The Promise of Solutions from Increasing Diversity in Ways of Knowing

Educational Lessons from Meteorology, Ethnobotany, and Systems Ecology

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ABSTRACT: The number of terms used for historically unrepresented types of knowledge in environmental management is large and growing. The emphasis on these "new" perspectives reflects a shift in how society values different ways of knowing. A primary reason behind this recognition of value is that fresh perspectives offer new problem framings, approaches to solutions, and linkages to other issues. Successes in collaborating across multiple knowledge domains have yielded new medicines, culturally appropriate regulations, and a better understanding of ecological dynamics, among others. These examples show the search for creative solutions cuts across disciplines, each of which has its own priorities, values, ethical practices, and approaches to knowledge creation. This review demonstrates how systems ecology, ethnobotany, and meteorology increase problem solving by legitimizing different ways of knowing. Pioneers in valuing nonscientific ways of knowing, they set the path forward for methods and theory used to inform research questions.

KEYWORDS: complex problem solving, creativity, ways of knowing

Introduction

Small-scale artisanal fishermen often tell scientists that studying the ocean to death does not help those whose livelihoods depend on the ocean. They claim that intense local knowledge and practice is needed to shift the scientific paradigm from one of monitoring decline to active restoration. In response to such claims, collaborative fisheries research partnerships are springing up all over the globe. But are these fishermen right? There are historical cases of utilizing multiple forms of expertise that might help answer this question while we wait for newer programs to mature. This article delves into these historical cases to see if there are any lessons we should take from them in developing new programs.

First, I will review what the education scholars tell us about different forms of expertise and different learning styles. I will begin the discussion of their application in the environmental sciences by pointing out familiar stories from the popular media that exemplify the need for recognizing different forms of expertise. Turning to more analytical discussions, I will first describe the landscape of terms used for forms of knowledge outside of professional science that emerged

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from the different cultures and values of different scientific contexts. After this background information, I will give a structured analysis of three early practitioners of knowledge studies in the environmental sciences. From these examples, I will then pull out some common lessons and themes that might be useful for other scientific contexts hoping to tap into different forms of expertise in order to help come up with creative solutions to persistent environmental issues.

Fostering Creativity

"Two heads are better than one." All elementary school students hear this phrase from their teachers, trying to encourage collaboration and inclusion. That sage kindergarten advice is echoed in experiences ranging from the stubborn school-age math problem to larger questions of conservation, medicine, and international relations. But what Western scientific professionals learned as children seems to have been forgotten when it comes to embracing alternative knowledges in finding solutions for resource management. We require humility from experts to remember that collaboration trumps individual expertise. As any elementary school student knows, the benefits of recognizing contributions from other ways of knowing are wide-ranging and cross-disciplinary. While this review focuses on the link between diverse ways of knowing and creative problem solving in collaborative situations, other benefits are documented: humility in the face of mistakes and other-regarding empathy in decision making (Yanow 2009), recognizing the context of knowledge (Jazeel and Mcfarlane 2007), and developing a more full understanding of the system (Fortmann and Ballard 2011), to name a few. Step one in reaping those benefits was historically to collect nuggets of information from newly recognized ways of knowing and apply them to issues facing modern society; recent efforts attempt to also capture context through collaborative, participatory approaches in the quest for creative problem solving.

As a multidimensional concept, creativity is hard to define. Rollo May defined creative courage as "the discovering of new forms, new symbols, new patterns on which a society can be built," needed "in direct proportion to the degree of change the profession is undergoing" (1975: 22). A shared functional definition still eludes academia, where the concept is often dismissed in lieu of more concrete metrics of evaluation such as content testing; at the same time, "unidisciplinary approaches to creativity [have] tended to view a part of creativity as the whole phenomenon, often resulting in what we believe is a narrow vision of creativity and a perception that creativity is not as encompassing as it truly is" (Sternberg 1998: 12). This review takes a wide view of creativity, pulling from May's (1975) definition—both creating new information and combining knowledge in a new way. Stale problems require this creativity to move out of a pattern of habitual incrementalism (Cates 1979), and this review proposes that diversifying ways of knowing offers one avenue by which to achieve this goal.

A pedagogical shift from the model of a teacher communicating "truths" to one fostering creative thinking as the desired outcome of education means that "objectivist measures" are not adequate to describe in-depth, holistic educational experiences of diverse students (Simons 1996). In studies explicitly linking particular ways of knowing to creative outcomes, expressive ways of knowing (that engage imagination and intuition) (Davis-Manigaulte et al. 2006) and engaging multiple dimensions of being (Tolliver and Tisdell 2006) encouraged students to actively problem solve and structure their own learning process productively. Of course, the ethical demand is to match consistent, effective pedagogy and evaluation across these different learning processes (Ettling 2006).

Education scholars were among the first to recognize multiple *ways of knowing* (logical-mathematical, linguistic, musical, spatial, bodily-kinesthetic, interpersonal, intrapersonal) through investigations in how children learn best and the need to diversify content delivery in the classroom so as to not privilege certain types of learners (Gardner and Hatch 1989). Starting with Perry's studies of college students in the 1970s, which uncovered an inherent understanding that knowledge is constructed, scholars scrambled to shift classroom practices to make use of that understanding (Burnard 2006). As schools shifted practice to ensure all types of learners were equally served, people trained in these new educational environments began to value more forms of knowledge. Yet, certain ways of knowing still struggle for such equality—in particular, knowledges of the environment produced by nonscientists such as farmers, fishers, and traditional medical practitioners.

The push toward "meaningful landscapes" in education is over a century old, and yet standard pedagogy has not yet emerged (Mueller and Bentley 2007). For many teachers and professors, this goal is manifested through creating a "scholarship of engagement", where the goal of the institution is to be a "place where multiple ways of knowing are valued and respected" (Semali and Maretzki 2004: 91). A key aspect to this scholarship is the development of creative capacity in children and across a diverse spectrum of situations, viewed as a "vital dimension of human intelligence" (Prentice 2000: 145). Creative capacity is best fostered by initiating children into the ways of learning that work best for them, in order to make imaginative leaps (Prentice 2000).

Education at all levels aims to produce graduates with the ability to contribute to their chosen profession. Professional and graduate schools were the first to implement engaged pedagogy that not only appreciated but applied diverse learning styles to a real-world problem. In a medical school context, problem-based learning has rapidly become the industry standard due to a "more enjoyable and effective professional development" (Engel 1992: 325). The approach presents challenges in faculty time commitment, the role of expertise, and fair evaluation of the different types of contributions offered by a diverse team of students—but in the end, it trains doctors better prepared for an interdisciplinary workplace (Schwartz 2013). As a result of successes in the medical context, problem-based learning is gaining practitioners in a wide variety of other settings, including grade school (Torp and Sage 1998), engineering (Mills and Treagust 2003), business (Stinson and Milter 1996), and chemistry (Ram 1999).

As "engaged learning" approaches gain popularity springing from the early advances in education—through service learning, citizen science, problem-based learning, and other applied teaching experiences—there are increasing numbers of cases where problem solvers are trained through solving real-life problems. For example, in the environmental sciences, Kimmerer (2012: 1) proposes engaging the "indigenous pedagogy of direct, experiential learning" and "holistic engagement of multiple elements of human capacity" to create not just new knowledge, but knowledge that is tied to action and spirit.

"Knowledge is best acquired by traversing it from a variety of perspectives" (McGinley and Tierney 1989: 243). For example, the Interinstitutional Consortium for Indigenous Knowledge at Pennsylvania State University boasts that it "transforms its institutions to a marketplace of multiple ways of knowing," moving beyond a positivistic research model and diversifying pedagogy to embrace non-Western thought (Semali and Maretzki 2004: 94). Knowledge development then occurs on two fronts: one at the frontiers of knowledge content and the other in stitching together new developments to make contributions to society (Prentice 2000). Put another way, "the creativity of science is bound up with the freedom of human beings to create in the free, pure sense" (Simons 1996). In summary, creative problem solving is a whole-brain holistic adventure that requires a group effort to employ as many perspectives as possible (Lumsdaine and Lumsdaine 1994).

Popular Examples of Valuing Knowledges

Even though few outside of academia use the term *way of knowing,* many are familiar with the high-profile benefits of alternative knowledges: the promising scientific developments, the long intellectual property battles that followed, and the case made for protecting cultural diversity and biodiversity for potential future discoveries. The textbook example of the promises and pitfalls of alternative knowledge is the case of the bioprospecting of Madacascar periwinkle (*Catharanthus roseus*), which Robert Noble (1990) discovered contained the cancer-fighting chemical vinblastine and for which American company Eli Lilly received the patent and large profits. Since the discovery, the rosy flower literally became the poster child for tropical rainforest conservation, promising the hope of more cures (*Edmonton Journal* 1989). Scientists hoped to realize the promise of cures by "picking the brains" of traditional healers in Madagascar, ethnobotanists becoming the new popular explorer heroes (McIlroy 1991). But these "heroes" extracted "gems" from one of the poorest nations without compensation (Peel 2001). The *Globe and Mail* of Toronto ended a 12-article coverage of the periwinkle case exposing the incorrect narrative of the wonder drug turned case for conservation and indigenous rights by documenting the systematic overexploitation of forest resources and poor labor practices that resulted from the discovery (Strauss 1992).

Recognizing the utility of indigenous knowledge is sometimes a slow awakening, as with the return to Hawaii's traditional land management system known as *ahupuaʻa.* Generally understood to be an ecosystem-based management approach, encompassing mountains to sea, the system is similar to other Pacific island governance systems also gaining management attention, such as Japan's *satoyama-satoumi* or Fiji's *vanua.* After decades of blending with Western governance schemes, the remaining areas of traditional management are celebrated by the media (Karp 2010), sometimes as tourist destinations (O'Leary 1998). The Hawaiian government boasts they have "rediscovered" *ahupuaʻa* in their quest for more sustainable, ecosystem-based management (WEC 2012). The newspaper *Indian Country Today* celebrates the return to *ahupuaʻa* for integrating land- and sea-based knowledge as well as promoting native voices in the management process (Jacobs 2010). The verdict regarding success is still out, but the return of traditional management offers some hope for Hawaii as "forestry's best-kept secret" (Davis 1994).

The final example includes the shift in message of a popular media icon, Smokey the Bear. After decades of fire suppression policies on American public lands, including an enormous education campaign, foresters realized that the Native Americans that once dotted the landscape actively managed forest fires—and, more importantly, that these fires are a healthy and necessary part of forest ecology. Interviews with native elders in Montana yielded the Tribal Forest Management Plan, which reconciles the role of fire in forests as both creator and destroyer and encourages controlled, prescribed burns (Matt 2000). The front page of the *Los Angeles Times* declared the historic ponderosa landscapes of Arizona both natural and cultural, but over the last century the culture has been forgotten, leading to the worst fires in history (Wade 2002). The United States' first inhabitants used to set small fires in the cool months to prevent destructive crown fires, which left a distinct archaeological footprint in the "pristine Rockies" (Remington 2002). Centuries of colonialism leave foresters scrambling to find elders willing to share their knowledge or clues from the archaeological record as fire suppression are officially recognized as a mistake.

These examples are spread across popular newspapers because they offer solutions to long-standing problems. The promise of "new" or "rediscovered" ways of knowing in these cases appears as an untapped resource just waiting for application to modern problems. That promise, however, is mediated by ethical issues involved in collaboration when combining diverse ways of knowing. Notably, knowledge is not something to be collected and combined loose of cultural context, values, and practices, a practice common in early knowledge studies (e.g., Schumann 2011; Huntington 2000). The popular cases exemplified here highlight different approaches to collaboration emerging from a different set of values to navigate a historical context. Each application of diverse knowledges arises out of different disciplinary practices, using varied methods and expectations of results. However, as a cross-disciplinary group of scholars wrestles with similar issues, are they re-creating the wheel? This review seeks to answer that question and summarize some of the lessons learned by early adopters of knowledge diversity.

Naming Alternatives

Each discipline thinking about multiple ways of knowing creates a term for nondisciplinary knowledge, and the number of terms grows with the concept's popularity. Before delving into the specific cases of this review, I call attention to the sometimes value-laden and controversial history of what to name these knowledges (the list is far from comprehensive). All of these terms refer to basically the same thing—the knowledge left out of the conversation when Western science is privileged as an authoritative way of knowing (Goldman 2003). Some of the most common and earliest-used terms now have associated connotations that may limit the potential of that type of knowledge or fail to recognize the full suite of knowledges in a given system, illustrated in each of the following examples.

Berkes, who writes extensively on ecological knowledge, defines *traditional ecological knowledge* as "a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings with one another and with their environment" (2008: 7). The term refers both to the way of knowing and the resulting body of knowledge. However, many people assign a static time component to the term "traditional", implying that the knowledge is one to be collected from community elders and relies on understandings of the world before the emergence of modern society, a world seen as static through generations (Antweiler 1998). Some also associate the term "traditional" with indigenous groups whose culture is sometimes described as "primitive", which is a false association tied closely to racist philosophies (Correia 2013).

Local knowledge gained use as critiques of the word "traditional" solidified "because it is the least problematical" (Ruddle 1994: 161). Because the term emerged largely in reaction to the temporal dimension in the use of the word "traditional", it tends to refer to recently created knowledge embedded in the context of a particular location. Ruddle (2000) describes common traits of local knowledge worldwide: it is based on observation, practical and behavior-oriented, structured but inductive, dynamic and capable of learning. Criticism lies in that places are made, and "local" is a relativistic and socially constructed term—for both the knowledge and the knowledge holder (Raffles 2002). Depending on the speed of local acceptance, new knowledge discovered through a scientist's experiments may be considered local to one place, or a career-long resident's discoveries may not be considered local because he was not born there (Raffles 2002).

Both traditional and local knowledge are often viewed as something to be collected and utilized alongside Western science (e.g., Pauly and Palomares 1993). *Ordinary knowledge* takes local knowledge a step further, defined as pertaining to local context and the normative understandings of their meanings (Fischer 2002). Ordinary knowledge involves the many ways of organizing and understanding nature, aware of basic social meanings and values underlying existing structures and relationships (Fischer 2002). The term is scarcely used outside of the participatory research community, where it refers to knowledge created through a participatory process, recognizing the inability to extract knowledge from the creator's worldview.

The much more general *alternative knowledge* groups together all possible terms, referring to types of knowledge outside the socially dominant, usually Western science. The term specifically references the power differential often present between alternative knowledge systems and the dominant knowledge system, calling attention to the fact that knowledge outside science is often denigrated as backward and unsophisticated (Gratani et al. 2011). Wilson (2006) uses the term generally when referring to political institutional arrangements that provide for nondominant knowledge input. The phrase *alternative knowledge system* is also common, referencing the values and worldviews associated with alternative knowledge. Using a case of marine protected area management in Brazil, Gerhardinger and colleagues (2009) concluded that it is the system part of the knowledge in which ethics play an important role in using multiple knowledges. They proposed a participatory knowledge-building approach to marine management, rather than the existing knowledge-using approach, to encompass this important context. The context-sensitive approach of participatory science produces knowledge differently, making current data management standards—based on Western science—a challenge to the legitimacy of alternative systems (Newman et al. 2011).

Recognizing the importance of this context sensitivity and using it to directly confront the global legacy of postcolonialism, a subset of knowledge scholars recognize *subaltern knowledge* as types of alternative knowledge suppressed by knowledges preferred by colonial powers. While other terms can engage with issues of power and struggle, "subaltern" is proposed to explicitly recognize the use of knowledge for empowerment (Kothari 2002). Subaltern knowledge must be translated for incorporation into current social structures, placing it at a distinct power disadvantage (Jazeel and Mcfarlane 2007). The word "subaltern" more commonly refers to the knowledge holders, people in a position of colonial dispossession, which restricts the discussion of knowledge to one intricately linked with power.

Individuals can possess multiple types of knowledge or blend these classifications as well as others. Citing the heavy flow between indigenous and scientific knowledge, Agrawal (1995) questions whether delineating different types of knowledge risks falsely encapsulating living, dynamic people and missing their changes over time. Instead, Agrawal and many other science and technology scholars (e.g., Jasanoff, Wynne, and Latour) argue that all knowledge is partial, constructed, and positioned in cultural context. However, because power is linked to certain ways of knowing and not all types are invited to decision-making tables, it is still helpful to name the different types (Kothari 2002). For the sake of this review, I will continue to use the term *alternative knowledge* to represent forms of knowledge outside the standard scientific positivist tradition (as described in Popper 1959).

Case Studies

The three cases featured in this review are far from the only types of research that stand to benefit from using diverse ways of knowing for creative problem solving. I selected them because efforts at knowledge integration began before educational scholars fully understood the multiplicity of knowledges every individual holds, so they represent independent efforts at utilizing diversity in hopes of new approaches to stale environmental problems. A look across disciplines currently engaging multiple ways of knowing offers a menu of possible strategies to structure that engagement, complete with benefits and drawbacks described after reflection on those strategies. These strategies include citizen science, recognizing and incorporating different means of information transmission, and coproducing knowledge, among others.

Experiences on the ground fall across a spectrum, between merely incorporating additional ways of knowing to systematically changing professional practice; location on the spectrum changes over time in response to ethical critique and experience achieving desired results. I will present three case studies that fall along this spectrum. First, meteorology successfully incorporates volunteers into their Cooperative Observer system to better understand weather patterns and, more recently, climate trends. Second, ethnobotany solicits local botanical knowledge to advance the world's pharmacopeia. Third, systems ecology looks at indigenous understandings of ecosystems and related management systems to better understand dynamism in nature. As a means of comparison, this review highlights the following components of each program: the major research methods used through time, stated priorities and goals, underlying values, ethical practices, and approaches to new knowledge creation (in that order). The purpose is to shed light on the culture supporting each individual discipline, as well as the underlying goal—creativity—uniting them all.

Meteorology

One of the oldest participatory science projects is the National Weather Service's (NWS) Cooperative Observer system, which "is truly the Nation's weather and climate observing network of, by, and for the people" (NWS n.d.). The scientific endeavor was established before hard societal delineation of scientific and alternative knowledge. Made official by the Organic Act of 1890, the data records extend back to 1644, with John Companius's observations (NWS n.d.), and include records from the Smithsonian weather-observing network and the US Signal Service (Doesken and Reges 2010). It currently relies on over 11,000 citizens to place and monitor thermometers, rain gauges, and other weather monitors nationwide. Data is sent daily and stored in the National Climatic Data Center, where it is publicly available for analysis. According to the NWS's website, 77 percent of data requests come from businesses, 13 percent from the public, 6 percent from government, and 4 percent from academics.

The recent advent of remote sensing and other meteorological technology has not suppressed excitement in the program, instead spawning new and more detailed spinoffs, including the Community Collaborative Rain, Hail, and Snow network (CoCoRaHS) and Weather Underground (Doesken and Reges 2010). Weather data also created demand for paired programs like the National Phenology Network monitoring lifecycle stages of organisms (an early form published data in 1918; Miller-Rushing et al. 2012) and AgClimate, a user-based query system using NWS Cooperative Observer data to predict agricultural risk at the county scale (Fraisse et al. 2006). At the most basic level, volunteers "ground truth" satellite data, adding context and identifying oddities (Doesken and Reges 2010). In complex issues like phenology, the participants' data add a detailed extra layer of explanation to help determine what might be driving observed trends (Morisette et al. 2009).

The NWS Cooperative Observer program depends on large amounts of data at the relatively small spatial scales at which weather occurs. The claim to fame for this program is the exceptional length of small-scale weather records that were first used to describe natural oscillations and more recently to document climate trends, even in areas with complex climates like North Carolina (Boyles and Raman 2003). The longevity of the program also lends credibility to the data as a demonstrated record of success and means of working through periods of insufficient funding (Clark and Illman 2001). The rich small-scale data is consistently more complex than computer-derived models and can be used to backcast, improving predictive models (Clark and

Hay 2004). The visibility of the NWS and the similarly aged Audubon Christmas Bird Count sparks interest in related scientific inquiry, and both now host questions raised by volunteers (Clark and Illman 2001).

Modern meteorology is an observation-dependent discipline where measurements are sometimes estimated and dependent on the microclimate of a particular place. While the NWS Cooperative Observer volunteers all receive extensive training and have ample opportunity to ask questions with their local scientific coordinator, the program values the sheer quantity of observations and information about those observations that can then be measured and compared (Doesken and Leffler 2010). The small-scale and long-term data set is perfectly poised to answer questions of climate variability and directionality, a question that lies outside the life span of any one investigator (Miller-Rushing et al. 2012). Given that the data are mostly requested by businesses, questions asked are inherently applied in a surprising array of places—for example, setting insurance rates for entertainment and determining how rain affects elementary classroom behavior (Doesken and Reges 2010).

As a data-rich pioneer in citizen science, the program was initially structured in the contributory model (a term used in Bonney et al. 2009), where participants feed data to scientist interpreters. As the program developed a direction of its own, it become more collaborative, with volunteers and data users directing research questions and data interpretation. Because the program is largely valued for its longevity, the methodology has remained the same since codification in 1890 and must remain so for comparability (NRC 1998). Therefore, modern knowledge creation is not in adding the millionth data point, but in the uses a comprehensive data set can serve. The longer the program is in existence, the more of these uses emerge from both volunteers and program coordinators—most recently and arguably most importantly, the utility of the data in tracking climate trends for the United States (Miller-Rushing et al. 2012).

Because the NWS Cooperative Observer program developed in an era when citizen science was a normal part of scientific inquiry (Silvertown 2009), it did not face concerns about data quality and trust between volunteers and the scientists that use the data that are common in citizen science today. The program is so institutionalized as a part of American society that many people do not realize the extent to which the data contributes to daily life (Doesken and Reges 2010), accepted as part of the current weather report. The program now depends on crowdsourced cyberinfrastructure, leaving the direction of the program in the hands of users under the ethic "the more the merrier" (Wiederhold 2011). However, a 1998 NRC report determined that volunteers felt "a pervasive sense" that the Cooperative Observer program needs more big-picture oversight to care for long-term data planning and the budget rather than the current scattered, crowdsourced contributions (NRC 1998). Such oversight would open a power dynamic concerning who decides how detailed long-term plans are; a later NRC report decided that designating people and technologies and, in particular, restricting responsibilities is "counterproductive and diversionary" to "fair weather" meteorological science partnerships (NRC 2003: 3).

Ethnobotany

Diverse chemicals lie in the flora of culturally and biodiverse regions of the world. Traditional medicines make use of those chemicals, and bioprospecting new pharmaceuticals from such medicines continues to aid drug development (Heinrich et al. 2009). The most common methods in ethnobotany are interview-based, best paired with visual confirmation from photo elicitation, a "walk in the woods", or garden tours (Thomas et al. 2007). Mistakes and ethical oversights by early bioprospectors led to the development of patchy international agreements through the World Intellectual Property Association and the Convention on Biological Diversity to protect access and benefit sharing, as well as provide for the preservation of these diversity hot spots (Oguamanam 2004). As a result, efforts shifted from merely collecting knowledge of useful plants to modeling cultural transmission of that information as appropriately as possible, for example, by encouraging grandmothers to teach scientists (Wenzel-Geissler and Prince 2009) and performing plays (Mueller et al. 2012) that encapsulate the alternative way of knowing in addition to the knowledge. Ethnobotanists intended these changes to increase respect for alternative knowledge producers and document their learning approaches to increase creative potential in the Western pharmacopoeia. A recent evaluation of the field of ethnobiology determined that the interdisciplinary field "negotiates the spaces between epistemologies and ways of knowing in the world" (Wyndham et al. 2011: 111).

Modern ethnobotany priorities include medicine but extend to larger societal issues, as "ethnobotany's position at the human-environment interface, as well as at the interface between different social groups, knowledge systems and academic disciplines, provides a strategically privileged position from which to engage with many of today's complex social and environmental problems" (Alexiades 2003: 15). Lessons learned from challenges plus the promise of emergent creativity from relationships formed at this interface offer practical hope for solutions to a variety of societal needs (Wenzel-Geissler and Prince 2009). A recent review of *Journal of Ethnopharmacology* articles urges conceptual and methodological requirements for the field as a means of professional practice and successful drug finding (Heinrich et al. 2009). Another review in *Human Ecology* asks whether "ethnobotany as a science has generated any general principles that can aid in the response to this growing demand for answers and solutions" (Albuquerque and Hanazaki 2009: 653). The authors identify five challenges that need to be addressed for the production of new ethnobotanical knowledge: attention to previous literature in ecology and participation, lack of overarching theoretical framework, need to use both qualitative and quantitative data when appropriate, oversimplification of results, and weak links to related disciplines.

The practice of bioprospecting that is inextricably linked to ethnobotany transformed the treatment of alternative knowledge into a "cultural good", traded in financial markets for its moneymaking potential in the pharmaceutical industry, agroindustries, and the Convention on Biological Diversity (Antweiler 1998)—for better (Posey 2002) or for worse (Castree 2003). As shown through a large multidisciplinary study of Kenyan knowledge, this separation of facts and resultant actions assumes a unified underlying reality and ignores that "the effects of knowing change when operations of knowing are moved between contexts" (Wenzel-Geissler and Prince 2009: 601). The Kenyan study also documented that problem solving does not come from better understanding the problem, but in leveraging social relations that determine a system's creative capacity (Wenzel-Geissler and Prince 2009).

Ethnobotany is embroiled in a long-standing debate over cultural preservation and intellectual property rights; on one hand, the knowledge is commodified for meeting development goals, while on the other hand, solidifying property rights contributes to the production of an alienable resource (Antweiler 1998). The very process of using Western intellectual property legislation separates the alternative knowledge from the way of knowing that created it and associated cultural protections and practices (Oguamanam 2004) and, as documented in the Pacific Islands nations, speeds the commodification and appropriation process (Parry 2002). Formed on the heels of serious property rights violations, ethnobiology professional associations view themselves at "the leading edge in the development of ethics theory and practice" (Wyndham et al. 2011: 111). Still, legal scholars posit that long academic and legal debates stifle the very scientific, political, and cultural creativity that motivated development of the field in the first place (Schmidt 2008). Therefore, in places not tied directly to intellectual property agreements, institutions guarding research ethics may provide needed structure to protect alternative knowledge holders (Bannister 2009).

Much of the ethnobotanical literature can be criticized for treating alternative knowledge as a static entity for collection to be put to practical use, but generating new knowledge from these systems requires action research (Antweiler 1998). Like in many contexts, creating new knowledge is where the dichotomy between alternative knowledge and scientific knowledge falls apart; a study of Indian tree management systems found that "diverse primary level practices and secondary level concepts are intermingled in ways that would be difficult to anticipate from separate understandings of the individual knowledge systems involved" (Brodt 1999: 357). Instead, modern developments are pulled from the diverse combined experiences of people working in a particular forest.

Systems Ecology

The scientific realization that humans in a landscape can serve a positive role in landscape conservation (Fairhead and Leach 1996) and the shift away from the model of observing "wilderness" as pristine ecology (Cronon 1996) challenged systems ecologists to theorize an ecosystem with the help of its resident citizens and their values, practices, and worldviews. These developments in the English-speaking world are decades behind similar conclusions in other cultures, most notably among German and Israeli landscape ecologists in the mid-1900s (reviewed in Naveh 1982). Resulting developments spawned a relatively large selection of methods to respectably and equitably solicit and combine diverse ways of knowing with the aim of seeing the complete picture, including cybernetics (Naveh 1982), participatory geographic information systems (GIS; Newman et al. 2011), games (D'Aquino et al. 2003), participatory modeling, including cognitive mapping and qualitative systems dynamics (Mendoza and Prabhu 2006), roundtables and workshops (Luz 2000), Bayesian belief networks (Smith et al. 2007), and causal flow diagramming and other systems dynamics tools (Abel and Stepp 2003). More structured methods attempt to make sense of a complex network of dynamic information that inevitably emerges from a diverse group of thinkers (Mendoza and Prabhu 2006) and contribute theoretically to a science of complex systems, including the study of weather (Abel and Stepp 2003).

A study of the European Union Water Framework Directive described the goals of its adaptive and participatory process as to "think like an ecosystem," harkening back to Aldo Leopold's dictate to "think like a mountain" (Tippett 2005). This and other studies use the ecosystem understanding in a normative way, with the goal of sustainable living—that is, figuring out how best to actively design an ecosystem with its human actors. As a result, in Turkana silvopastoral systems, for example, the participatory description focused on existing positive practices and holistic preventative sustainability measures rather than the typical problem-driven approach (Barrow 1991). Agriculturists also realized the need for new approaches for learning to deal with high uncertainty and interpretive data (Pretty 1995). Fundamentally, however, including humans in systems ecology overturned deeply ingrained beliefs in Clementsian climax ecology and required entirely new theoretical and methodological approaches to the science of ecology (Naveh 1982). Developing this approach is sometimes described as a metaphorical boat traveling between the unknown shores of disciplines and knowledge systems (Cundill et al. 2005).

The systems ecology approach directly values diverse perspectives, recognizing that in the past, incorrect understandings led to negative outcomes. Resilience created through increasing the number of options in water management, for instance, leads facilitators to encourage envisioning the big picture and respecting "the green shoots of new seedlings" that sprout through-out the network of processes in the system (Tippett 2005: 608). In their review of socioecological systems in crisis, Folke and colleagues (2005) found that social institutions enabling collaboration and conflict resolution framed creativity for successful renewal and reorganization in response to the crisis. Collaboration builds trust through creating a new, shared knowledge base that leads to mobilization and self-organization (Lebel et al. 2006).

Research priority setting should be in the hands of participants, so the "expert" in systems ecology research now takes the role of facilitator. In Turkana silvopastoral systems, for example, extension agents filled this role after cultural awareness training (Barrow 1991). In several landscape ecology and planning exercises in Germany, public awareness and participation was necessary to include not only the information from stakeholders but also their worldviews, for a holistic description of the system (Luz 2000). Pulling from participatory agricultural development, Rocheleau (1994: 4) warns that involvement alone is not the answer, citing a need to "broaden our definitions of research and participation, to accommodate a wide spectrum of land users and local knowledges and to expand our repertoire of research methods," going on to describe a number of institutions successful in facilitating this new type of research.

In Queensland, Australia, multiple tools for participatory systems analysis provided an accurate analysis with feasible steps toward improving fire management and identified where areas of new research would provide the most help (Smith et al. 2007). The different types of knowledges (paradigmatic, normative, descriptive, analytic, etc.) that new forms of ecology combine shape a more robust and holistic system for examining and designing the world (Ehrenfeld 2000). Eksvärd and Rydberg (2010) describe through their case of organic tomato production how participatory action research and systems ecology research complement and add to each other through the collaborative learning process in moving toward describing an open, dynamic system and transitioning to a more complex domain of knowledge creation.

Systems and landscape ecology participatory approaches follow closely on the heels of agroecosystem research, which first realized the need for postpositivist methods and created "a whole new professionalism" based around new systems of participatory learning focused on trust (Pretty 1995: 1247). Early ecologists responding to research in emergent properties of complex "biosystems" stated an ethical obligation not to follow reductionist tendencies in ecology to quantify energy flow but to qualitatively describe system structure and information flow (Naveh 1982). There is still a divide as to whether this philosophical shift simply changes the methods associated with the science of ecology, or whether the normative potential of the research necessitates participatory practice (Ehrenfeld 2000).

What Pioneers Teach Us about Methods and Theory for Creative Problem Solving

Each discipline uses different ways of knowing to meet different ends, be that gathering as much information as possible or creating solutions to particular problems. However, more general benefits are shared across approaches. For example, the NWS Cooperative Observer program started with the aim of informing the daily weather reports, but now holds one of the most informative data sets for the understanding of climate change. In ethnobotany, the quest for cataloguing plant chemistry became a route for rural development and began to question the ability to "collect" information free of its cultural context. In some cases, the chemicals identified as potential pharmaceuticals did not work outside the spiritual rituals and preparations meant to deliver the medication (Erlin and Berlin 2004). Each of these cases makes apparent the value of a more holistic view of knowledge, the potential benefits, and the contexts from which it arises.

There are some shared theoretical constructs between the three cases discussed here. For one, the push for integrating types of knowledge feeds into the human tendency to classify ways of knowing to ensure diverse representation, even though these categories are arbitrary and relationships between them complex (Raymond et al. 2010). Whether that classification comes in the form of how knowledge is taken up and formed, like the multiple intelligences of education theory (Gardner and Hatch 1989), or based on the origin's ethical and geographical context, like the place-based classifications of systems ecology (Berkes 2008), each case recognizes that knowledge is rooted in a multiplicity of individual worldviews. Instead of clear divisions between types, these roots of knowledge are tangled, intertwined, and sometimes merge. In his critique of the knowledge divide, Agrawal (1995) describes how naming knowledge scientific or indigenous reinforces power dynamics already present—by dividing types of knowledge and thus allowing one to be placed higher than the other. Instead, these cases illustrate the value of elucidating the structure and relationships among those roots.

Attempts at separating ways of knowing for collection and analysis have made apparent that knowledge is not a stand-alone concept. Our ways of defining and delimiting knowledge itself affects how knowledge is produced, and determines whether creative problem solving will take place. For the NWS Cooperative Observer program, fostering new knowledge involved welcoming as many people as possible to the thinking table, extending from their roots as wide-scale data collectors to the transformative potential of querying that enormous data set from a variety of perspectives. For systems ecology, the theoretical approach started with what constitutes nature and the conceptual links between humans and nature. Through participatory stakeholder approaches and new conceptual structures like ecosystem-based management, ecosystem ecologists reached a similar conclusion in the need for the facilitation of the sharing of diverse perspectives. Ethnobotany pushed a bit farther, in response to critiques of early research practices, to explicitly foster knowledge creation through diverse ways of learning—be that through interviewing grandmothers or putting on plays. All this is based on what education scholars have long told us—that learning for problem solving is inherently a group effort, involving multiple pedagogies for the transfer of information and the explicit development of both new knowledge and the links between existing knowledges. Despite this readily accessible foundation, each scientific discipline independently rediscovered the need for participatory, collaborative, coproduction of knowledge, to both see the whole picture and develop new knowledge. Understanding the basis of knowledge production should then dictate what methods must be used to move forward in the field.

The case studies show that in order to effectively coproduce knowledge and solve real problems, the following considerations are crucial: to show appreciation for the value of diverse ways of knowing; to not compartmentalize knowledge in a culturally inappropriate manner; and to define ethical practices and expectations for those involved in knowledge production. Each discipline may have their own methodological requirements, but these three practices cut across all three cases described, and each would help future efforts at utilizing coproduction of knowledge, avoiding the pitfalls of the past.

It is important to remember that these different disciplines put effort into thinking about different ways of knowing not out of an ethical commitment to be inclusive but because they receive direct benefits as a community of scholars through the increased number of intellectual possibilities made available by diverse perspectives. To a certain degree, the question then becomes, is there a systematic, culturally appropriate way to express appreciation for that value and somehow compensate the knowledge holders? For the NWS Cooperative Observer program, the value in a large-scale citizen science project is in the possibilities offered by such an undertaking: the products of the research become something larger than any one individual within it, be that a citizen participant or scientific analyst, placing appreciation on the founders of the program and the potential useful discoveries of the future. In systems ecology, the potential value is in increasing resilience in the face of ecological crisis through an increased number of adaptation options derived from multiple worldviews and perspectives of the ecosystem. In ethnobotany, the value of biodiversity becomes a proxy for a list of potential disease cures. Through field experiences, ethnobotanists have also come to value the cultural contexts that created traditional medicines and the creativity and pharmaceutical potential emergent in the network of people thinking about plant chemistry. For each field, a plethora of options on the table and acceptance of different perspectives and ways of learning are key; this is a move away from a standard research approach toward triangulating "truth" from a number of different paths.

Lessons from the search for transformative learning tell us that spirituality, culture, and worldview are all part of the learning process and continue to shape interpretation of knowledge (Ettling 2006). Similar lessons emerge in systems ecology as practitioners realize people do not cleanly divide the scientific from the spiritual or political (Mueller et al. 2012). Ethnobotany, through seeking out alternative knowledge, changes the way we think about knowledge systems and makes a case for recognizing the particularistic and fragmented logic originating from just a single cultural context, with lessons to be learned on both the knowledge holders' side and the scientific side (Kothari 2002). Even the earliest of these cases, tracking weather data, has evolved into something more complicated than simply recording rainfall and temperature, tracking urban development patterns for microclimates, contributions to climate change, and a plethora of other details, as participants see necessary. Information, especially with the aim of solving complex problems, cannot be compartmentalized by topic or discipline. To this end, the existing practices of these pioneering scientific disciplines suggest that all knowledge types and ways of learning can and should be incorporated into research from the beginning, from problem definition, through the end goal of knowledge contribution, to a coproduced solution.

The most important methodological conclusion resulting from the lessons of early coproduced knowledge is the intentional attention to ethical practices that are needed as both a matter of procedure and to ensure legitimate results. This is also where shared expectations across disciplines are useful from the participants' perspectives (who may not see the divisions of the ivory tower as clearly as academic researchers). The NWS Cooperative Observer program is as inclusive as possible and has been from the origin of the program. While they have succeeded in ameliorating issues of access, the large number of diverse participants with different reasons to participate creates a data management challenge and questions whether some participants and their data may get lost in the shuffle. In systems ecology, the ethical push is for researchers to shift their science philosophy past positivism and include multiple methodologies to capture the multiple ways of transmitting information, especially participatory and collaborative methods. In ethnobotany, the role of ethics was the most overt, and is now institutionalized in the form of intellectual property and research agreements for each project, as expected by a professional code of ethics. Though each field determined their standards of ethics differently, they share a call for attention to diversity in learning styles and underlying worldviews and seek fair and equal treatment for all ways of knowing as a means of showing the value of their contributions.

Conclusion

The epiphany that knowledges outside of professional science have something to offer is just a first step, soon followed by scholarship on the nature of knowledge itself, how it is learned, measured, and recorded. Successfully incorporating diverse ways of knowing requires a philosophical shift in what constitutes expertise, how research is conducted, and the nature of research relationships. In the environmental sciences, there is ample evidence that different ways of knowing can be successfully incorporated into research, so long as someone consciously thinks about the best form of integration, that is, through coproduction of knowledge and careful attention to context. Examples emerging separately at different points in time to meet a variety of scientific needs show that not only can knowledge be successfully integrated, but the efforts at integration pay off in terms of creative approaches to environmental problem solving.

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