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Commentary. Integrating Research, Education, and Traditional Knowledge in Ecology: a Case Study of Biocomplexity in Arctic Ecosystems

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Introduction

Integrating research and education is a fundamental goal of institutions and agencies supporting science because of the benefits to society of a more informed and scientifically literate population. The value of engaging public interest in ecological research is to maintain support for and integrate science in solutions to environmental problems (Hudson, 2001; Avila, 2003). The National Science Foundation lists criteria for assessing broader impacts of research projects which include (1) the integration of research and education—advancing discovery and understanding while promoting teaching, training, and learning; and (2) developing opportunities to broaden the participation of groups underrepresented in science (NSF, 2006). Educational researchers are developing models and assessing outcomes of integrating research and education at diverse grade levels (Trautmann and Krasny, 2006; Bowen and Roth, 2007); the value of integrating traditional ecological knowledge (TEK) in research has been demonstrated in several ecosystems (Huntington, 2000; Kimmerer, 2002; Ford et al., 2007; García-Quijano, 2007) but specific approaches and achievements of efforts integrating research and education are not widely disseminated in environmental research journals. Thus, while there is a call for environmental scientists to broaden their activities to engage in outreach (i.e., have broader impact) there is a lag in the assessment of the effectiveness of these activities and of their value in mainstream scientific culture. Environmental scientists seldom evaluate these impacts, and there are few venues or incentives to report on these activities in ways that would enhance their research careers. For an individual scientist, efforts expended in integrating research and education often occur at the expense of research productivity and this results in a lack of reward for a researcher's efforts to broaden research impacts (Andrews et al., 2005; Uriarte et al., 2007).

One way to address the imbalance between efforts devoted to broader impacts vs. avenues for reporting on these efforts is through the publication of case studies and assessments of integration efforts in journals that reach a research audience as opposed to an education audience. This venue exists in a very few, high-profile, broad-interest research journals (e.g., *Science*, *Bioscience*) but could be more widespread in journals addressing a range of environmental research. Examples of successful integration help researchers and institutions evolve better mechanisms to achieve goals beneficial to society, including improved public understanding of science, greater diversity of research and stakeholders, and better application of current scientifically based information to managing environmental issues.

In that spirit, we present as an example an effort integrating an interdisciplinary research project investigating the interactions of climate, vegetation, and permafrost in the study *Biocomplexity of Arctic Tundra Ecosystems* with a university field course, *Arctic Field Ecology*, and with indigenous Inuit students and elders. The integration allowed university students and native community members to participate with the research team, drawn by the opportunity to gain education and experience. This participation has had synergistic benefits with the research agenda and diversified the pool of stakeholders involved in the research (see Box 1).

Impacts

PROJECT DIVERSITY

Sixty participants were brought into the project through the education component and 51 participants through the research component (Table 1). Participants involved through the education component included 5 scientists, 29 *Arctic Field Ecology* students, 9 Inuit elders, 16 additional Inuit participants, and 8 technicians or administrative personnel. Roughly half of the participants could be characterized as receiving education and this included undergraduate, graduate, and postdoctoral students, Inuit students, and a

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BOX 1
A case study: biocomplexity in arctic ecosystems—integration components and activities.

The Biocomplexity study. The study took place along an 1800 km North American Arctic Transect (NAAT) and included research sites in northern Alaska and the western and central Canadian Arctic (Fig. 1). Sites where located to sample along the range of bioclimatic subzones found across the Arctic (Walker et al., 2005). Each field season a research/education team sampled one portion of the transect, beginning in Alaska (2002), establishing sites on Banks Island (2003), Prince Patrick Island (2004), and Ellef Ringnes Island (2005). The sites were essentially self-sufficient tent camps established with air support and with resources for a group of 25–30 individuals to conduct research and teaching over the summer months.

The research component. The goal of the research was to understand the links between biogeochemical cycles, vegetation, disturbance, and climate across the summer temperature gradient in the Arctic in order to better predict ecosystem responses to changing climate (Walker et al., 2004). Research sites were established to investigate small patterned-ground features variously known as frost boils or non-sorted circles and related features such as frost cracking and turf hummocks (Tarnocai and Zoltai, 1978; Mackay, 1979, 1980; Chernov and Matveyeva, 1997; Walker et al., 2004; Kokelj et al., 2007) (Fig. 1). Areas dominated by small patterned-ground features contain diverse and ecologically important ecosystems in the Arctic and are important to global carbon budgets (Ping et al., 2008). The team measured the morphology, dynamics, vegetation and soil characteristics, and climate relationships of patterned-ground systems in the Arctic, and the project included laboratory and modeling efforts investigating the initiation and persistence of these features and their interaction with vegetation and nutrient cycling (Peterson and Krantz, 2003; Daanen et al.; 2006; and see Walker et al., 2008, for synthesis of research results).

The education component. The primary education component was the University of Minnesota *Arctic Field Ecology* course (Gould et al., 2003) but also included traditional activities of postdoctoral and graduate students, Research Experience for Undergraduates (REU) participants, the Teachers and Researchers Exploring and Collaborating (TREC) program, visiting and collaborating scientists, a soil science field course (*Alaska Soil Geography*), and the extent to which researchers integrated the project in their corollary university educational duties. The *Arctic Field Ecology* class was designed to (1) give students background in regional ecological issues; (2) introduce students to the project objectives, methods, and personnel; (3) provide for interaction with participating scientists, including discussion and field experience; (4) encourage students to develop questions for future research; (5) involve Inuit students; and (6) give Inuit and non-Inuit students the opportunity to interact with Inuit elders. The idea was that the educational component would introduce a group of students and local Inuit not directly supported by the research project to the goals, methods, personnel, and findings of the research—and as such increase the broader impacts of the research effort.

Youth-Elder-Science camp. Elders came from one of four surrounding villages and had strong connections with the site. Some, who had been born in the area but had not visited in over 50 years, were overcome by emotion as they stepped off the floatplanes at the site—clearly grateful for the opportunity to return. During the camp, elders developed a teaching plan each morning. They focused on interpretation of nearby archeological sites and artifacts, including stone wolverine traps, fish and game caches, caribou drives, tent rings, stone fishing weirs, and wood implements. They demonstrated traditional skills of hunting and preparation of food and hides (Fig. 2), sewing, throat singing, and drum dancing, and they discussed language, terminology, and current land use and management issues. With the scientists, students investigated variation in vegetation, soils, and soil organisms along toposequences at the site (Fig. 2). We found common ground among Inuit students and their peers from universities in the patterns of vegetation and soils, particularly the relationships of topography to species composition, vegetation cover, snow depths, soil moisture, thaw depths, and patterned ground features.

teacher with the Teachers and Researchers Exploring and Collaborating (TREC) program. Many participants had dual roles over the course of the project. Eighty-two percent of all the personnel participated in field activities. Participants came from nine countries including the United States, Canada, Russia, Puerto Rico, Brazil, France, Germany, Switzerland, and the Netherlands. Indigenous participants came from Nuiqsut (Alaska), and from Omingmaktok, Kugluktuk, Cambridge Bay, Kingaok, and Sachs Harbour (Canada). Both the research and education components represented a high degree of geographic diversity, but the education component significantly increased this element.

INDIGENOUS INVOLVEMENT

Traditional ecological knowledge (TEK)— the understanding of ecological relationships in a landscape derived from experience—was integrated with the field class for three reasons: (1) The evidence of past indigenous use of the land is prevalent in the relatively undisturbed landscape of the Arctic. The history of human land use is an important component of understanding the landscape. (2) Indigenous residents are active managers of the natural resources of the region. They control the access to and can affect the structure of ecosystems through management of research, development, recreation and subsistence hunting. (3) Indigenous elders are a storehouse of traditional ecological knowledge, passed down orally over generations (Thorpe, 1997; Kimmerer, 2002). This source of information complements scientific ecological knowledge (SEK). Thus, the benefits of including TEK are that indigenous elders provide information and insights unavailable to non-indigenous instructors, and Inuit students have the opportunity to learn and interact with non-Inuit scientists and students. Indigenous elders also provide inspiration to students by opening a window on new ways to perceive the landscape and increasing enthusiasm for future study and research. The integration of TEK and SEK centered around the idea that students could draw on two distinct pools of knowledge in order to generate ideas and broaden their understanding of the arctic system. The culmination of the TEK component was a youth-elder-science camp (see Box 1) organized in collaboration with the Kitikmeot Inuit Association with the goal of bringing students, scientists, and elders together in the field to teach students both traditional and scientific knowledge about the landscape. The camp was located at the mouth of the Hiukitak River on the Arctic coast of Bathurst Inlet, Nunavut, Canada—a

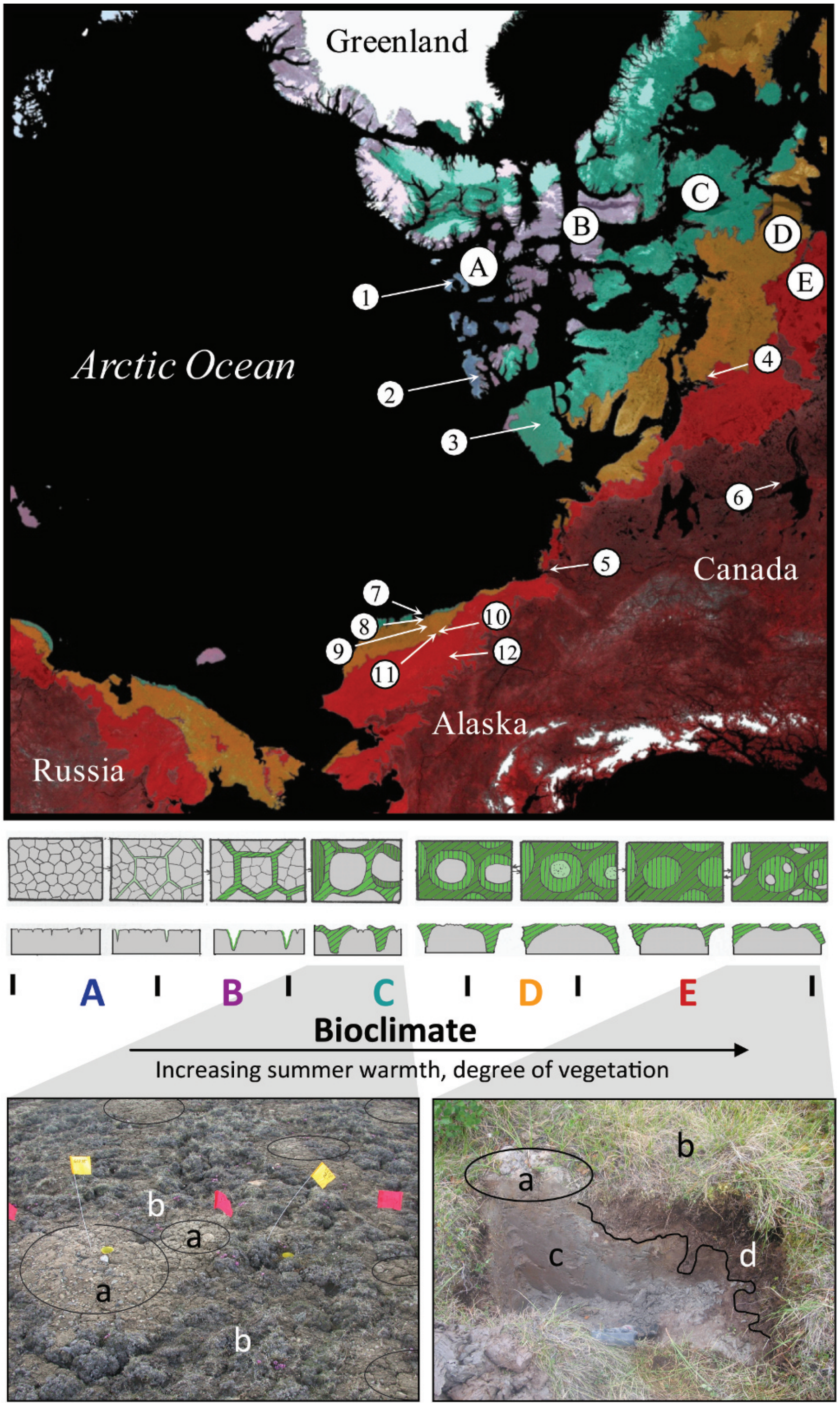

FIGURE 1. Site locations along the North American Arctic Transect (NAAT). Bioclimatic subzones follow Walker et al. (2005) and from colder to warmer include subzone A (blue), B (violet), C (turquoise), D (yellow) and E (red). The southern limit of subzone E is the northern limit of trees. Site locations include *High Arctic Canada*: (1) Isachsen, Ellef Ringnes Island, NU (A), (2) Mould Bay, Prince Patrick Island, NT (B), (3) Green Cabin, Banks Island, NT (C); *Low Arctic Canada*: (4) Hiukitak River, NU (E); *Subarctic Canada*: (5) Inuvik, NT, logistics and laboratory, (6) Yellowknife, NT, logistics; *Arctic Alaska*: (7) Howe Island (C), (8) Deadhorse (D), (9) Franklin Bluffs (D), (10) Sagwon moist nonacidic tundra (D), (11) Sagwon moist acidic tundra (E), (12) Happy Valley (E). Small patterned ground features (10 to 200 cm diameter) vary in degree of vegetation cover and ecological properties along the climatic gradient (modified from Chernov and Matveyeva, 1997, and following Walker et al., 2008). In subzone C the feature area (a) is barren and covers a large proportion of the landscape. The inter-feature area (b) is vegetated. In subzone E (warmer summer climate) the feature area (a) may be barren and exposed by differential frost heave. The inter-feature area (b) is heavily vegetated. Fine mineral soils (c) are forced upward by frost heave and contain numerous ice lenses. An organic soil horizon (d) accumulates beneath the vegetated surface of the inter feature areas. Frost heave is greater within the feature than in inter-feature areas.

site chosen by elders that it is rich in local history, accessible by float plane, undeveloped, and representative of the regional climate and vegetation.

CONTRIBUTIONS TO RESEARCH

The integration of the *Arctic Field Ecology* course with the research component added several aspects to the research agenda. For example, the original research design did not include an examination of soil biotic processes. Through the mentoring of instructors, students participated in projects in decomposition, soil invertebrates, and soil microbial processes which resulted in new research on soil invertebrate and microbial diversity and function (González et al., in review). Two of the four post-doc students involved in the project began their involvement as students in the *Arctic Field Ecology* course, developing a new numerical spatial model to understand the hydrological processes involved in the formation of non-sorted circles (Daanen et al., 2007) and

TABLE 1

Number of participants followed by the ratio of males to females in the research, educational, and administrative components of the study *Biocomplexity of Arctic Tundra Ecosystems*, organized in columns as they were introduced to the project (through research or education channels). Participants may appear in more than one category if they had multiple roles or if their roles changed over time. Subtotals and totals for the research component, the educational component, totals by group, or for the overall total do not double count individuals.

		Research		Education		Totals	
Conducting research or administration	Scientists, PI and CoPIs	5	100/0	2	50/50	7	86/14
	Collaborating scientists	8	75/25	3	33/67	11	64/36
	Inuit elders			9	44/56	9	44/56
	Professional technicians	6	50/50	3	67/33	9	56/44
	Administrative and logistics (7 Inuit)	7	28/72	5	60/40	12	42/58
	Additional Inuit participants			9	33/67	9	33/67
	Subtotal	26	66/34	31	45/55	57	53/47
Receiving education	Postdoctoral students	4	75/25			4	75/25
	Graduate students	10	50/50			10	50/50
	REU and other undergraduate students	10	40/60			10	40/60
	Arctic Field Ecology students			20	60/40	20	60/40
	Inuit Arctic Field Ecology students			9	56/44	9	56/44
	TREC teacher	1	0/100			1	0/100
	Subtotal	25	48/52	29	59/41	54	54/46
	Totals	**51**	**52/48**	**60**	**56/44**	**111**	**57/43**

collaborating with a synthesis of the plant community information along the transect (Vonlanthen et al., 2008). Students from the field class have participated in over 22 papers and posters presented at scientific meetings and conferences and a number of research publications (e.g., Daanen et al., 2006; González et al., 2006; Kuss et al., 2006; Okie et al., 2006; Rivera-Figueroa et al., 2006). The students also contributed to insights regarding complex patterned-ground systems through their participation in seminars and discussions involving all research participants at the field camps.

BENEFITS AND COSTS

The education component increased the broader impacts of the study by increasing the number and diversity of participants in the *Biocomplexity* study. Students assisted in field sampling and in the development of research products. Less tangible benefits that participants in the educational component brought to or took away from the project are difficult to measure. These include ideas, enthusiasm, memories, and experiences that shape future decisions—and that have potentially broad impacts. The costs of the educational component to the initial NSF grant were about 10% of the total funding. Ten institutions offered matching support of salaries or other resources beyond the original grant, and total costs of the education component were more than double those allocated by the initial grant funding.

An additional "cost" worth mentioning is the price instructors pay in terms of the percentage of time devoted to teaching and logistic planning versus conducting research and obtaining publishable results. Having research ecologists lead the educational component brings the students a step closer to the research process and enhances the learning experience. Research ecologists, however, are evaluated both formally and informally by their research output. Organizing an educational experience in remote regions requires time and expertise not only in field ecology, but also in logistics, emergency medical training, and student supervision. Time spent in these efforts is not directly related to teaching or research but is necessary for the safe and successful integration of research and education in field studies. As a benefit to researcher/instructors, there is an opportunity to incorporate student efforts in addressing research questions and collecting data that can be analyzed for publication. This is a worthwhile effort but the narrower research agenda of a project must be balanced with the needs of the students for a broad educational experience. Achieving a balance requires planning of research and associated activities so that they serve a dual purpose of enhancing the educational experience and providing publishable data.

Conclusions

In spite of more than a decade-long call to increase the broader impacts of research efforts through the integration of research and education, a review of recent environmental research literature gives little indication of what efforts have been undertaken, what impacts have occurred, and what the costs and benefits of those efforts are. Analyses and case studies of integrating research and education are for the most part restricted to education journals. The impetus on creating broader impacts is placed on research scientists through the course of their work, but there is a comparative lack of opportunity to disseminate information regarding these efforts to their peers. Greater presentation of efforts to enhance broader impacts in environmental research journals would improve the future success of these efforts by helping researchers and institutions evolve better mechanisms to increase public understanding of science, increase diversity of research and stakeholders, and better apply science to management problems. In the case study presented here, the educational component provided a wider degree of participation in the biocomplexity study than would have occurred otherwise and enhanced the research output of the study through the efforts of students and instructors. Fifty percent of the participants in what was primarily a research effort received educational benefits. The long-term impacts of a more diverse research team are less tangible but we hope positive in terms of broader impacts.

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FIGURE 2. The arctic field ecology youth-elder-science camp involved such diverse activities as (a) stretching hides of caribou recently harvested by the elders and (b) observing microscopic soil invertebrates.

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