Brunet, N. D., G. M. Hickey, and M. M. Humphries. 2014. The evolution of local participation and the mode of knowledge production in Arctic research. *Ecology and Society* **19**(2): 69. http://dx.doi.org/10.5751/ES-06641-190269

Research

The evolution of local participation and the mode of knowledge production in Arctic research

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ABSTRACT. Arctic science is often claimed to have been transformed by the increased involvement of local people, but these claims of a new research paradigm have not been empirically evaluated. We argue that the "new" participatory research paradigm emerging in Arctic science embodies many of the principles of the Mode 2 knowledge production framework. Using the Mode 2 thesis as an assessment framework, we examined research articles appearing between 1965 and 2010 in the journal *Arctic* to assess the extent to which there has been a paradigm shift toward more participatory approaches. Results suggest that the involvement of local people has increased only slightly over the last half century and continues to vary systematically among disciplines, organizations, and regions. Analysis of three additional journals focused on Arctic and circumpolar science establishes the generality of these slight increases in local involvement. There is clearly room for more community involvement in Arctic science, but achieving this will require either increasing the proportional representation of the organizations, disciplines, and regions with a track record of successful Mode 2 research, or encouraging Mode 2 research innovation within the organizations, disciplines, and regions currently predominated by Mode 1 approaches.

Key Words: *civic science; community participation; environmental change; Mode 2; research policy; traditional knowledge*

INTRODUCTION

Stakeholder participation in research is increasingly acknowledged as critical to ensuring the legitimacy and applicability of research findings (Chilvers 2008, Kainer et al. 2009, Barreteau et al. 2010, Phillipson et al. 2012, Tsouvalis and Waterton 2012). Although the challenges associated with participation are numerous, the integration of local insights into the research process and the subsequent generation of knowledge and policy have resulted in many benefits (Gearheard and Shirley 2007, Pearce et al. 2009). For instance, it is widely recognized that stakeholder engagement is an approach to producing knowledge that is “sufficiently grounded in local needs and realities to support community-based natural resource management” and is often seen as “crucial to the sustainable management of forests and other natural resources” (Wilmsen 2008:121). Participation is also recognized as an important method in “building the adaptive capacity and social learning required for the development and maintenance of resilient and sustainable socio-ecological systems” (Barreteau et al. 2010:2). Further, studies suggest that the active participation of stakeholders in research that informs management policy leads to broader understanding and acceptance of management decisions derived from the research (Wilson et al. 2006, Jones et al. 2008).

Community engagement in Arctic science has received considerable attention, in part because local people have long been employed as guides and interpreters in northern science (Bocking 2007). Furthermore, modern treaty and land claim agreements frequently specify that research conducted within traditional territories should address local priorities and incorporate local knowledge (Inuit Tapiriit Kanatami and Nunavut Research Institute 2007). Finally, northern communities and their leaders have expressed a strong desire for their traditional knowledge to feature more prominently in the international discourse about the nature and impact of environmental change in the Arctic (Gearheard and Shirley 2007, Inuit Tapiriit Kanatami and Nunavut Research Institute 2007). Today, research conducted in the Arctic is intended to be both globally relevant and locally important, achieved through both international coordination and local community participation. The opportunities and challenges associated with Arctic research have led to international cooperation and coordination emerging as a defining feature of Arctic science, exemplified by International Polar Year efforts, which were first initiated in 1882 (International Council for Science 2004).

Modes of knowledge production

An important and expanding literature argues that there has been an international and multidisciplinary shift in the mode of scientific knowledge production, with traditional forms of scientific discovery, Mode 1, being expanded upon or even replaced by more participatory and application-focused forms of science, Mode 2 (Gibbons et al. 1994, Nowotny et al. 2003). Table 1 presents the essential characteristics of these modes of knowledge production and contrasts them with two related concepts in Arctic science: participatory research (Minkler and Wallerstein 2008, Wilmsen 2008) and the new Arctic research paradigm (National Science Foundation and Barrow Arctic Science Consortium 2004, Graham and Fortier 2005, Southcott 2011, Wolfe et al. 2011).

The transition toward more participatory research approaches in Arctic science can be viewed as both a contributor to, and an outcome of, a more generalized Mode 1 to Mode 2 transition (Minkler and Wallerstein 2008, Wilmsen 2008). Therefore, we believe the Mode 1/Mode 2 dichotomy offers a useful and applicable framework for assessing whether Arctic science is moving toward the interests and involvement of Arctic people, while also linking this assessment to contemporary international research policy discourse. Using this framework, we can view the transition from Mode 1 to Mode 2 approaches to Arctic science as being characterized by fundamental changes in how scientists

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Table 1. Comparative review of Mode 1, Mode 2, participatory research, and the new northern research paradigm. Italics are direct quotes from Nowotny et al. 2003:186-188.

Mode 1 (Nowotny et al. 2003, Berkes 2008)	Mode 2 (Nowotny et al. 2003)	Participatory Research (Minkler and Wallerstein 2008, Wilmsen 2008)	"New" Arctic research paradigm (Graham and Fortier 2005, Southcott 2011)
Knowledge is generated independently of context.	*Knowledge is generated within a context of application.*	Knowledge is cultural. There is no objective truth about the world. Knowledge is situated within certain historical and social context.	Partnership. Knowledge is developed through meaningful relationships between researchers and communities.
Hegemony of theoretical and experimental science.	*This is different from the process of application by which 'pure' science, generated in theoretical/experimental environments, is 'applied'; technology is 'transferred'; knowledge is subsequently 'managed'.*	Success is defined by the utility and action of outcomes.	Research must be beneficial to all participants and affected parties.
Autonomy of scientists and host institutions.	*The mobilization of a range of theoretical perspectives and practical methodologies to solve problems.*	Research process results from a negotiated settlement between all parties involved.	Based on mutual understanding and cooperation.
Internally driven taxonomy of disciplines.	*Knowledge is embodied in the expertise of individual researchers and research teams as much as, or possibly more than, it is encoded in conventional research products such as journal articles or patents.*	Researchers as facilitators of the research process.	We must strive to build the capacity of northern communities so they can conduct their own research.
Most knowledge is generated in centralized locations such as universities.	*Much greater diversity of the sites at which knowledge is produced, and in the types of knowledge produced.*	Knowledge produced by science is negotiated.	Research process built of effective communication strategies.
Focused on western/scientific forms of knowledge.	*Has allowed many new kinds of 'knowledge' organizations to join the research game.*	Integrates and recognizes the validity of local knowledge. Participation of nonscientists in research processes. Conscious engagement with relationships of power.	Researchers must actively engage local knowledge holders and experts.
Knowledge production characterized as objective.	*Knowledge that is highly reflexive. The research process can no longer be characterized as an 'objective' investigation of the natural (or social) world.*	Trustworthiness over validity. Self reflexive.	Active engagement of community members in all aspects of research.
Consequences of new knowledge are considered outside the research process.	*The consequences (predictable and unintended) of new knowledge cannot be regarded as being 'outside' the research process.*	Participation of stakeholders and affected parties affected by situation under study. Concerned with social change/supports action.	Research processes must be empowering for northern communities.
Traditional means of quality control, based on peer review process.	*Novel forms of quality control.*	Participation of stakeholders in every aspect of research process. Community control.	Local collection, validation, and ownership of data.

conduct their research. Such changes can include explicit recognition of the context within which scientific research questions are asked and efforts to assess and maximize the applicability of the knowledge generated. This transition also allows for the inclusion of diverse stakeholders in the research process, including novel forms of quality control that could include expanded peer-review processes involving the knowledge users (Klenk and Hickey 2013).

Research objective and justification

Using the Mode 2 thesis (Gibbons et al. 1994, Nowotny et al. 2003) as an assessment framework, our objective was to assess evidence for a new research paradigm in Arctic science and to uncover major factors contributing to this progression. Similar to the global relevance of the physical and biological change processes occurring near the poles, we believe that changes in the research approaches used in Arctic science are globally important, both as immediate contributors to international policy and as a regional case study of participatory research trends that are likely to play out in other parts of the world in the coming years.

Case study: Arctic science

We assessed the emergence of participatory approaches and shifts in the mode of knowledge production based on research articles published within the journal *Arctic* (http://www.arctic.ucalgary.ca) between 1965 and 2010. We selected *Arctic* because it publishes northern science exclusively; is an authoritative, international source of northern scholarship; and is an eclectic,

Table 2. Criteria used to evaluate the Mode of knowledge production in Arctic research.

Mode	Context of introductory and concluding text
1	Entirely academic or applied research, with no mention of applicability to contemporary local people
1.25	Mostly academic or applied research, with some mention of applicability to contemporary local people
1.5	Even mix of academic/applied relevance and local applicability
1.75	Mostly focused on applicability to local people, with some mention of academic/applied relevance
2	Entirely focused on local people, with no mention of academic/applied research relevance
	Transdisciplinarity of abstract or research focus
1	Academic approaches or sources only
1.25	Primarily academic approaches or sources with limited mention of local knowledge
1.5	Primarily academic approaches or sources but including explicit use, application, or testing of local knowledge
1.75	Attempted copresentation, integration, and/or synthesis of local and academic knowledge
2	Predominant focus on local knowledge
	Heterogeneity of author institutions and funding/in kind support (university/federal vs. territory/state vs. local)
1	Authors, funding, and substantial in kind support all from one level
1.25	Authors from one level, funding, or substantial in kind support from two levels
1.5	Authors from one level, funding, or substantial in kind support from three levels
1.75	Authors from two levels
2	Authors from three levels
	Evidence of reflexivity/social accountability
1	No evidence of reflexivity/social accountability in relation to local people
1.25	Statement of licensing or research ethics compliance
1.5	Evidence that a specific methodology/interpretation was modified in recognition of impacts on local people
1.75	Evidence that general methodology/interpretation was modified in recognition of impacts on local people
2	Evidence that general methodology/interpretation derived from recognition of impacts on local people
	Evidence of nontraditional quality control in methods and acknowledgements
1	No evidence of local quality control
1.25	Evidence that local people were involved in data collection (e.g., field assistants, carcass samples, translation, interviews)
1.5	Evidence of local quality control at the results interpretation or manuscript review stage
1.75	Evidence of local quality control at research design stage
2	Evidence of local control at multiple stages of the research process

multidisciplinary journal that publishes papers applying diverse approaches to widely ranging areas of inquiry, spanning physical, life, and social sciences. The format and content of research articles have also remained relatively homogenous since the creation of the journal, making it easier to develop specific and replicable criteria to study articles over the whole study period. We also analyzed three other journals focused on polar science, using the same criteria to assess the generality of trends apparent in the journal *Arctic*.

An important limitation of using published papers to assess the mode of knowledge production is that we only assessed the published presentation of Arctic science, which may not reflect how and why the knowledge was produced. We selected criteria that we hope helped us get behind the presentation and toward the mode of knowledge production, acknowledging that our assessment was influenced by differences in how the science was presented in addition to how the science was done.

RESEARCH DESIGN

We contextualized the Mode 2 framework for Arctic science by identifying specific criteria for each general characteristic outlined by Nowotny et al. (2003). Importantly, these criteria needed to be reasonably easy to assess as objectively as possible from reading the published article (see Table 2).

Recognizing that Mode 1 and Mode 2 approaches are best interpreted as two end points on a continuum (van Aken 2005), our criteria included thresholds identifying Mode 1 and Mode 2 end points, as well as three incremental thresholds. For convenience we labeled these increments as 1.25, 1.5, and 1.75 between end points 1 and 2, but intended them to be interpreted qualitatively; that is, 1.25 represented an approach slightly in the direction of Mode 2 but not much different than Mode 1 and 1.5 represented an approach roughly midway between the Mode 1 and 2 end points.

Study of the journal *Arctic*

We randomly selected 25 articles from the journal *Arctic* for each given year, obtained the electronic version of the full text, and then assessed their eligibility for inclusion. We selected articles published between 1965 and 2010 to capture the 1970-1980 period when adherence to Mode 1 science was most likely to be most dominant (Levere 1993, Edqvist 2003) as well as the post-1980s period when several fundamental shifts occurred in northern science policy (e.g., Bielawski 1984). Much of this shift was driven by the policy called Northward Looking: A Strategy and Science Policy for Northern Development, which was released by the Science Council of Canada in 1977 and led to new research grant programs such as The Human Context of Science and Technology in 1981, which formally recognized the importance of local partners in science.

We limited our analysis to research articles that described their specific methodology and generated new knowledge. These included most research notes, but excluded review papers, editorials, opinion pieces, historical accounts, and other regular *Arctic* editorial sections such as InfoNorth, obituaries, and profiles. Any excluded papers were replaced with new random selections from articles published in that year until we obtained 25 research papers or ran out of alternatives. Fewer than 25 research papers could be located in 1966-1967, 1971, 1976, and 1977, but in all other years we assessed 25. The minimum number of articles was 16 in 1966. In total, we assessed 1113 articles over 46 years. Two of us, M. M. Humphries and N. D. Brunet, analyzed half of the papers each, one doing odd years and the other even, with the observer recorded and included in the analysis as an explanatory variable.

Once papers were deemed eligible, we completed a content analysis (Babbie 2002) of the text. We paid particular attention to the introduction and conclusion for context; the abstract and main method description for transdisciplinarity; the authors' addresses and funding sources for heterogeneity; the introduction and discussion for reflexivity; and the methods and acknowledgements for nontraditional quality control (Table 2). We then quantified several additional attributes from each paper as potential explanatory variables, including the discipline, the location, the organizational origin of the research, and the extent of focus on environmental change.

The disciplinary focus of each paper was classified broadly as physical science, life science, social science, or multidisciplinary. Papers classified as physical sciences included climate research, atmospheric research, physical geography, geology, and cryosphere research. Papers classified as life sciences included all biological sciences, paleontological studies focused on faunal descriptions, and biomedical research focused on human physiology. Social science papers included research focused on human subjects, including anthropology, human geography, community health research, resource policy, and archaeology. Papers were classified as multidisciplinary if they focused on two or three of these disciplinary categories. Because research on harvested wildlife is often identified as a priority by northern communities (Shirley 2005; Council of Yukon First Nations, Yukon Northern Climate ExChange, and Yukon Climate Change Secretariat, 2011, Yukon climate change needs assessment, *unpublished manuscript*), we further subdivided life sciences papers according to whether or not they focused on traditional food and fur-bearing species, based on cross-referencing species emphasized in the title and abstract (Novak et al. 1987, Kuhnlein and Turner 1996; H. V. Kuhnlein and M. M. Humphries, *unpublished manuscript*). Social science papers were also further subcategorized according to whether they focused primarily on living people, i.e., contemporary; remains and artifacts, i.e., archeological; or written history, i.e., historical. We labeled these subcategories as disciplines, recognizing that our seven categories in fact represent only three widely recognized disciplines, two of which were subdivided into topic-area categories.

We classified the organizational origin of the research according to whether the first author's institution was a local government, territory or state government, federal government, university, or other, which were primarily consulting firms. The research region was classified according to whether the primary region of focus was Alaska, Canada, Greenland, Scandinavia, Russia, or circumpolar.

Finally, the extent to which the paper focused on environmental change was assessed by doing a full-text search, excluding French-translated abstracts and literature cited, for "warm$" and "chang$." The search was intended to capture phrases such as climate change, environmental change, changing climate, climatic warming, global warming, and so forth. We then read the text surrounding each search return to ensure the usage was related to long-term, large-scale, directional environmental change. Papers were then assigned to one of four categories of emphasis: no if 0 mentions, minor if 1-4 mentions, moderate if 5-19 mentions, or major if 20 or more mentions.

Analyses

We first determined temporal patterns in Mode 1 and Mode 2 Arctic science between 1965 and 2010 for all five criteria, i.e., context, transdisciplinarity, heterogeneity, reflexivity, and nontraditional quality control. These patterns are presented using bubble plots, which usefully present proportional prevalence in situations in which variables are semidiscrete. As a result, there are many overlapping data points.

Second, we conducted a statistical analysis to identify which variables best predicted the mode of knowledge production in Arctic science. In this general linear model, the response variable was mode: 1, 1.25, 1.5, 1.75, or 2. The explanatory variables were year, year², location, discipline, organization, and environmental change focus. In this analysis, the response variable was not normally distributed because it was an interval with a small number of discrete values, was bounded between a minimum and maximum, and was skewed with more low than high values. Although the nonnormality of the resulting model residuals did not affect the estimation of coefficients, it did compromise estimation of their error and significance. Accordingly, confidence intervals, t statistics (β'/standard error), and P values for coefficients were generated using sequential subsets of data via a jackknifing procedure. All statistical analyses were conducted with R (R Development Core Team 2011).

In a final analysis of papers published in the journal *Arctic*, we evaluated temporal, regional, and disciplinary trends in the research focus on global environmental change. In this general linear model, the response variable was global environmental change focus, i.e., no, minor, moderate, or major, and the explanatory variables were year, location, discipline, and organization. To account for potential nonlinear temporal trends, we also included a quadratic effect of year (year²).

Multijournal generality

To assess the generality of findings from the journal *Arctic*, we also conducted an abridged review of scientific articles in three other journals focusing on polar science in different disciplines: *Arctic, Antarctic and Alpine Research*, focusing mostly on physical sciences; *Polar Biology*, focusing mostly on life sciences; and the *International Journal of Circumpolar Health* (IJCH), an interdisciplinary journal with articles bridging contemporary health, life, and social sciences. These journals were also selected because of their importance and because they have been published at least since 1985, although two of the journals changed their titles during this interval (in 1985 IJCH was *Arctic Medical Research* and *Arctic, Antarctic and Alpine Research* was *Arctic and Alpine Research*).

We randomly selected 10 articles from each of these three journals for the years 1985 and 2010, a period that would be long enough to demonstrate a Mode 1 to Mode 2 transition. After obtaining the electronic version of the full texts, we assessed their eligibility for inclusion.

Similar to our analysis of *Arctic*, we limited our analysis to research articles that described their specific methodology and generated new knowledge. These included most research articles and notes, but excluded review papers, editorials, opinion pieces, historical accounts, and other regular editorial sections. Any excluded papers were replaced with new random selections from articles published in that year until we obtained 10 research papers for each journal for both years. In total, 60 articles were reviewed. Once papers were deemed eligible, we completed a content analysis (Babbie 2002) of the text, paying particular attention to the introduction and conclusion for context, the abstract and main method description for transdisciplinarity, authors' addresses and funding sources for heterogeneity, introduction and discussion for reflexivity, and methods and acknowledgement for nontraditional quality control (Table 2).

RESULTS

Study of the journal *Arctic*

Mode 1 approaches dominated papers published in *Arctic* from 1965 to 2010 (Fig. 1). There was, however, a modest increase over time in the prevalence of Mode 2 and intermediate mode approaches for all five characteristics, particularly between the mid-1980s and 2010. Nevertheless, even in the most recent years of analysis, only a small proportion of papers included Mode 2 approaches. We also found that Mode 2 approaches are not new in Arctic science; a number of strongly Mode 2 studies, particularly in context and transdisciplinarity, were published between the mid-1960s and mid-1970s. Examples are provided in the Discussion section. Recognizing the potential importance of editorial preferences for journal content over time, we reviewed *Arctic's* Aims and Scope over our study period and found no evidence to indicate a significant change of focus. The format of the journal also remained essentially the same throughout our study period. Nevertheless, we recognize that editorial preference and changes at the journal could have affected the research accepted for publication.

General linear model analysis of the contributors to variation in the mode of knowledge production indicated significant effects of lead author institution, discipline, region where the research was performed, and year (Fig. 2, Appendix 1). Lead author institution had the most pronounced effect on the mode of knowledge production, with local governments and to a lesser extent territorial and state governments associated with more Mode 2 research than other organizations. The mode of knowledge production also varied by discipline, with social sciences research and, to a lesser extent, life sciences research being more Mode 2 than physical sciences research. Life sciences articles focused on wildlife species that are used for fur or as traditional food were more Mode 2 than life science articles focused on other species. Similarly, social sciences articles focused on contemporary people were more Mode 2 than archeological or historical research. Regional differences in the mode of knowledge production were not as pronounced as institutional and disciplinary differences, but research conducted in Canada and to a lesser extent Alaska tended to be more Mode 2 than

Fig. 1. Patterns in the Mode of knowledge production in Arctic science and Mode 2 approaches over time, above and beyond differences accounted for by the influence of discipline, organization, and region in our analysis of research papers published in *Arctic* 1965-2010. Circles are bubbles, with size reflective of the proportion of studies in that category. Lines are 5 yr running means. Characteristics and evaluation criteria are described in Table 2.

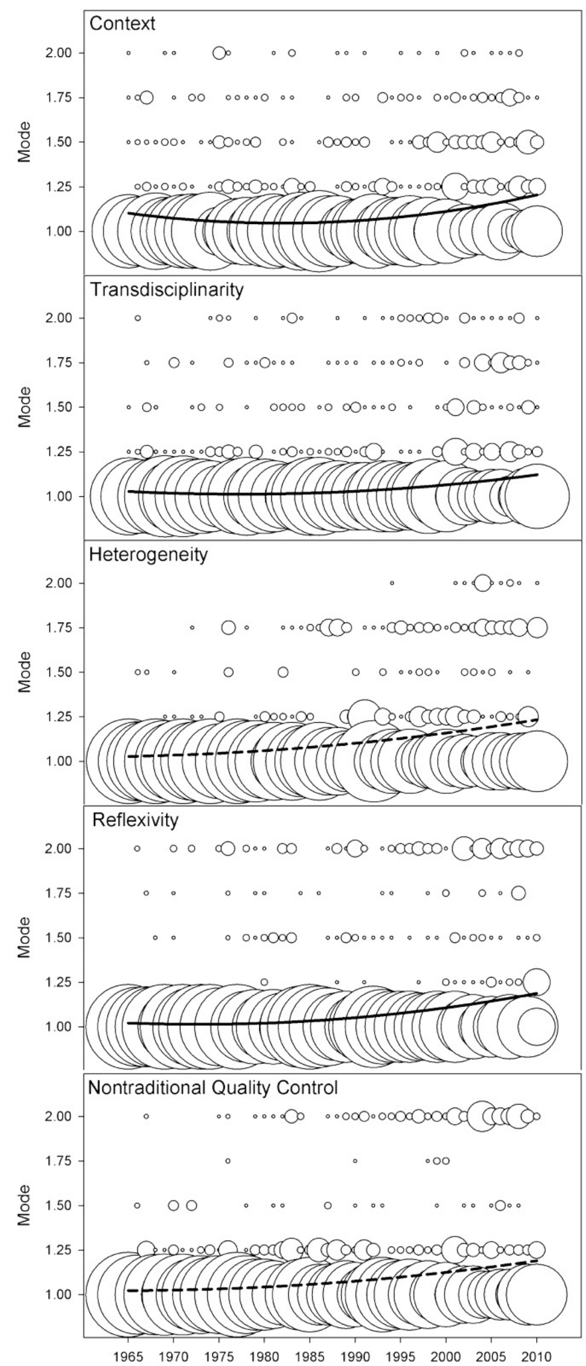
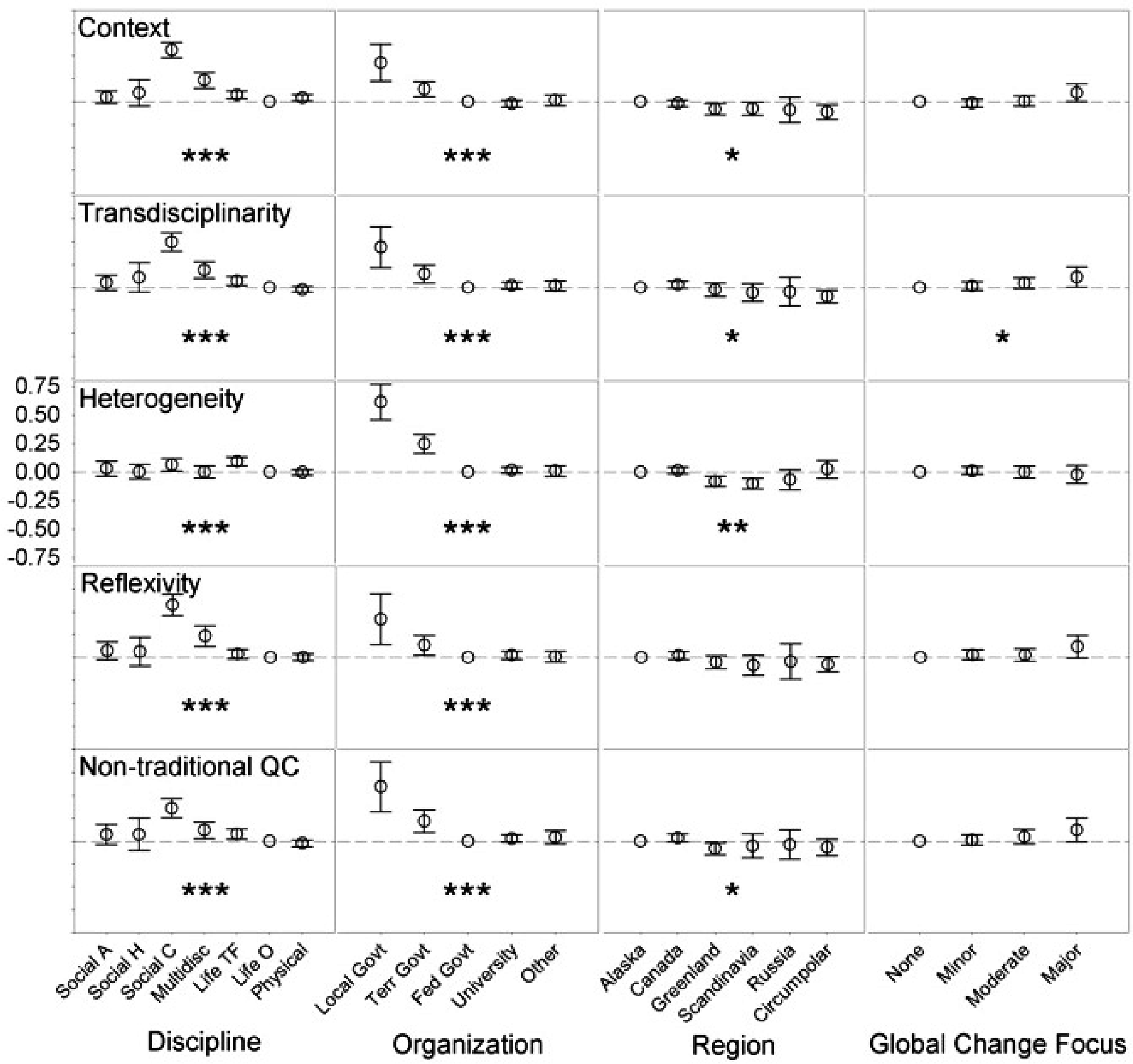


Fig. 2. Regression coefficients from an initial multiple regression analysis of Mode score predicted by the five explanatory variables included. Coefficients are expressed relative to one arbitrarily chosen level of each explanatory variable, which has a value constrained to 0. Therefore, it is arbitrary whether most points are above, below, or grouped around the line, but the general direction of the trend is meaningful. Points higher on the Y-axis, with error bars that do not overlap with other points, are more Mode 2 than the points of comparison that are lower on the Y-axis and more Mode 1. Therefore, for example, social sciences, local governments, and Alaska are all more Mode 2 than their counterparts.



research focused on the European and circumpolar Arctic. Observer differences were small, but were significant for context and reflexivity (Fig. 2), which may indicate that the criteria used to assess these two characteristics were less explicit and more ambiguous than those used for the other characteristics. Papers with a major focus on environment change were not significantly more Mode 2 than papers less focused on environmental change (Fig. 2). After accounting for all other covariates, there remained a significant nonlinear time trend, with context, transdisciplinarity, heterogeneity, and reflexivity all weakly accelerating as a quadratic function of time. However, context started somewhat more Mode 2 and declined toward a Mode 1 minimum, i.e., scores were closest to 1, in the early 1980s, with Mode 2 articles then increasing to the end of the time series.

From 1965 to 2010, the number of papers published in *Arctic* with a first author from a local government increased, but remained very low (Fig. 3). During the same period, there was a strong decline in the proportion of *Arctic* papers focused on the physical sciences (Fig. 4). The proportion of social sciences papers remained relatively constant, whereas the prevalence of life sciences and multidisciplinary research increased substantially. The number of *Arctic* papers with a minor, moderate, or major focus on environmental change increased dramatically over time, particularly since 1995 (Fig. 5).

Fig. 3. The organizational composition of research included in our analysis of research papers published in Arctic 1965-2010. Papers were classified based on lead author of the paper. This sample is not necessarily reflective of the organizational composition of all articles published in Arctic, because it includes only research articles that describe specific methodology and results, while excluding review papers presenting no new data, as well as editorials, opinion pieces, historical accounts, and other regular editorial sections.

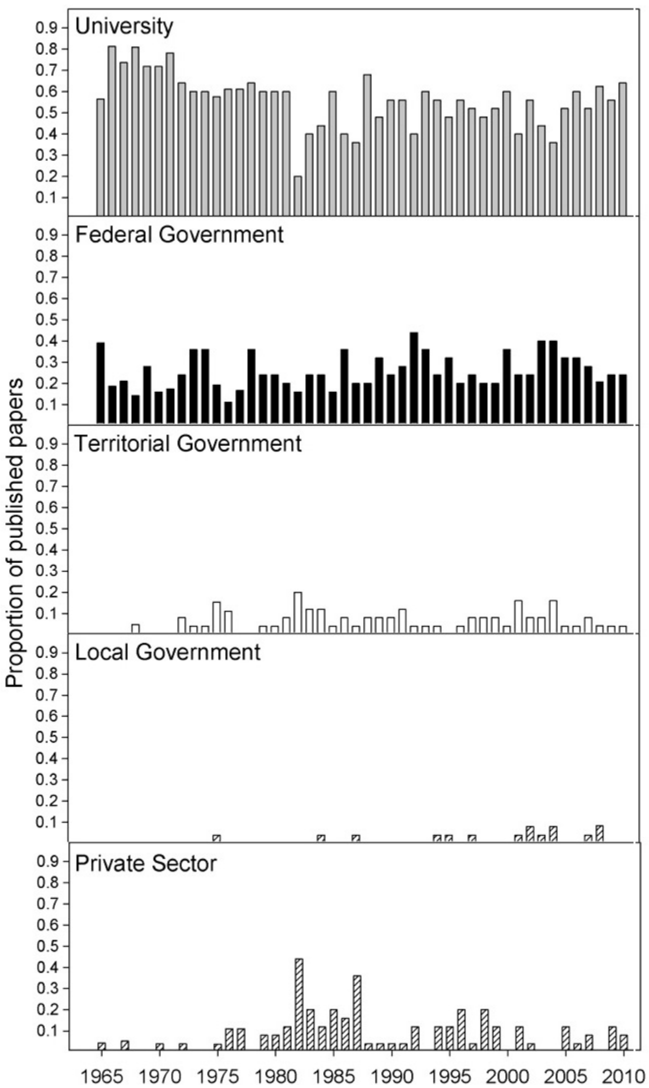


Fig. 4. The disciplinary and subcategory composition of research included in our analysis of research papers published in Arctic 1965-2010. This sample is not necessarily reflective of the disciplinary composition of all articles published in Arctic, because it includes only research articles that describe specific methodology and results, while excluding review papers presenting no new data, as well as editorials, opinion pieces, historical accounts, and other regular editorial sections.

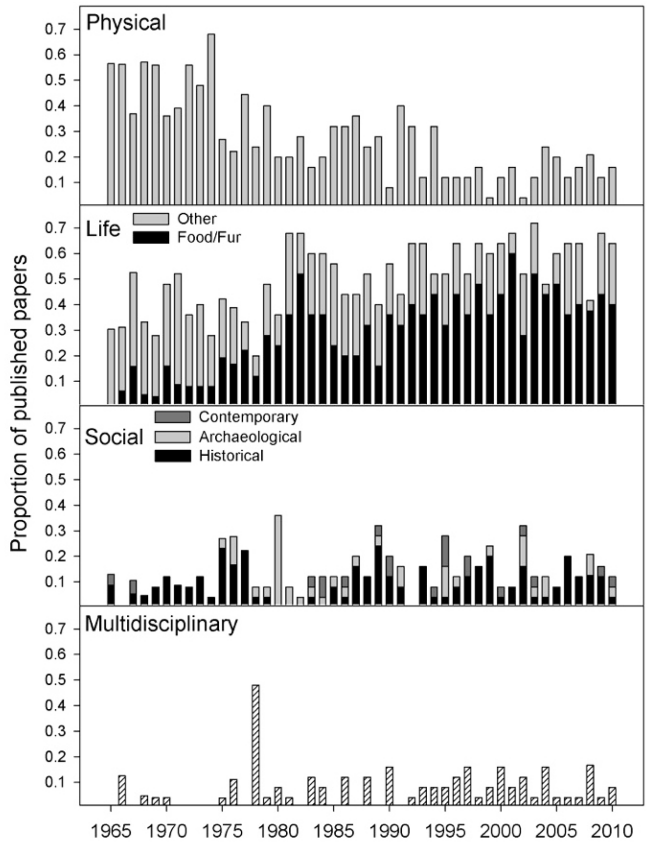
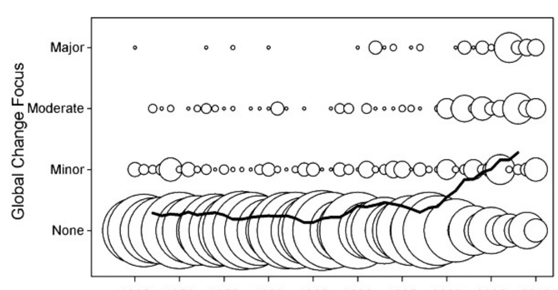


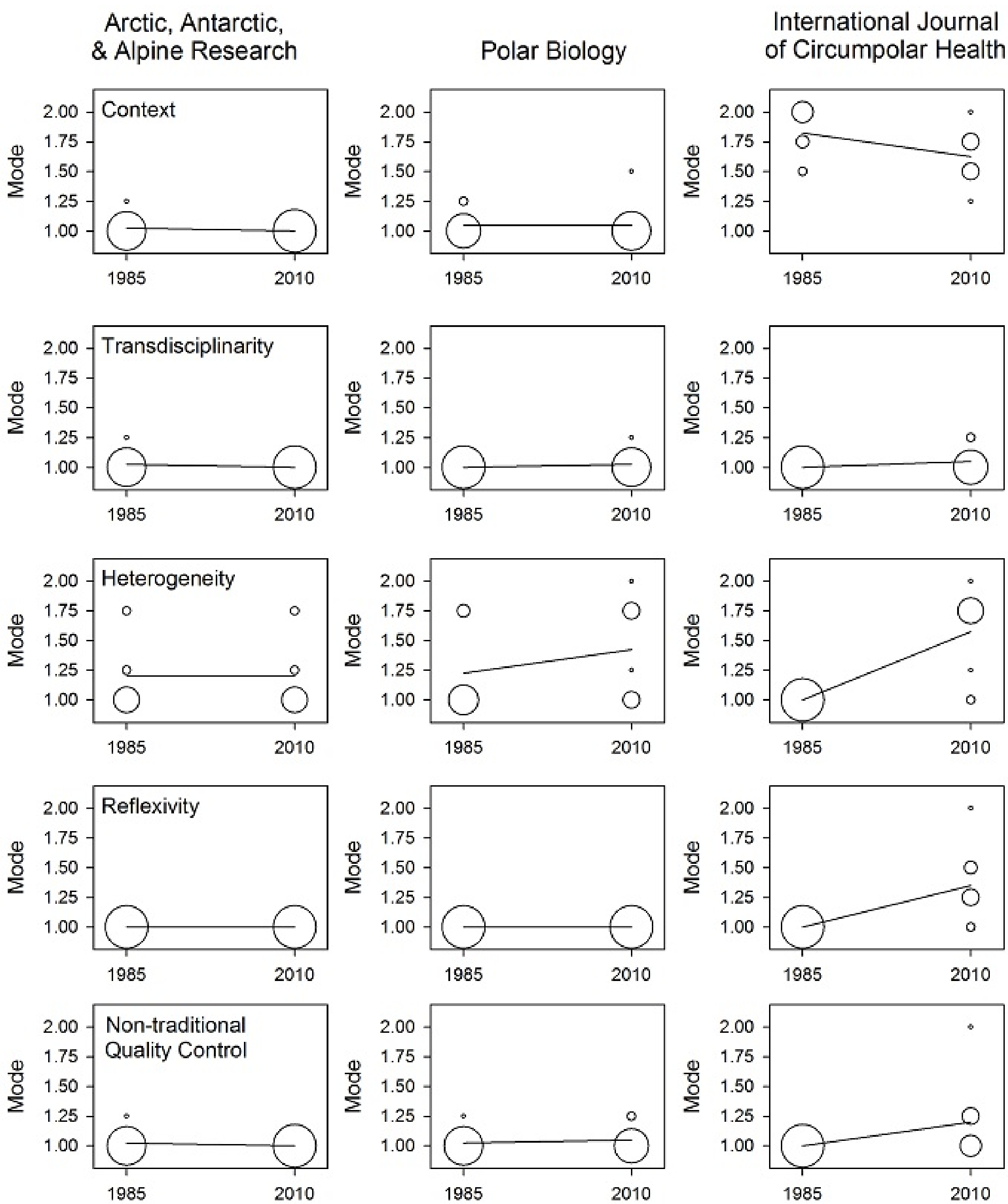
Fig. 5. The prevalence of global environmental change as a topic in our analysis of research papers published in *Arctic* 1965-2010. This sample is not necessarily reflective of the organizational composition of all articles published in *Arctic*, because it includes only research articles that describe specific methodology and results, while excluding review papers presenting no new data, as well as editorials, opinion pieces, historical accounts, and other regular editorial sections.



Study of the three other polar journals

Across three additional polar science journals, the transition from Mode 1 to Mode 2 from 1985 to 2010 was limited or nonexistent for most criteria (Fig. 6). IJCH was more Mode 2 in context than the other journals we analyzed, but this Mode 2 attribute declined from 1985 to 2010 in the transition from *Arctic Medical Research* to IJCH. There was a slight shift in *Polar Biology* from 1985 to 2010 toward more Mode 2 heterogeneity, consistent with trends observed in life sciences papers within the journal *Arctic*. Finally, IJCH became more Mode 2 from 1985 to 2010 in heterogeneity, reflexivity, and to a lesser extent, nontraditional quality control.

Fig. 6. Patterns in the Mode of knowledge production in Arctic science and Mode 2 approaches in 1985 and 2010 in our analysis of research papers published in the journals *AAAR, IJCH, and Polar Biology.* Circles are bubbles, with size reflective of the proportion of studies in that category.



DISCUSSION

Prevalence of Mode 1 and Mode 2 research in Arctic science

Arctic communities, leaders, and research policy have clearly expressed the importance of engaging local people in Arctic research, including the incorporation of traditional knowledge into research findings and the codevelopment of research agendas (Shirley 2005, Inuit Tapiriit Kanatami and Nunavut Research Institute 2007). However, our Mode 1 versus Mode 2 classification of 1173 papers published in four polar science journals suggests that community engagement in Arctic research continues to be very limited and heterogeneous. Across all years and disciplines, 74% of papers published in *Arctic* had a strictly Mode 1 context, 78% made no mention of local knowledge, 80% lacked heterogeneity of authorship and funding, 83% showed no evidence of reflexivity in relation to local people, and 77% showed no evidence of nontraditional quality control. There was a modest shift in the journal *Arctic* toward more Mode 2 approaches between 1965 and 2010, occurring largely after the mid-1980s. However, Mode 2 research also occurred in the 1960s and 1970s, and remained rare in the most recent years of analysis. Our analysis of three additional journals supports our findings from the journal *Arctic*, albeit with more evidence of Mode 2 approaches in contemporary health research than other disciplines. If there has been a paradigm shift in Arctic science toward more community engagement, this shift is far from complete. Mode 1 science predominates contemporary Arctic research and, if current trends persist, will predominate future Arctic science.

Early examples of Mode 2 Arctic science identified by our analysis include the study by Irving et al. (1967) of Willow Ptarmigan (*Lagopus lagopus*) migration in Alaska. This study focused on an Inuit community's use, knowledge, and personification of the birds, copresented local and scientific knowledge about their migration, and included a community member as a coauthor. Although many northern scientists have long relied on the land skills and land knowledge of local guides to do their research, wildlife research has a long history of also using local harvest records and harvester knowledge to better understand wildlife behavior and abundance. However, reliance on local knowledge and expertise in wildlife research declined in the postwar era when researchers began to emphasize the importance of trained observers, systematic observation, and scientific instrumentation (Banfield 1954, Kelsall and Calaprice 1972, Levere 1993, Bocking 2007). Another early example of Mode 2 research identified in our analysis presented a compelling account of why participatory approaches were needed in the Arctic and how to accomplish them (Francis 1973). Northern peoples' rejection of imposed roles as subjects of investigation and curiosity was described in 1973 much as it continues to be described now (Inuit Tapiriit Kanatami and Nunavut Research Institute 2007).

Examples of early and recent Mode 1 Arctic science are too numerous to describe in detail, but collectively these studies emphasize that a considerable portion of Arctic science, now and in the past, appears to be rather distant from community concerns and involvement. Much Arctic research is conducted in locations that are physically distant from communities and places that community members frequently visit (e.g., Abnizova and Young 2010), involves geological time periods that are temporally distant from the experience and oral histories of contemporary people (e.g., Swanson 2006), involves physical and biological phenomena that are distant from the primary interests and knowledge of local people (e.g., Gradinger and Bluhm 2010), and involves methodologies that are distant from the expertise and interests of nonscientists (e.g., Laidler et al. 2008).

Factors contributing to the heterogeneity of research approaches in Arctic science

The mode of knowledge production varied by researcher organization, discipline, and region, but not according to the extent of research focus on global environmental change. These contributing factors are presented in order of their explanatory power from most influential to least influential.

Researcher organization

Studies with lead authors from local and territorial governments were positioned closer to Mode 2 than studies with lead authors from federal governments, universities, and other organizations including the private sector. In fact, lead author organization was the strongest mode predictor in our statistical analysis. The average mode score across all five criteria was 1.6 for articles with a first author from a local government, 1.3 with a first author from a territorial government, and 1.1 with a first author from a university or federal government. The number of studies with lead authors from local and territorial governments has increased over time, but these studies remain a small proportion of the papers published in *Arctic*, representing fewer than 7% of papers published between 2008 and 2010. Within our sample, examples include education research from the late 1990s (Stenton and Rigby 1995, Norton and Kassam 1997) and wildlife management studies from the last decade (O'Hara et al. 2003, Person et al. 2007), which actively engaged communities in every aspect of the research process. It is not surprising that papers with lead authors from local and territorial governments tend toward Mode 2 in heterogeneity, especially because they often involved authors and funding from other levels of government and/or universities. However, these papers also tended to be more oriented toward questions of relevance at the local level, focused on participatory approaches, and inclusive of traditional knowledge and community forms of quality control (Agrawal 1995, Wolfe et al. 2007).

The integration of traditional knowledge in scientific studies has been found to play an important role in empowering local communities to engage in research and publish work themselves (Berkes 2008) and provides important insights for research (see Inuit Tapiriit Kanatami and Nunavut Research Institute 2007). Some studies have indicated that the rise of traditional knowledge has helped initiate a paradigm shift in the natural sciences (Agrawal 1995, Gearheard and Shirley 2007, Berkes 2008, Norton 2008, Bohensky and Maru 2011, Chaplin et al. 2013) characterized by respect for other knowledge systems and the acknowledgment that all knowledge is situated within specific historic and social contexts (Scott 1996). Although this shift goes beyond the scope of Arctic science, it does indicate that the phenomena under study are part of a larger process occurring globally. Further case studies in different contexts would be valuable.

Discipline

Disciplinary differences were the second most important contributor to the mode of knowledge production. Social sciences were more Mode 2 than other disciplines across all criteria other than heterogeneity. Life sciences were found to be slightly more Mode 2 than physical sciences for most criteria. An earlier study by Gorham and Spalding (1989) also found that there was 40% local involvement in the biological sciences compared with only 10% local involvement in the physical sciences. However, we found considerable mode diversity within the life sciences, with papers focused on traditional food and fur-bearing species more oriented toward Mode 2 approaches than life science papers focused on other species or phenomena, which were overall similar in mode to physical sciences papers.

Other literature has noted that life sciences research oriented around harvested wildlife species is more likely to involve local hunters, trappers, elders, and other traditional knowledge holders (Huntington 2000, Mulrennan and Scott 2005, Gearherd and Shirley 2007, Berkes 2008). Thus, certain fields within the life sciences have historically been, and continue to be, more amenable to the engagement of local partners and perspectives. For example, C. Scott and M. M. Humphries (*unpublished manuscript*) suggest that the underlying models or paradigms in wildlife and ecosystem ecology could engage traditional knowledge holders in profound and meaningful ways. Scott (1996) also suggested that events or phenomena occurring at temporal and spatial scales similar to those of human life may inevitably be of more interest to local partners. Further supporting this claim, respondents in a Canadian Climate Impacts and Adaptation Research Network–North report on community research needs in Nunavut, Canada, found that community members were most interested in climate impacts related to the environment and wildlife, particularly in the context of subsistence harvesting and management (Shirley 2005). There are, however, important exceptions to these disciplinary generalizations, including examples of Mode 2–oriented research on oceanography (Carmack and Macdonald 2008), geomorphology (Eisner et al. 2009), and climate science (Barber et al. 2008).

Overall, between 1965 and 2010 in the journal *Arctic*, there was an increase in the number of life sciences papers, particularly wildlife studies related to traditional food and furbearers, a decline in the number of physical science papers, and no clear change in the number of social science papers. These shifts in disciplinary presence in *Arctic* are likely to be marginal contributors toward the slightly increased prevalence of Mode 2 approaches.

Region of study

The region of study was a significant, but weak, predictor of research mode in our sample. In particular, studies conducted in Canada and Alaska tended to be more Mode 2 across most criteria than those conducted in Scandinavia, Greenland, and Russia. Detailed exploration of the causes and consequences of these regional differences is outside the scope of the present study, but we will briefly discuss U.S. and Canadian research contexts and their influence on community engagement in science.

In Canada, there have been significant changes in the institutional, legal, and political context of Arctic governance since 1990 (Association of Canadian Universities for Northern Studies 2003, Graham and Fortier 2005, Gearheard and Shirley 2007, Inuit Tapiriit Kanatami and Nunavut Research Institute 2007), resulting in new research policies and procedures that better reflect the needs of Arctic residents. In Nunavut, published guides for negotiating research relationships between Inuit and academic and government researchers present step-by-step information on community involvement, local perceptions of science, licensing, access, communication, and so forth (Inuit Tapiriit Kanatami 2002, Inuit Tapiriit Kanatami and Nunavut Research Institute 2007). In certain jurisdictions, special regulations are also in place relating to the collection, dissemination, and ownership of traditional knowledge. For example, in the Yukon Territory, the Umbrella Final Agreement signed in 1993 by the Council for Yukon Indians, now the Council of Yukon First Nations, the Government of Canada, and the Government of Yukon stipulates that any researcher who wants to work on Yukon First Nation Settlement Land must first obtain the permission of that First Nation. The agreement also requires mandatory reporting to affected communities (Cultural Services Branch 2008). Court decisions in Canada have also served to empower Arctic peoples and provide tools and experience to better engage researchers.

In the United States, a 2004 report from the National Science Foundation and the Barrow Arctic Science Consortium indicated “a continuing commitment to research in the Arctic and working with residents to shape research so that it is not in conflict with the subsistence lifestyles of many Arctic residents and whenever possible addresses questions relevant to their lives” (2004:4). It also offers checklists and principles of conduct to promote mutual respect and communication between scientists and Arctic residents. In Alaska, the presence of the University of Alaska likely supports better partnerships with local communities and agencies. The presence of receptive and engaged agencies and local governments such as North Slope Borough and the community of Point Barrow may further support these relationships. Another interesting factor that warrants further investigation is the history of industrial development and oil production in the region and their impact on establishing research partnerships. Industry funds substantial amounts of research in Alaska, and a better understanding of corporate policies regarding community engagement would provide important insights into the forces that might help shape participatory processes.

Environmental change

Although environmental change has emerged as a major focus of Arctic science, it is only marginally predictive of research mode. In other words, the prevalence of Mode 1 and Mode 2 approaches did not differ between papers that focused on global environmental change versus those that focused on other topics. Papers published in *Arctic* with some mention of environmental change accounted for 76% of research in 2010 compared with 20% in 1965, with most of this increase occurring in the past 15 years. This increase coincides with a period of intense international activity related to climate change and environmental change research (IPCC 1990, 1996, 2001, 2007). Many papers focused on environmental change used participatory approaches to integrate local concerns and knowledge into the research process and to identify mitigation and adaptation strategies (Nickels et al. 2002, Pearce et al. 2009, Ford and Pearce 2010, Wolfe et al. 2011). However, many other forms of environmental change research continue to be oriented around Mode 1 approaches, including forest ecology (e.g., Juntunen et al. 2002), wildlife ecology (Towns et al. 2010), and atmospheric sciences (Timlin and Walsh 2007).

CONCLUSION

Arctic science is being transformed by both an intensified focus on environmental change and increased involvement of local people (see, e.g., Graham and Fortier 2005, Pearce et al. 2009). In this study, we empirically assessed claims of a new research paradigm in Arctic science that is oriented around local engagement and participation. We approached this assessment through a Mode 1 versus Mode 2 classification of articles published in the journal *Arctic* as well as three other leading polar science journals. We found that shifts toward Mode 2 research approaches over time have been small and scattered, with Mode 1 approaches continuing to dominate Arctic science. The emergence of Mode 2 approaches was unrelated to a pronounced increase in the prevalence of environmental change research. Instead, it was correlated with the increased involvement of northern organizations and the increased prevalence of life sciences research focused on harvested wildlife and social sciences research focused on contemporary people. Thus, local people are becoming more involved in Arctic science, but the nature and level of this involvement remain limited and vary systematically among disciplines, organizations, and regions.

In this paper, we describe how Arctic research is done, not how Arctic science should be done. Whether the modes of knowledge production and the extent and form of community engagement that they reflect can or should be different is a broader question of research policy. There is clearly room for more community involvement in Arctic science. Our analysis indicates that the emerging focus on environmental change research will not by itself lead to substantially more community involvement because environmental change research spans the same range of Mode 1 and Mode 2 approaches as other Arctic research does. More community involvement could be achieved by increasing the proportional representation of the organizations, disciplines, and regions with a track record of successful Mode 2 research or by encouraging Mode 2 research innovations within the organizations, disciplines, and regions currently predominated by Mode 1 approaches. On the other hand, many forms of Arctic science appear to be well served by Mode 1 approaches, and their continued existence and value need to be acknowledged in Arctic science policy.

Efforts to increase community engagement in Arctic science need to recognize the diversity of research interests and approaches in polar science, and to be skeptical of one-size-fits-all solutions. Clearly, community collaboration and partnerships should be encouraged and facilitated when appropriate. However, there are likely to remain many situations in which circumpolar research priorities and approaches do no align well with local community priorities and engagement. This is, perhaps, the elephant in the room or, given our Arctic science context, the woolly mammoth in the permafrost. The Arctic is a vast, interesting, and important place that is home to more than 4 million people. Contemporary Arctic research aspires to engage and benefit local communities and to advance international science and discovery. Some research can do both, and some is likely to do one much better than the other. Finding the appropriate balance in research aspirations, approaches, and expectations will be one of the grand challenges of Arctic science in the coming decades.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/6641

Acknowledgments:

We would like to acknowledge Dr Quinn Fletcher for improving the statistical analyses and Drs Marianne Marcoux and Guillaume Larocque for assisting with access to the papers. We would also like to thank Dr Elena Bennett and the Humphries Lab for insightful comments on previous versions of this work. This work was funded by the Fond Québécois de Recherche sur la Science et la Culture, the Natural Sciences and Engineering Research Council of Canada's Northern Research Chair Program, and McGill University.

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Appendix 1. Detailed results of multiple regression analysis of the Mode score predicted by the five explanatory variables included in our study of the journal Arctic (1965-2010)

Response Variable: Context

Adj $R^2 = 0.330$, $F_{21,1091} = 27.02$, $p < 0.0001$

Predictor	Sum Sq	Df	F	P
Intercept	0.822	1	19.313	< 0.0001
Year	0.824	1	19.350	< 0.0001
Year^2	0.828	1	19.441	< 0.0001
Observer	0.560	1	13.154	< 0.001
Region	0.540	5	2.539	0.027
Discipline	16.348	6	64.010	< 0.0001
Organization	2.539	4	14.914	< 0.0001
GlobalChange	0.298	3	2.333	0.073
Residuals	46.440	1091		

Response Variable: Transdisciplinarity

Adj $R^2 = 0.266$, $F_{21,1091} = 20.22$, $p < 0.0001$

Predictor	Sum Sq	Df	F	P
Intercept	0.191	1	3.851	0.050
Year	0.191	1	3.863	0.050
Year^2	0.193	1	3.898	0.049
Observer	0.014	1	0.282	0.596
Region	0.638	5	2.578	0.025
Discipline	14.022	6	47.238	< 0.0001
Organization	2.295	4	11.597	< 0.0001
GlobalChange	0.395	3	2.663	0.047
Residuals	53.975	1091		

Response Variable: Heterogeneity

Adj $R^2 = 0.271$, $F_{21,1091} = 20.65$, $p < 0.0001$

Predictor	Sum Sq	Df	F	P
Intercept	0.161	1	3.917	0.048
Year	0.164	1	3.987	0.046
Year^2	0.168	1	4.083	0.044
Observer	0.026	1	0.622	0.431
Region	0.904	5	4.392	<0.001
Discipline	1.643	6	6.647	<0.0001
Organization	8.226	4	49.928	<0.0001
GlobalChange	0.037	3	0.301	0.824
Residuals	44.936	1091		

Response Variable: Reflexivity

Adj $R^2 = 0.276$, $F_{21,1091} = 21.18$, $p < 0.0001$

Predictor	Sum Sq	Df	F	P
Intercept	0.294	1	4.487	0.034
Year	0.297	1	4.534	0.033
Year^2	0.302	1	4.604	0.032
Observer	1.127	1	17.199	<0.001
Region	0.582	5	1.776	0.115
Discipline	18.550	6	47.177	<0.0001
Organization	2.050	4	7.819	<0.0001
GlobalChange	0.396	3	2.014	0.110
Residuals	71.496	1091		

Response Variable: Non-traditional Quality Control

Adj $R^2 = 0.204$, $F_{21,1091} = 14.56$, $p < 0.0001$

Predictor	Sum Sq	Df	F	P
Intercept	0.130	1	2.013	0.156
Year	0.132	1	2.043	0.153
Year^2	0.135	1	2.088	0.149
Observer	0.000	1	0.002	0.969
Region	0.800	5	2.469	0.031
Discipline	7.439	6	19.133	<0.0001
Organization	4.476	4	17.270	<0.0001
GlobalChange	0.465	3	2.394	0.067
Residuals	70.694	1091		