]	65 [10]	66 [9]	64 [9]
Provincial Government	39 [2]	12 [3]	14 [2]	13 [2]	22 [3]
Non-profit	28 [2]	4 [1]	11 [2]	15 [2]	13 [2]
Private Sector	20 [1]	2 [1]	10 [2]	7 [1]	8 [1]

* The complete network does not represent sums, rather it captures all possible networked connections
** Analysis includes available data only; thus, data from 2017-18 & 2018-19 is not included

Appendix 3C: ArcticNet actor turnover and retention over the four phases*



** Analysis includes available data only; thus, data from 2017-18 & 2018-19 is not included.*

Appendix 3C captures the breakdown of unique actors (both organizational and individual) over time. Each color represents a different phase.

Appendix 3D: Structural characteristics for centrality and boundary spanning by sector

Organizations

	Complete Network*		Phase 1		Phase 2		Phase 3		Phase 4**	
	Avg degree	Avg Betw.	Avg degree	Avg Betw.	Avg degree	Avg Betw.	Avg degree	Avg Betw.	Avg degree	Avg Betw.
Organizations	**31.3**	**145.9**	**19.0**	**41.1**	**21.5**	**74.7**	**24.6**	**81.5**	**23.5**	**83.9**
Min /Max	1 /209	0 /5426	3 /69	0 /721	2 /107	0/1607	2 /112	0 /1669	1/120	0/2447
Canadian Academic	64.2	598.0	37.3	92.5	37.3	237.0	41.1	260.6	38.7	250.7
Northern	26.0	68.5	16.3	10.6	16.3	19.5	18.0	34.2	19.7	45.5
International	19.7	15.4	12.7	2.2	12.7	1.0	18.8	6.3	14.9	9.7
Federal Government	48.3	268.2	37.8	41.2	37.8	182.5	37.2	173.5	34.0	127.6
Provincial Government	37.6	62.7	16.3	0.1	16.3	16.1	25.2	11.1	29.5	57.6
Non-profit	21.6	18.2	18.0	0.2	18.0	10.8	23.0	35.9	17.5	5.8
Private Sector	19.5	2.8	16.2	0.2	16.2	0.0	13.5	0.8	16.8	0.0

Continued on the following page

Individuals

	Complete Network*		Phase 1		Phase 2		Phase 3		Phase 4**	
	Avg degree	**Avg Betw.**	**Avg degree**	**Avg Betw.**	**Avg degree**	**Avg Betw.**	**Avg degree**	**Avg Betw.**	**Avg degree**	**Avg Betw.**
Individuals	**43.2**	**1469.2**	**29.1**	**276.2**	**32.6**	**452.3**	**38.9**	**561.8**	**31.5**	**682.2**
Min /Max	2 / 398	0/138519	3 / 133	0/11430	2 / 155	0/35167	3 / 186	0/37459	3 / 132	0/25116
Canadian Academic	45.8	2057.2	29.8	399.2	33.7	671.4	40	783.9	32.2	859.2
Northern	41.1	1031.5	28.0	31.1	33.5	281.0	39.3	413.5	30.4	675.7
International	35.6	249.1	23.3	16.6	23.6	14.5	36.5	78.8	29.8	249.3
Federal Government	41.5	1087.0	24.8	98.6	31.5	268.9	35.6	310.7	30.6	429.2
Provincial Government	52.7	309.5	48.0	44.5	33.8	3.6	43.2	2.5	35.5	0.0
Non-profit	38.6	1278.8	32.5	719.4	30.3	0.0	34.9	1001.3	22.7	0.0
Private Sector	36.1	13.0	33.5	41.5	32.3	0.0	23.1	0.0	34.6	0.0

Avg degree = average degree; Avg Betw = average betweenness

Appendix 3E: ArcticNet actors with the largest ego networks

Organizations		Individuals	
All Phases 1 (total 301 orgs)	**Ego network size**	**All Phases 1 (total 1659 indiv)**	**Ego network size**
Université Laval	209	Male; Fisheries and Oceans Canada	398
Université du Québec à Rimouski	177	Male; Fisheries and Oceans Canada	371
Government of Nunavut	153	Male; University of Manitoba	367
University of British Columbia	151	Male; Trent University	319
Université de Montréal	149	Male; Memorial University of Newfoundland	318
Phase 1 (total 94 orgs)		**Phase 1 (total 394 indiv)**	
Université Laval	69	Male; Fisheries and Oceans Canada	133
McGill University	62	Male; University of Manitoba	117
University of Manitoba	59	Male; University of Manitoba	115
Université du Québec à Rimouski	57	Male; Canadian Museum of Nature	99
Fisheries and Oceans Canada	49	Male; Fisheries and Oceans Canada	95
Phase 2 (total 151 orgs)		**Phase 2 (total 622 indiv)**	
Université Laval	107	Male; Trent University	155
Université du Québec à Rimouski	82	Male; Fisheries and Oceans Canada	150
Memorial University of Newfoundland	78	Male; Université Laval	143
McGill University	77	Male; Université Laval	142
University of Alberta	70	Male; Université Laval	135
Phase 3 (total 167 orgs)		**Phase 3 (total 732 indv)**	
Université Laval	112	Male; University of Manitoba	186
Université du Québec à Rimouski	99	Male; Fisheries and Oceans Canada	181
University of British Columbia	84	Male; Nunatsiavut Government	176
Trent University	80	Male; Université Laval	164
Government of Nunavut	76	Male; Fisheries and Oceans Canada	164
Phase 4 (total 175 orgs)		**Phase 4 (total 728 indv)**	
Université Laval	120	Male; University of Manitoba	132
Université de Montréal	89	Male; Fisheries and Oceans Canada	120
Université du Québec à Rimouski	89	Male; Université Laval	119
Memorial University of Newfoundland	80	Male; Fisheries and Oceans Canada	113
Government of Nunavut	79	Male; Université de Montréal	104

Appendix 4A: Detailed list of ArcticNet documents consulted for Public Value Mapping

Report Type		Number of Documents
ArcticNet Newsletters - Spring 2006- Volume 1 Number 1 - 2007 – Volume 2 Number 1		2
(Bi)annual Reports - ArcticNet Annual Report 2004-05 - ArcticNet Annual Report 2005-06 - ArcticNet Annual Report 2006-07 - ArcticNet Annual Report 2007-09 - ArcticNet Annual Report 2009-10 - ArcticNet Annual Report 2010-11 - ArcticNet Annual Report 2011-13 - ArcticNet Annual Report 2013-14 - ArcticNet Annual Report 2014-15 - ArcticNet Annual Report 2015-17		10
Conference Proceedings: Annual Scientific Meeting (ASM)		
- ASM 2005 - ASM 2006 - ASM 2007 - Arctic Change 2008 - ASM 2009 - ASM 2010 - ASM 2012	- ASM 2013 - Arctic Change 2014 - ASM 2015 - ASM 2016 - Arctic Change 2017 - ASM 2018 - ASM 2019	14
Research Compendia - ArcticNet Compendium Phase 1 V1 (2004-2008) - ArcticNet Compendium Phase 1 V2 (2004-2008) - ArcticNet Compendium 2011-12 - ArcticNet Compendium 2012-13 - ArcticNet Compendium 2013-14 - ArcticNet Compendium 2014-15 - ArcticNet Compendium 2015-16 - ArcticNet Compendium 2016-17 - ArcticNet Compendium 2017-18		8
Integrated Regional Impact Studies (Full Reports) - IRIS 1: Western and Central Canadian Arctic (2015) - IRIS 2: Eastern Canadian Arctic (2018) - IRIS 3: Greater Hudson Bay Marine Region (2019) - IRIS 4: Nunavik and Nunatsiavut (2012)		4
Total		38

Appendix 5A: ArcticNet Timeline of Activities*

*This is an overview of the types of activities conducted by ArcticNet over time and is not an exhaustive list. Content summarized from Annual Reports.

Phase 1 & 2	**Phase 1**				**Phase 2**		
	2004-2005	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**	**2009-2010**	**2010-2011**
NAO Milestones	*Funds awarded* *NAO established in 2003*		NCE International Partnership Initiative Funding ($815,000)				Renewal 2011-18
Parallel Processes	Nunavik Health Survey			International Polar Year (IPY) Funding		Canada's Northern Strategy; Canadian High Arctic Research Station, Diefenbaker icebreaker (2008)	
Evaluation	Annual Report from researchers to NAO, Annual report from NAO to NCE Program						
				NCE Mid-Term Review			
Publications							
Annual Report	2004-05 Report	2005-06 Report	2006-07 Report	2007-09 Report		2009-10 Report	2010-11 Report
Compendium	Compendium Phase 1 V1 & V2				None		
Research							
Research Funding	Call for proposals	Fund 27 projects	30 (+3 North by North projects)	30 projects	28 projects	40 (+12 new projects)	38 projects
Themes	Themes linked to IRIS				Revised structure; 4 Themes		
Integrated Regional Impact Studies	IRIS Process				IRIS - Theme 4 changed to a region	IRIS - new P4	IRIS
Recruiting Researchers						Award 2 Research Excellence Chairs (Søren Rysgaard, Marcel Babin)	

Phase 1 & 2	**Phase 1**				**Phase 2**		
	2004-2005	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**	**2009-2010**	**2010-2011**
Meetings							
Conferences	*Annual Scientific Meeting (ASM)* 2004 Quebec, Quebec	ASM 2005 Banff, Alberta	ASM 2006 Vancouver, BC	ASM 2007 Collingwood, Ontario	Arctic Change Conference, Quebec, Quebec	ASM 2009 Victoria, BC	ASM 2010 Ottawa, ON
Hosting Awards			Inuit-sponsored award for graduate students	2007 Networks of Centres of Excellence Young Innovator Award			
Research Infrastructure							
CCGS Amundsen	NAO Coordinates ArcticNet CCGS Amundsen Science Program; Annual expeditions						
Other research Infrastructure				Network of research stations and laboratories such as the ones maintained by the Polar Continental Shelf Program (PCSP), the Centre d'études Nordiques (CEN), the Nunavik Research Centre, the Churchill Northern Studies Centre, the Aurora Research Institute and the Nunavut Research Institute.			
Collaborations							
Data Management				Launch AN Polar Data Catalogue (July 2007)	Polar Data Catalogue		Polar Data Catalogue; ArcticNet Publications Database (Partner with ASTIS)
Inuit Research Advisors	Positions established in 2004; Co-funded by ArcticNet, the Nasivvik Centre for Inuit Health and Changing Environments and the Northern Contaminants Program						
Outreach						Art exhibit - Vancouver Aquarium	
Training							

Phase 1 & 2	Phase 1				Phase 2		
	2004-2005	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**	**2009-2010**	**2010-2011**
ArcticNet	ArcticNet Training Fund (for members to access other icebreakers)						
ArcticNet Student Association (ASA)	ASA Created in 2004	First General Assembly	ASA participate in NCE Trainee Association; Develop training & tools; Newsletter; Regional Workshop (Winnipeg, Quebec)		Arctic Change Student Day; Regional Workshop (Quebec); U.Northern British Columbia Research Group	ASM Student Day; SoB Workshop; Partner with APECS; Regional Workshop (Quebec)	Student Day
Schools on Board (SoB)	SoB field program				SoB field program; SoB received NSERC Promo Science Award	SoB *International*; SoB *Circumpolar Inuit Field Program*; Canadian Network for Environmental Education and Communication	SoB field program; Co-host 2010 Arctic Climate Change Youth Forum; SoB: IPY book Polar science & global climate…

Phase 3 &4	**Phase 3**				**Phase 4**		
	2011-2012	**2012-2013**	**2013-2014**	**2014-2015**	**2015-2016**	**2016-2017**	**2017-2018**
NAO Milestones	Renewal 2011-18		Oil partnership completed - focus on new programs	Formal Agreement with France; Formal MOU with Norway	New oil partnerships	Inuit Research Legacy Workshop	

Phase 3 &4	Phase 3				Phase 4		
	2011-2012	**2012-2013**	**2013-2014**	**2014-2015**	**2015-2016**	**2016-2017**	**2017-2018**
				IQ Partnership - Inuit Student Centre			
Parallel Processes		Canadian High Arctic Research Station	Arctic Council - Canada became Chair May 2013			Weston foundation provided funding to Parks Canada to find Terror & Erebus	
Evaluation	Annual Report from researchers to NAO, Annual report from NAO to NCE Program						
					NCE Mid-Term Review		
NAO Publications							
Annual Report	ArcticNet Annual Report 2011-13		ArcticNet Annual Report 2013-14	ArcticNet Annual Report 2014-15	ArcticNet Annual Report 2015-17		None
Compendium	ArcticNet Compendium 2011-2012	ArcticNet Compendium 2012-2013	ArcticNet Compendium 2013-2014	ArcticNet Compendium 2014-2015	ArcticNet Compendium 2015-2016	ArcticNet Compendium 2016-2017	ArcticNet Compendium 2017-2018
Research							
Research Funding	34 projects	38 (+2 KT projects)	38 projects	38 projects; Call for Proposals P4; Call for Proposals for Inuit Education (between Amaujaq and ArcticNet)	41 projects; 19 continued from previous phase; 22 new		
Themes	Add Knowledge Translation Theme						
Integrated Regional Impact Study	IRIS 4 Published	Launch IRIS 4 (Nov); IRIS 2 Workshop (2012)	IRIS to inform Arctic Council process	IRIS 1 published	IRIS transition to dynamic platform; Arctic Council launched reports based on IRIS		

Phase 3 &4	Phase 3				Phase 4		
	2011-2012	**2012-2013**	**2013-2014**	**2014-2015**	**2015-2016**	**2016-2017**	**2017-2018**
Recruiting Researchers	Award 2 Research Excellence Chairs (Søren Rysgaard, Marcel Babin)				2 Research Excellence Chairs		
Meetings							
Conferences		ASM 2012 Vancouver; Partner for IPY Conference	ASM 2013 Halifax, NS	Arctic Change 2014, Quebec, QC	ASM 2015 Vancouver, BC	ASM 2016 Winnipeg, MB	Arctic Change 2017 Ottawa, ON
Hosting Awards		Host Arctic Inspiration Award					
					W. Garfield Weston Foundation: Weston Family Prize for Lifetime Achievement in Northern Research		
Research Infrastructure							
CCGS Amundsen	Amundsen hosted International science summit July-Aug 2011; lobbying, relationship building	Amundsen Repairs Amundsen got $50M funding March 2012	Amundsen helicopter crash	Amundsen - Platform Outcome Measurement Study; Amundsen & other vessels; Amundsen CFI Application	Amundsen CFI Application Funding; Amundsen - separate website;		Amundsen - 18.2M for ongoing maintenance (Jan)
	NAO Coordinates ArcticNet CCGS Amundsen Science Program; Annual expeditions				Amundsen Science Established		
Other research Infrastructure	Network of research stations and laboratories such as the ones maintained by the Polar Continental Shelf Program (PCSP), the Centre d'études Nordiques (CEN), the Nunavik Research Centre, the Churchill Northern Studies Centre, the Aurora Research Institute and the Nunavut Research Institute.						
Collaborations							
Inuit Research Associates	Positions established in 2004; Co-funded by ArcticNet, the Nasivvik Centre for Inuit Health and Changing Environments and the Northern Contaminants Program						

Phase 3 &4	**Phase 3**				**Phase 4**		
	2011-2012	**2012-2013**	**2013-2014**	**2014-2015**	**2015-2016**	**2016-2017**	**2017-2018**
Data Management	Polar Data Catalogue; ArcticNet Publications Database (Partner with ASTIS)				Polar Data Catalogue; ArcticNet Publications Database (with ASTIS); Polar Data Forum (Oct Waterloo)		Polar Data Workshop Ottawa 2017
Outreach		ArcticNet Photo gallery: Polar Photography; Twitter Account			Polar Photography		
Training	Training Fund						
					Field safety fund		
ArcticNet Student Association	ASA - SoB partnership to host Arctic Science day in Winnipeg	Student Day; ASA 2 day workshop at IPY conference	Student Day; ASA supported events at U Manitoba, Laval	Student Day with APECS; Partner with SoB; ASA events at Memorial Univ, UofM; ASA - SoB Arctic Science Day, New partner: Climate Change Connection	Student Day; ASA - SoB partnership to host Arctic Science day in Winnipeg	Student day; ASA – SoB partnership; ASA - APECS partnership; New partner: Let’s Talk Science	
Schools on Board (SoB)		SoB field program; SoB Arctic Climate Change youth Forum; Partnerships: International Institute for Sustainable Development for Circumpolar Indigenous Youth Leaders Program	SoB did not take place due to Amundsen curtailment; New: Schools on Tundra (2013); Partnerships: ASA; Let’s Talk Science; Arctic Connection; Science camp in Cambridge Bay	SoB field program; SoB Arctic Climate Change Youth Forum with Arctic Change Conference; Partnerships: ASA-SoB NSERC PromoScience (Winnipeg, Cambridge Bay);	SoB field program; SoB Arctic Science Day in Winnipeg, Cambridge Bay, Resolute, Quebec City; SoB underwent first evaluation	SoB field program SoB Arctic Climate Change Youth Forum; SOB Arctic Science Day in Winnipeg; Partnerships: ASA; Let’s Talk Science; CuiroCity; SoB Documentary	SoB to pilot a Northern Youth Mentorship Field Program