Bridging the Divide:
Incorporating Local Ecological Knowledge into U.S. Natural Resource Management

by

Alexis Schulman

B.S.E., Environmental Engineering (2004)
Princeton University

SUBMITTED TO THE DEPARTMENT OF URBAN STUDIES AND PLANNING
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER IN CITY PLANNING

AT THE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

September 2007

Author____________________________
Department of Urban Studies and Planning
August 17, 2007

Certified by________________________
Professor Judith A. Layzer
Department of Urban Studies and Planning
Thesis Supervisor

Accepted by________________________
Professor Langley Keyes
Chair, MCP Committee
Department of Urban Studies and Planning

ABSTRACT

For the past 100 years, natural resource management in the United States has reflected a belief that the top-down application of science to predict and control the natural world will, in the words of Gifford Pinchot, the Nation's first head of the U.S. Forest Service, "support the wise use of the earth and its resources for the lasting good of men." However, over the past two decades, a growing number of critics have challenged the technocratic optimism of this "conventional management", arguing that the public should be more deeply engaged in the decision-making that drives natural resource management and policy. Part of the rationale for this argument is based on the growing recognition that Western, scientific management has discounted the value of local ecological knowledge (LEK), a system of knowledge developed over time through observation and interaction with the natural environment. Although advocates have expounded the benefits of using LEK, in practice, LEK is rarely integrated into the scientific assessments that drive management decisions.

To understand what affects whether or not LEK is incorporated into management science, this thesis examines: 1. What are the particular barriers to integrating LEK into management science? 2. When LEK is integrated into management science, why is it used and how are specific barriers to its use overcome? These questions are addressed through an intensive examination of two U.S. cases: the Sonoran Desert Conservation Plan in Pima County, Arizona and the evolution of fishery management science in the New England groundfishery. This study confirms academics and practitioners' claims that a major barrier to incorporating LEK is a "language" divide: LEK is rarely presented in scientific terms and thus it is difficult for scientists to understand its relevance or confirm its accuracy. Furthermore, scientific studies are often too complex for untrained locals to understand and thus engage with. However, this study also reveals that conflicting interests and values between scientists and bearers of LEK are not only common in resource management, but also significantly discourage knowledge exchange by embedding risk in the very acts of eliciting and divulging LEK. Furthermore, although individuals who are able "translate" between the local and scientific communities can overcome the language divide, interest and value conflicts are rarely overcome by similar translation. Instead, this analysis suggests that incentives must be created to encourage the sharing and eliciting of LEK and outweigh the associated perceived risks. Collaborative research programs in the New England fishery provide one such model. Based on these findings, recommendations for improving knowledge sharing and incorporating LEK into natural resource management are made.

CONTENTS

ACKNOWLEDGMENTS

Foremost in the frighteningly long list of people to whom I am extremely grateful is my advisor, Judy Layzer. Although I doubt I can ever thank her enough, I am grateful for the constant flow of wise input, review, conversation, and guidance she provided while I brainstormed, researched, and wrote this thesis. I am equally grateful for her patience, pragmatism, and humor throughout; it has all meant a great deal to me.

I was also fortunate to have as a reader Larry Susskind, whose spot-on insights helped hone my thinking and writing on this topic, as well as the enthusiastic support and advice of Herman Karl and Charles Curtain. I am further indebted to the MIT-USGS Science Impact Collaborative for its support and the many opportunities it afforded me over the past two years.

The number of people who sincerely and graciously shared their experiences, ideas, and even homes with me during interviews was staggering. Thanks to them all. In particular, thanks to Pima County's Julia Fonseca, Bill Shaw, Maeveen Behan, Linda Mayro, Pat King, Mima Falk, Phil Rosen, Dennis Caldwell, Beryl Baker, Cecil Schwalbe, Carolyn Campbell, Kerry Baldwin and Paul Fromer (in San Diego). Many thanks up and down the New England coast to Madeleine Hall-Arber, Cliff Goudy, Ted Ames, James Wilson, David Goethel, James Acheson, and the crew at the Cape Cod Commercial Hook Fishermen's Association.

In the event that my copious references to his work *Seeing Like a State* do not make my intellectual indebtedness clear, I also wish to thank James C. Scott, who I do not know, but would like to thank for writing his brilliant book and inspiring me as well as this line of research.

Finally, to my mom and dad, and Chrissy...Words cannot begin to express my love and gratitude; thank you for all you are and all you have been. And to my oldest friends, Corinne, Sarah, and Juan (who took care of me in the rough spots), and to some of my newest, David, Timmy, and Sharlene (who kept me sane and laughing): my deepest love and thanks.

The next necessary thing...is neither the construction of a universal Esperanto-like
culture...nor the invention of some vast technology of human management.
It is to enlarge the possibility of intelligible discourse between people
quite different from one another in interest, outlook, wealth, and power,
and yet contained in a world where tumbled as they are into endless connection,
it is increasingly difficult to get out of each other's way.

—Clifford Geertz, Local Knowledge: Further Essays in Interpretive Anthropology

INTRODUCTION

Local Ecological Knowledge: The Promise

For the past century, natural resource management in the United States has reflected a belief that the top-down application of science to predict and control the natural world will, in the words of Gifford Pinchot, the Nation's first U.S. Forest Service head, "support the wise use of the earth and its resources for the lasting good of men" (Pinchot, as cited in Ward 2000, 327). However, over the past two decades, a growing number of critics, including many scientists, have challenged the technocratic optimism of this "conventional management". They contend that conventional management has not accomplished what it promised; it has not been able to sustain both the healthy functioning of natural systems and humans' use of their resources. Instead, ecosystem health is steadily declining: biodiversity continues to decrease and landscapes are degraded, while conflict and litigation frequently overwhelm management decisions. Critics fault conventional management for creating these conditions with policies that overlook and are unresponsive to local social and ecological nuances and system interrelationships and an undemocratic reliance on scientists to develop "rational" solutions to environmental problems that inherently require the consideration of values and equity (Ludwig 2000).

Many academics and activists now argue that the public should be more deeply engaged in resource management decision-making (Backstrand 2000, Fischer 2000, Walker 2002). Part of the rationale for this argument is based on the growing recognition that Western, scientific management has discounted the value of local expertise—often to the detriment of the unique social and ecological system being managed (Fischer 2000, Scott 1998, Wynne 1996). Since anthropologists first began to study the knowledge systems of indigenous cultures in the third world, it has become clear that many local communities have extensive ecological expertise—a system of knowledge developed over time through observation and interaction with the natural environment. Studies have found that this local expertise, or "local ecological knowledge" (LEK), does not reside only with indigenous communities, but also with non-indigenous, resource-dependent ones, such as farmers, ranchers, and fisherman, as well as observant individuals. Proponents of integrating LEK into management's knowledge base have offered a three-fold argument. They suggest that it can improve the understanding of local ecological and social conditions, producing management decisions and policies that are more responsive to these conditions, offer models of adaptive, sustainable resource use, and quell some of the conflict and mistrust that arises when local expertise is ignored and discredited as "anecdotal".

Thesis Questions and Methods

While much has been written about LEK in theory, some scholars have noted that LEK is rarely used in practice (Huntington 2000), and others have argued: "the challenge now is to move beyond the seeming preoccupation with theoretical issues to a substantive engagement with the applied issues" (Davis and Wagner 2003). Indeed, there is a dearth of literature related to the application of LEK in resource management, particularly in the United States, where regulatory mandates present a very different arena for "using" LEK than that of rural development in the third world—on which most LEK research has focused. In the United States, numerous independent agencies, from the Environmental Protection Agency to the United States Forest Service, are charged with regulating and managing the U.S. environment. However, as Ozawa (1996) notes, even the oldest of these agencies has been "built on the assumption that certain types of decisions ought to (and could) be based on technical expertise, not politics." Since the early 1900s, congressional legislation, directing and constraining agency rulemaking, has translated this assumption into law; enabling statutes often require that agencies regulate using the "best available science," while corresponding acts "make explicit reference to the technical basis for decisions" (Ozawa 1996). Litigation and judicial review, which frequently entails a "hard look" at the "rational" and evidentiary basis of regulations, has further reinforced the need for agencies to support their rules with meticulous scientific and technical arguments (Jasanoff 1995).

Thus, for LEK to be perceived as useful and legitimate for policy formation and management rulemaking, LEK would have to be incorporated into a scientific framework—one guided by established scientific methodology that, generally, entails observing a phenomenon, formulating and testing hypotheses for the phenomenon, and recording the process. This raises a host of largely uninvestigated, applied questions, two of which I take up in this thesis: First, given the claim that LEK is rarely used in practice, what is preventing scientists from using it? Specifically, what are the particular obstacles to incorporating LEK into management science? Second, when LEK is used, why is it used and when specific obstacles to its use are overcome, how and why does this occur?

I address these questions through an intensive examination of two case studies. The first is the development of a conservation land system for the Sonoran Desert Conservation Plan (SDCP) in Pima County, Arizona. The second is the evolution of fishery management science in the New England groundfishery. I chose these cases for several reasons. First, they exhibit similarities in several important dimensions. In both cases management science purportedly drew on LEK, but, in each, scientists also disregarded either a particular "type" of LEK or all LEK for some period of time. Both cases concern regions of comparable size; and in both cases the relevant scientific studies have been completed in the past few years, leaving some time for the dust (and heated emotions) to settle. Furthermore, the cases are different in theoretically important ways. They involve very different organizational and decision-making structures. In addition, participants used opposite strategies to manage the potential politicization of the science: in Pima County, scientists remained scientifically insulated, while fisheries scientists embraced collaboration. These difference allowed me to explore some of the reasons LEK, or certain types of LEK, was or was not used, what variables affected how it was used, and what impacts it had—or participants perceived it to have—on the science.

Because LEK does not represent a codified system of knowledge, is rarely written down, and may not be discussed in reports or papers, to answer my questions I drew substantially on information revealed through semi-structured interviews. This was particularly true for the SDCP, where I held hour -long interviews with twenty representatives of all relevant parties, chosen through snowball sampling. Information gleaned from interviews was confirmed through interviews with other participants, as well as with other primary sources, such as technical documents and reports. The New England fishery case, on the other hand, has of late become the poster child for the use of

LEK in U.S. resource management. To analyze this case, I relied more on documents, such as scientific studies and reports, and secondary sources, which were more abundant than for the SDCP. However, I also included semi-structured interviews with sixteen key informants for methodological detail and personal perspectives that were not always available in the formal documentation.

Road-Map

Through this thesis and the case study analysis in particular, I argue that, when it is achieved, the incorporation of LEK into management science does provide the benefits and impacts discussed in theory. However, I find there are two major obstacles to the incorporation of LEK into resource management science, which, to be overcome, require very different approaches. Confirming the literature on LEK, the first obstacle is a "language" divide that frequently exists between scientists and bearers of LEK. In the sense I use it, this language divide not only refers to the differences in the terminology that scientists and locals may use, but also the potential differences in their conceptualizations and representations of ecological systems and the methodologies they use to learn about those systems. Put simply, this divide makes communication, and thus knowledge sharing, between scientists and locals extremely difficult. It prevents scientists from recognizing the relevance or accuracy of LEK, as LEK is seldom acquired or presented scientifically. With limited time and research budget, scientists rarely can afford to invest energy in understanding and confirming LEK, particularly when its relevance or accuracy is uncertain. From the perspective of untrained locals, scientific methods and assessments are often too complex and time-consuming to understand, which stymies their attempts to engage productively in the research. The two cases, however, suggest that an effective way of overcoming this language divide is through a "translator." Such an individual is familiar with and operates in both the local and scientific communities, perceives the relevance of certain LEK, and can facilitate its incorporation into a scientific framework.

The second obstacle, I argue, is infrequently discussed in LEK literature and is that of conflicting interests and values systems: it is not always that case that scientists and the bearers of LEK have the same goals, priorities, and world views as relates to natural resources. In fact, in U.S. natural resource management this is often the case; scientists are frequently precautionary and conservative in their assumptions and recommendations, while the communities with the most extensive LEK are extractive resources users, who are often more utilitarian in their values and also resistant to efforts that might limit their use and extraction of the resource. The cases analysis shows how knowledge sharing between scientific and local communities with conflicting interests then becomes a potentially political, personal, and thus risk incurring, exercise. By working with critics, or drawing on their LEK, scientists fear that their research will be politicized and discredited. Furthermore, when resource users feel threatened by scientists, due to conflicting interests, they are less likely to offer their LEK—particularly if is sensitive information that later might be "used against them." I suggest that the interest divide is far more difficult to bridge than the language divide and as risk is embedded in the very acts of eliciting, divulging, and using LEK; it cannot be overcome through an intermediary translator. Instead, it requires someone or some institution to shift the pre-existing incentive structures—so that benefits of cross-community work outweigh the associated risks.

I present this argument as follows: In the first two sections, "Enlightened Management" and "Local Ecological Knowledge," I provide context for this thesis and its two core questions. The first sections focus on the origins and ideologies of scientific management and its influence on U.S. resource management. It also presents the critiques of conventional management and the rationale for recent calls for public participation in management science. The following section builds on this argument, and introduces one form of this participation: the integration of local ecological knowledge (LEK). It reviews research developments on LEK as well as current theories and literature that provide the theoretical context for rest of the thesis.

I then present the first of two case studies: the development of a "Conservation Land System" (CLS) in Pima County, Arizona. This case demonstrates how scientists were able to design a more accurate CLS by incorporating the LEK of individuals with varying levels of connection to the scientific community. However, the case also shows how scientists determined what LEK was useful and credible by defining an expert community, based on a shared scientific language as well as common conservation interests and values. Through the scientists' interaction with non-expert bearers of LEK, the case shows how language and interests presented challenges to LEK's integration with management science. Finally, it shows how expert translators were able to bridge the language divide between the scientific and local communities, but also shows that the risks associated with conflicting interests, as seen in the scientists' interaction with local ranchers, cannot be overcome through translation.

The second case study, "The New England Groundfishery," examines role of LEK in fishery management throughout the latter part of the 1900s, as groundfish stocks in the Gulf of Maine declined precipitously. The case demonstrates how advancements in fishery science and technology and increasingly precautionary science and rulemaking, created both a language and interest divide between fishermen and scientists that prevented fishermen's LEK from being incorporated into management science. The case further shows how these divides have been, and are being, bridged. As seen in the Pima County case study, this case demonstrates that an individual with a foot in both the local and scientific world can act as a translator between the two communities' knowledge bases. However, unlike in Pima County case, this case also begins to provide a model for how interest conflicts between scientists and locals can be overcome through the example of collaborative research initiatives, which have provided incentives for collaboration and aligned scientists and fishermen's goals in joint research projects.

In Chapter Six, I reiterate my finding, discuss their implications, and make policy recommendations for how LEK might elicited and incorporated more effectively into natural resource management.

ENLIGHTENED MANAGEMENT

Questioning Convention

In 1993, Ludwig et al. published an innocuously titled article, "Uncertainty, Resource Exploitation, and Conservation: Lessons from History" in the prestigious *Science* magazine. Six years earlier the Brundtland commission had established "sustainability"[1] as the new development and resource management paradigm, and scientists were already scrambling to put the concept on a "sound scientific footing" (Lele and Norgaard 1996). Citing management failures, from depleted fisheries to agricultural environmental disasters, Ludwig and his coauthors rejected the premise that scientists could provide answers to the environmental problems that faced society or dictate the path to sustainability, as many policy makers were asking them to do.

The article hit a nerve. The New York Times covered it ("Biologists Fear Sustainable Yield is Unsustainable") and the journal Ecological Applications dedicated an entire issue to reactions from the ecological community. Some scientists responded warily, cautioning against "throw[ing] the research baby out with the gridlock bathwater," pointing out that science is essential to environmental problem solving and should not be dismissed (Policansky 1993). But, at its core, Ludwig's article was not arguing against the value of science, but against a Western ideology that had privileged technical know-how to the exclusion of other forms of knowledge, squelched democratic debate with scientific reasoning and solutions, and attempted to manage uncertain natural systems with false precision. And, if the response from the ecological community was any sign, many scientists were beginning to agree: the conventional approach to management wasn't working.

---

[1] Sustainability, in the context of development, recognizes that social and economic well-being operate within the environmental well-being. It is not a purely an environmental concept – indeed its vision is to "explicitly link science with a moral framework rooted in the tenet of intergenerational equality" (Sarewitz 2000), which made attempts to strictly translate it into "definitions, criteria, and indices" was, to many, all the more baffling (Lele and Norgaard 1996).

The Enlightenment and “High Modernism”

The ideology that Ludwig et al. (1993) implicitly references can be traced back nearly three hundred years in Western history. It is generally agreed to have arisen in the Enlightenment, the philosophical and intellectual movement of 18th century Europe and America, which is itself closely linked to the Age of Reason (17th century) and the Scientific Revolution. During these centuries, great scientific minds like Galileo, Kepler, Newton, and Leeuwenok, the father of microbiology, used developing telescopic technology to study the planets; mathematically described the motion of orbiting bodies; established fundamental natural laws, such as gravity; and uncovered the existence of microorganisms with powerful new microscopes.

Enlightenment thinkers sought to combine these advances in science and technology with the power of the rising nation-state. The ideology was most pronounced in the writings of Auguste Comte, who argued that the only authentic form of knowledge was acquired through scientific methodology, as well as Saint-Simon, who envisioned a technocracy, in which scientists, above and removed from the messiness of the political process, would lend their knowledge to “those most capable of steering humanity’s progress toward the new industrial order: engineers entrepreneurs, and banker-financers who would build it; the artists writers and musicians who would serve as its ideologues; and the political leaders who would wield their baton over the whole ensemble” (Friedman 1987, 52).

The anthropologist James Scott refers to this technocratic ideology as “high modernism” (Scott 1998). He describes it as “a faith that borrowed, as it were, the legitimacy of science and technology. It was, accordingly, uncritical, unskeptical, and thus unscientifically optimistic about the possibilities for the comprehensive planning of human settlement and production” (Scott 1998, 4). Although some high modernist visions have a distinctly elitist, if not outright authoritarian, bent, the faith itself (in the cooperation of expert knowledge with government power to improve the human condition) is not necessarily undemocratic. In theory, the so-called experts are subordinate to the political process, so their power is always checked by the people (Fischer 2000, Brint 1994). However, when this check is removed— when the expert analysis is privileged as the only authentic knowledge or vision—and the government uses its power to see this vision through, high modernism becomes more troubling for several reasons.

First, if expert-driven, "rational administration" supplants political deliberation, then the "politician [becomes] at best something like a stopgap" (Habermas 1970, 64). Thus, in addition to being excluded from the deliberations of "experts," citizens cannot exercise political influence through their elected officials. Not only does such governance oppose the tenets of a representative democracy—elected officials acting in the people's interests—as Fischer (2000, 14) argues, it also "opens the door to increasingly sophisticated forms of expertocracy that offer fewer and fewer opportunities for meaningful public deliberation."

Second, part of what has made the scientific approach to knowledge production so incisive is a "reductionist" conceptualization of the world. That is, the scientific approach often takes as a given that any system can be decomposed into an array of its fundamental elements and processes. To uncover what these elements and processes are, and how they influence the system, scientists apply the "scientific method" to rigorously test conjectures about how the system components work. In theory, knowledge is derived through reason and objective analysis, and its legitimacy is premised on its ability to be falsified (Popper 1965). Therefore, the reductionist approach requires reducing "reality into describable component parts" and decontextualizing these components (i.e. ignoring "processes of interaction") to reveal system understandings or "laws of nature" that are independent of place and time (Sarewitz and Pielke 2000). Although these qualities of reductionism have allowed humans to develop knowledge and technologies that were previously unimaginable, when reductionist science has been unskeptically applied with the utilitarian interest of controlling the complex natural world, these very same qualities frequently have become liabilities.

Germanic Scientific Forestry: A Disaster in Reductionism

There are numerous examples throughout history where the top-down application of reductionist science to "better" society has failed miserably. One case, recounted by Scott (1998), begins in Prussia and Saxony in the late 18th century, at the origin of scientific forestry. At this time, the application of scientific knowledge to the harvesting of wood was part of a larger scheme to "reduce the fiscal management of the kingdom to scientific principles that would allow systemic planning" (Scott 1998, 14). Before scientific forestry methods were introduced, harvesting was a disorganized and inefficient affair: the forest maps were incomplete or outdated, it was very difficult to locate to the most valuable trees, and some of the most economically important stands were being degraded. As the resources became scarcer, officials sought to organize the process. With the utilitarian interest of achieving the highest sustained yield (what in modern management is termed a "maximum sustained yield"), forest scientists surveyed, tagged and transformed the forest trees into tables for measurement and calculation. Taking the scientific approach even further, whole new forests were planned and planted—many in place of older, mixed-species forests—to further simplify the practice, allowing greater control and maximization of output. A linear matrix of only commercially valuable trees were planted; a narrow vision of the forest, which excluded all elements outside the managers' immediate interest, was created in flesh. Anything disruptive of this uniformity, such as underbrush, fire, or "local populations", was perceived as a threat to management. As Scott (1998) also notes, this regimentation did more than make calculations easier; it facilitated centralization of management by removing the need for "discretion," based on experiential knowledge built up over time, which managers and harvesters relied on to maneuver in the old growth forests. In this way, "relatively unskilled and inexperienced labor crews could adequately carry out its tasks by following a few standard rules..." (Scott 1998, 18).

At first the program worked beautifully, producing the predicted high yield of timber, while reducing harvesting effort; all of which reinforced the foresters' efforts. But after the first 100 years (essentially the first rotation) insects, fire, and poachers, some of the natural and social elements that managers had tried to keep out, had crept back in. And the very successful exclusion of other elements, such as detritus and non-commercial species, actually made the forest weaker. Lack of ground litter decreased the occurrence of certain plants, animals, and microorganisms essential to soil building and nutrient cycling, and the homogeneity of the species meant that if several trees acquired a disease or parasite, the entire forest was put at risk. Furthermore, adverse weather—storms, drought, floods—whose effect would be dampened in a diverse forest, had far more destructive consequences in the monoculture. In some cases, this severely lowered productivity; in others, the result was massive tree death (Scott 1998).

Although the birth of German scientific forestry is an extreme example (and in retrospect, the science may look very naïve), it illuminates the potential trouble in top-down applications of reductionist science to control complex natural systems. The forest was simplified; the elements of commercial interest were decontextualized; and the local nuances, which actually made the forest function, were lost. The scientific forestry program initially succeeded in maximizing production, "ultimately, however, its emphasis on yield and paper profits, its relatively short time horizon, and, above all, the vast array of consequences it had resolutely bracketed came back to haunt it" (Scott 1998, 21).

U.S. Resource Management and the Enlightenment Program

Even as the environmental and economic costs of projects such as Germany's tree farming became apparent, the ideologies of Enlightenment thinking remained extremely persuasive and influential. In the U.S., they cast a long shadow over resource management, which became a serious concern in the late 1890s as expansion and settlement gave way to intensive and unregulated resource use. Degradation of forests, range and agricultural lands as well as severe over-hunting of wildlife spawned the first conservation movement, in which early modernist ideals were given new life in the vision of Gifford Pinchot. The nation's first professional forester, Pinchot trained in France at a school that followed German forestry techniques and curriculum (Scott 1998). On his return to the States and subsequent appointment as first head of the Forest Service, Pinchot articulated a "wise use", utilitarian ethic, reminiscent of the early German foresters. On forestry, he wrote:

> [it] is tree farming…to make the forest produce the largest possible amount of whatever crop or service will be most useful, and keep on producing it for generation after generation. The forest, rightly handled—

> given the chance— is, next to the earth itself, the most useful servant of man (Pinchot 1910, as cited in Meine 1995, 11).

Pinchot's brand of conservation characterized nature as something "to be...actively manipulated by scientifically informed experts to improve and sustain yield. How then, to live on a piece of land without spoiling it? By strengthening the oversight role of government, enacting science-based regulations and resource management practices..." (Meine 1995, 12).

By the 1930s, the young science of ecology was demonstrating that the natural world was not merely a "collection of...useful, useless, and noxious species arrayed upon an elemental landscape of soils and waters. Rather it was a vast, intricately organized and tightly integrated system" (Calicott 1991, as cited in Meine, 21). Such developments spurred some managers to argue for a new, interdisciplinary approach to natural resource management. However, before such concepts could take root in the agencies, World War II and the Cold War intensified and entrenched the early high modernist visions. Through World War II, science and technology had become a military, thus government, enterprise and at the war's end it continued to be—not only in terms of providing weaponry, but also as a font of knowledge and expertise to sustain U.S. military and geopolitical dominance (Sarewitz 2000). In 1945, Vannevar Bush's report to Roosevelt, *Science, The Endless Frontier*, encapsulated the technocratic optimism of the era and its new vision for science, governance, and society. In it, he laid out a top-down organization for science, with more responsibilities to and support from government, impacts on all levels of government, and benefits that would span society. The U.S. program for science that congealed during the Cold War has been termed the "Enlightenment program" for good reason, as it "prescribed the linking of scientific knowledge about the laws of nature to the technological control of nature of itself for the benefit of and progress of humanity" (Sarewitz 2000).

In resource management, the widespread faith in technology was internalized in practice. The methods (so-called "conventional management") employed across agriculture, forestry, fisheries, and range management reflected the confidence in using science and technology to meet the needs of a burgeoning post-war population.

Management relied on large-scale, technological fixes, applied with an intense, tunnel-visioned focus:

> …to improve agricultural productivity, expand and intensify farm operations using fertilizers and pesticides, a limited number of "modern" seed varieties, and an ever growing array of "labor-saving" technologies; to improve range forage production, remove woody vegetation, apply herbicides, and seeds with more "desirable" forage species; to build up stocks of fish and game, introduce exotic species and expand artificial propagation programs (Meine 1995).

Other strategies included the calculations and enforcement of a maximum sustainable yield—a certain number of species or amount of a resource to be withdrawn in a sustained fashion over a certain time period; in the case of wildlife protection, management focused on reducing predators to levels that would support a rebound in another population of interest and value. In turn, this required simplifying the natural environment: narrowing the focus to only several species and indices of interest. In the process, other essential elements, such as the impacts of habitat quality, spatial and temporal scales, and other inter-species linkages, were ignored. The management foundation laid by Pinchot grew stronger and the original technocratic vision narrowed even further, and was reified in related agency mandates, policies, and laws, which required, for example, that management decisions be based on "best available" science. The pre-war interest in holistic, interdisciplinary management vanished from the scene.

Legacy of the Enlightenment Program in U.S. Resource Management

As in 1930s, dissenters rose up in the latter part of the century to challenge the technocratic status quo. In the field of resource management, by the late 1980s and early 1990s the cracks in the system were beginning to spring leaks (Miller 1985, Lele and Norgaard 1996). While the utilitarian "maximization" objective of management is now being replaced with the supposedly more environmentally protective goal of "sustainability", the tools and ideologies of enlightenment era management have proved largely resistant to forces of change. However, conventional management is failing on a number of fronts.

Conventional management rests on a three major assumptions, of which all have been called into question. The first is that reductionist science can decompose the inner workings of natural systems, and managers can, and should, apply the resulting knowledge to predict and control nature. As the science of ecology (and related fields, like systems biology, landscape ecology, conservation biology, and so forth) has developed, what has become *most* clear is not how nature works, but how very complex it is, and how naïve the dream of reducing it to its supposed fundamental parts (Williams 1997). Furthermore, at the large scales at which management works, the top-down application of scientific knowledge and "universal" principles has often forced a very problematic and deleterious simplification of the unique system being managed. In this way, local nuances, interrelationships, and inherent scientific and system uncertainty are overlooked or simply ignored.

A second assumption is that the management issues facing society are purely scientific and technical in nature. Pretending for a moment that science could lift nature's veil and reveal its inner workings, conservation and management challenges cannot be reduced to a biological or economic calculus. They are political, economic, and social, and thus ineluctably linked to values, equity, and social justice (Ludwig 2000). There are very human decisions to be made in establishing goals, priorities, and weighing trade-offs. Take the concept of sustainability; As Lele and Norgaard (1996) point out, any meaningful definition of sustainability must define "1. What is to be sustained and at what scale, and in what form? 2. Over what time period and what level of certainty? 3. Through what social process and with what trade-offs against other social goals?" Although science is critical to informing such decision-making, over the past century policy makers have essentially asked scientists and their science to supplant the democratic deliberation that these problems demand, and to depoliticize issues and decisions that are inherently political.

Third, conventional management assumes that the natural sciences used to make and justify management decisions are objective, rational, and apolitical. However, to further complicate matters, science has been revealed to be something less than a purely objective, value-free inquiry. In the face of uncertainty, scientists' models of the world must be a combination of well-understood knowledge (with general scientific consensus) and other informed, but subjective "guesses" (Lele and Norgaard 1996). Indeed, at nearly all levels of the scientific process, judgments are made regarding which methods and assumptions to use, as well as how to interpret the results. While scientists may strive to be objective, many of these choices cannot help but be personal, related to discipline, values, social position, even gender (Lynn 1986, Zuckerman 1988).

Due in part to these flawed assumptions, conventional management has been unable to stem the steady decline of environmental quality and ecological services. Furthermore, the exclusivity of conventional management's decision-making processes has often failed to produce the voluntary compliance that its policies depend on. Instead, science-based management has engendered public backlash and political gridlock. As both the language and methods of science have become more sophisticated and less accessible to the layperson, opportunities for non-experts (i.e. the majority of citizenry) to inform decision-making are increasingly limited. As Fichser (2000, 18) notes there is a "subtle, apolitical form of authoritarianism in this technocratic strategy. When...expert solutions are legitimated as rational, efficient, and enlightened, it is not easy for their unwilling recipients to resist their application."

Although it may not be "easy", those impacted by but excluded from management decision-making *have* developed methods of resistance. One highly successful approach is to attack, challenge, and manipulate "the scientific understanding of the problem" (Layzer 2006). Science becomes one of the few legitimate—and often most powerful—bargaining chips available, and advocates who disagree with the implications and interpretations of the science exploit scientific uncertainty; they present rivaling data and experts who will challenge the science, often in court (Murphy 1991, Noss and Cooperrider 1994). In short, a dispute over scientific uncertainty is a surrogate for an underlying value debate "about the preservation of the environment and the distribution of benefits of industrialization" (Sarewitz 2000).

Management science is also frequently rejected or resisted by the people "on the ground"— by the ranchers or the fisherman who use the land and water—for another reason: it is at odds with their own understanding of the natural system (Weeks and

Packard 1997). Those who promote conventional management on the basis of its technocratic authority, tacitly presume that scientific knowledge is the pinnacle of human knowledge and that other forms of know-how that are not derived or confirmed through scientific methods, are more "primitive" or irrational, and therefore less legitimate and even useless to management. Therefore, many scientists and policy makers attribute arguments over the validity of management science to "misunderstanding." They adopt what has been termed a "deficit model:" the users are confused and don't understand the science; they propose public education in science as a remedy (Petts and Brooks 2005). Misunderstanding should never be ruled out. However, in many cases certain communities have legitimate disagreements with the science and even more accurate understandings of the local system, but are written off as ignorant, leading to divisive conflicts and misguided management (Wynne 2000).

LOCAL ECOLOGICAL KNOWLEDGE

Civic Science

Given the environmental, social, and political problems incurred by conventional, scientific management, some academics and activists argue that to improve decision-making, public participation in science—in problem formulation, selection of methodology, and interpretation of results—is essential. For example, Backstrand (2000) urges that environmental decision-making be "reframed to include the triangular interaction between scientific experts, policy-makers, and citizens."

The term "civic science" has developed as an umbrella term for whole range of participatory approaches to science, whose goals, methods, and outcomes are variable (Backstrand 2000). On one end of the spectrum, civic science is an attempt to increase public understanding of science, or open up its methods for citizen review and scrutiny. On the other end of the spectrum, it is citizens and members of a community actually engaging in research. In "participatory research," community members work as equals with practitioners to define what the problem is, what methods will be used to address it, how the data will be analyzed and interpreted, and how the results will be used (Fischer 2000).

It is difficult to trace the citizen science movement to any one origin. In the third world, it developed reactively against the imposition of western technologies over the past half-century. It is part of a larger resistance to a forced "modernization" that has been detrimental to the environmental, economic, and social fabric of many rural communities. In this context, civic science, and participatory research more specifically, is a tool for challenging dominant expertise, shifting the balance of power, and producing knowledge that is relevant to a community's needs (See: Sillitoe et al. 2002).

In industrialized nations there are have been similar movements with similar motivations. A large number of these cases are in the field of epidemiology, the study of how and why disease is distributed in human populations (Corburn 2003, Corburn 2002, Fischer 2000). One of the best-known cases of U.S. participatory research, recounted in the book "A Civil Action," occurred in the late 1970s, in Woburn, Massachusetts.

Perceiving a link between toxic waste that had contaminated several of the town's drinking wells and high levels of leukemia, a number of residents began to map cancer clusters to demonstrate a connection. The effort eventually led the citizens to an interested Harvard biostatistician and together they designed a study that statistically established a connection between leukemia levels and toxic exposure. Although the results of their investigation came under fire because of their "unorthodox methodology," the study bolstered a successful civil lawsuit against two companies (Fischer 2000, 155).

However, participation in science takes time, resources, and requires answering a whole host of methodological questions (e.g. Who participates? How are decisions made? How are conflicts handled?) So, why do it?

First, its proponents argue that citizen participation "gives meaning to the practice of democracy" as opposed to just paying it "lip service" (Fischer 2000, 243). Related to this, is that participation can allow scientific uncertainty and trade-offs to be dealt with collectively, as opposed to leaving them only to the judgment of one expert or expert community.

Second, citizen participation in science may help restore the credibility of scientific expertise, which, as noted, has increasingly come under public attack. Backstrand (2003) provides the example of European efforts to patch relations between scientists and the European public (tarnished after the mad cow disease outbreak and concern over genetically modified foods) by enhancing "transparency, civil participation, dialogue and accountability in science and policy."

A third, and key, argument recognizes that citizens not only have a right to help determine their future, but, as mentioned, they may also be sources of valuable, place-based knowledge. Although, as Fischer (2000, 195) says, "thanks to the modern commitment— if not obsession with— the wonders of science and technology, local knowledge has come to be ignored," many are arguing that this knowledge can complement and contribute to expert understanding of environmental problems.

The recent "rediscovery" of local knowledge, particularly as it relates to the environment (termed "local ecological knowledge," or LEK), is causing a stir in resource management and its related scientific disciplines (Berkes and Folke 2000). But what exactly is local knowledge and LEK, and how can it change the way we understand and manage our environment?

Discovering Local Knowledge

Imagine an indigenous[2] cultivator in Mexico, before the introduction of "modern" agricultural technologies—pesticides, herbicides or lab engineered seeds. In order to survive, he requires an extensive personal bank of knowledge, techniques, and skills. Through years of experimentation with and observation of his seed varieties, soils, and climate, he has techniques for growing crops that are well adapted to the local and variable conditions. He knows how to adjust his approach when rainfall patterns change or temperatures fluctuate. Furthermore, he may have many fields to manage, each unique in terms of slope, orientation, altitude, or soil quality. In each of these fields he may plant different seed varieties, or combinations of crops with synergistic effects, or employ different planting patterns that they are well suited to the unique field conditions. With each growing season, he learns more and develops new farming approaches (adapting old ones and incorporating new methods), to increase both dependability and output. And what he learns is not only stored in his mind, but may also be shared and swapped with other farmers in the community, creating a community databank of farming practices, that is rarely written down, but continuously drawn upon and modified.

This picture—of the complex nature of knowledge in what were once considered "primitive" cultures—is a generalization of the one that was emerging in 1960s, as anthropologists began to investigate the knowledge bases of rural communities, primarily in the third world. At this time, many government modernization schemes were premised on the belief that these communities were operating with knowledge that was "inefficient, inferior, and an obstacle to development," and had to be converted to practices blessed by government agencies and their scientific experts (Agrawal 1995, Geiser 2002). Indeed, an outcome of this perspective was the so-called Green Revolution. Sponsored by the Rockefeller Foundation in the 1940s, and later through the Ford Foundation and national governments, the goal of the Green Revolution was to bring Western agro science and technology, in the form of bio-engineered seeds, chemical fertilizers, pesticides, and mechanization, to developing nations to increase crop yields. In these strategies, the local knowledge of the targeted community was left, quite "unscientifically," uninvestigated (Scott 1998); in fact, it is unclear if outsiders even imagined that it *could* exist.

At the same time, anthropologists' studies were demonstrating that these communities not only *had* an extensive armory of techniques and knowledge bases, but they were often more efficient and practical than the ones that were being imposed by outsiders. Drawing on the sociologist Jan Douwe Van der Ploeg's study of indigenous potato cultivation in the Andes, Scott (1998) compares the two models—the technocratic and the local—and their logics. On the technocratic, Scott (1998, 302) writes:

> The logic of the process—a logic not even remotely realized on the ground— is to transform the farmers into "standard" farmers growing the standard genotype [seed variety] on similar soils and leveled fields and according to the instructions printed right on the seed packets, applying the same fertilizers, pesticides, and amounts of water. It is a logic of homogenization and virtual elimination of local knowledge. To the degree that this homogenization is successful, the genotype will likely succeed in the short run. Conversely, to the degree that such homogenization is impossible, the genotype will fail.

While scientific agriculture begins with a model of the "ideal" plant type, and sets about determining how to mold the environment to support this ideal, the process of the local farmer, who takes the natural environment as his starting point, is quite the reverse:

> The logic of actual farming is one of an inventive, practiced response to a highly variable environment...cultivation in the Andes is a "craft". The cultivator begins with an exceptionally diverse local ecology and aims at adapting to it and gradually improving it. The Andean farmers' skills have allowed them to achieve results that are quite respectable in terms of narrow productionist goals and extraordinarily so in terms of yields and sustainability (Scott 1998, 301).

Similarly, in a more recent study of traditional English sheep farmers in the aftermath of the 1986 Chernobyl nuclear power plant meltdown, Wynne (1996) found that the government scientists charged with crafting policy and recommendations for the sale and grazing of the North England sheep developed their models and experiments assuming that the standardization of nature and farming was "natural" (like the agroscientists in the above example), and that their methods could represent realistic farming practices. However, by not integrating the sheep-farmers' expertise, many of the scientists' assumptions were completely wrong: They conducted contamination experiments by penning in sheep, which was something the farmers would never do, and they made management recommendations that the natural system could not handle, such as encouraging farmers to graze their sheep longer on less contaminated pastures, which would have led to desertification and erosion. These errors were all obvious to the sheep farmers, one of whom commented: "You just wonder what the hell are these blokes [the scientists] talking about?...what do this lot know about anything? If it weren't so serious it would make you laugh" (Wynne 1996). However the scientists implicitly regarded the farmers' knowledge of the local natural system and their own practices within it as useless and ignored it. Thus not only were the scientists' recommendations frequently based on a misunderstanding of the natural and social system, but they also failed to help the farmers productively deal with the radiation, and instead bred anger and mistrust among the local community (Wynne 1996).

The intent in comparing these scientific and "local" understandings of environmental issues is not only to critique the imposition of scientific management, but also point out how deeply mistaken and problematic the assumptions about its "beneficiaries" have been. The continuing work of anthropologists and others have revealed that many communities with deep connections to their local environment have complex knowledge systems, techniques, and skills—not only in the realm of agriculture—but related to many aspects of their natural surroundings.

Defining and Understanding Local Ecological Knowledge

The term local ecological knowledge (LEK) refers to a "wide array of practical skills and acquired intelligence in responding to a constantly changing environment" (Scott 1998, 313). To clarify what can be a confusing assortment of ill-defined and related terms: a community has an extensive suite of place-based knowledge, related to their customs, beliefs, practices, economies, and so forth; this has been termed "local knowledge." Local ecological knowledge is a subset of this general local knowledge and pertains exclusively to the local environment. The term "indigenous," or "traditional," ecological knowledge is commonly used to refer to the LEK held by indigenous groups. However, because non-indigenous, resource dependent communities (Canadian herring fishermen, for example) (Huntington 2000), individuals who do not belong any definable "community" (Yli-Pelkonen and Kohl 2005) and even those who are part of a local scientific or "expert" community (Fazey 2006a, Robertson and McGee 2003) can also be bearers of extensive local ecological knowledge, LEK is here used as an umbrella term.

LEK is developed through intimate experience, observation, and adaptation in a single environment and culture, and thus is deeply context dependent and can be linked to cultural beliefs and customs (Berkes and Folke 1998); it is rarely applicable elsewhere. While scientific knowledge is often concerned with large-scale processes and generalizable trends, LEK is, by definition, place specific and often quite detailed. However, LEK is not "closed" or "stagnant," as it is sometimes characterized. It is in fact very responsive to new ideas, methods, and technologies introduced from the outside—adopting those that seem to work and shunning those that do not (Agrawal 1995, Scott 1998). What is learned is typically internalized and communicated orally—hardly ever written down. Depending on the history of the community or individual, LEK may represent knowledge amassed over hundreds, if not thousands of years. However, it may be richer in some areas than others. For example, Sillitoe (1996) found that the Wola community in New Guinea had extremely complex knowledge of sweet potato varieties, whereas their knowledge of geology was quite limited.

Some scientists have attempted to breakdown LEK into specific categories, which together form a "knowledge system that is unique from Western science" (Davis and Wagner 2003). For example, resource users or observant individuals and communities may have "location specific knowledge": knowledge about where species occur, details on species' lifecycles and habitat requirements, climate and seasonal patterns, hydrology, and geomorphology (Stevenson 1996, Drew 2005).

Furthermore, because some communities, particularly resource dependent ones, need to be aware of interconnections between species or certain processes, they also have knowledge of "environmental linkages" in an ecosystem (Stevenson 1996, Drew 2005).

This includes knowledge of how their interaction with the environment impacts certain communities or processes. For example, a fisherman may have an understanding of how his practice of otter trawling (dragging a net along the bottom of the ocean floor) for groundfish affects the sea bed, and how this in turn impacts the local lobster population that rely on this habitat for protection during maturation. Or, a hill sheep-farmer may understand what intensities of grazing are detrimental to his pastures' ecological integrity, and how to "rest" them to prevent desertification. In his investigation of how indigenous LEK (traditional ecological knowledge) could be incorporated into Canadian environmental impact assessments, Stevenson (1996) terms this type of knowledge "level 2" knowledge, because it is "less accessible and comprehensible in terms of...Western systems of knowledge" than "location specific knowledge" (Figure 1).

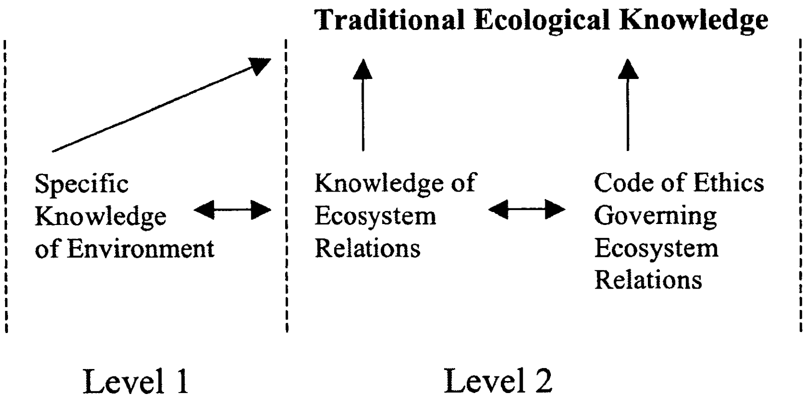

FIGURE 1. Components of traditional ecological knowledge. Level 2 components are more complex and less likely to be incorporated into conventional environmental assessments and management than Level 1 components. (Adapted from Stevenson 1996)

Just as LEK can be richer in some areas than others (potatoes versus geology), the same holds true for its distribution in a community: some members of a community are far more knowledgeable than others, because of experience, exclusivity, or innate skill. These individuals may also possess what has been termed "expert experiential knowledge" (Fazey et al. 2006b). Thus in addition to having substantial knowledge of location specific information or ecological linkages, they have an expertise that cannot always be "reduced to isolated facts or propositions" (Fazey et al. 2006b). Research on chess masters provides a useful analogy (deGroot 1965, as cited in Fazey et al. 2006b). In the 1960s, when scientists attempted to compare master chess players to very good players, they could find "no difference between the two groups in the number of moves they thought they could make or the number of counter moves they anticipated from their opponents. The experts [chess players] however, appeared to 'chunk' pieces of information together allowing them to recognize features and patterns not noticed by the other players." In this same way, locals with ecological expertise "may be able to recognize emergent properties and make good predictions [about an environment], even though they may not be able to explain precisely how they do it" (Fazey et al. 2006b).

Local Ecological Knowledge and Natural Resource Management

Since the social scientist Robert Chambers first argued it to the international development community in 1979, the idea that local people "know" has now gained wide acceptance in rural development circles and been demonstrated in numerous studies (Geiser 2002). Over the past decade, many in resource management and related scientific fields have begun to take note (Neis et al. 1999, Berkes et al. 2000, Huntington 2000, Drew 2005, Bart 2006). Proponents of using LEK to inform management suggest that it can improve understanding of natural systems and their links to social systems, provide models of management that are "sustainable" (i.e. they allow humans to use resources while operating within the constraints imposed by a resilient and healthy natural system), and, improve relationships and trust among communities, scientists, and policymakers. Because biologic scientific data is often patchy and fragmented, Berkes et al. (2000) argue that LEK can fill in some of these gaps and improve the overall understanding of local ecosystems and human interaction with these systems. For example, in the management of certain wildlife populations, accurate and comprehensive data on harvest rates and practices, habitat, migration patterns, and population size are essential to modeling how the system works and assisting in management decisions; LEK can assist in developing more accurate models of the population dynamics and the relevant natural and social systems (Gilchrist 2005).

Along the same vein, in many cases LEK might provide the only historical picture of certain ecosystems. It can help establish historical environmental "baselines" (e.g.

prior species abundance), against which current changes can be measured, as well as explain what natural and social changes have taken place within an environment over time. This type of historical information is crucial to illuminating how environments have transformed, and to developing explanations for why that transformation has occurred (Bart 2006). And if one can understand what caused undesirable change then it may be possible to establish a management strategy to improve conditions. For example, if one can understand what precipitated a population crash, one is in a better position to develop management approaches to successfully rebuild the species.

In addition to expanding the management knowledge base (both current and historical), LEK can challenge and sometimes correct scientific paradigms. A good case of this is the Bowhead Whale census in Alaska (see: Huntington 2000). In 1977 an international ban was placed on the hunting of Bowhead whales, a tradition of the Alaskan Eskimos. In response to the political backlash, scientists agreed to establish a hunting quota based on a census of the whale population. They developed population estimates by observing passing whales from cliffs along their migration path. The Eskimos, however, challenged the estimates, arguing that the scientists' assumptions were flawed. First, the scientists assumed that the whales only traveled within sight of the observation cliffs, and second, that when ice blocked the migration route, they no longer passed. The Eskimos, who traditionally traveled out on the ice and deeper into the water by boats, saw whales migrating at the times and places scientists assumed they did not. An expanded study, using sonar and aerial counts, later proved both of the Eskimos' critiques correct; Population estimates increased from 3000 to 8000 (Huntington 2000).

LEK may even be a source of new models for how to use an environment and its resource sustainably. Some ecologists have noted that many indigenous communities seem to have developed sustainable resource management techniques; that is, they are able to harvest resources without compromising the health of the ecosystem they depend on (Berkes and Folke 1998)[2]. Many of these practices are adaptive— that is the communities' resource use responds to changes in the environment. The Maasai tribe of

---

[2] This is more often the case in self-regulated communities (typically indigenous groups), which have, over long periods of time, developed management techniques that are culturally internalized in certain rules or taboos. This is less likely to be the case in regulated communities in the first world.

Kenya, for example "widen the radius [of grazing] around wells progressively as the wet season advances, so as to leave enough forage around the wells for the dry season" (Niamir-Fuller 1998). Overall, this adaptive grazing regime has been found to preserve the healthy functioning of the African grasslands under variable climactic conditions, while simultaneously meeting the resource needs of the community (Berkes et al. 2000).

LEK also has ramifications for the social and political aspects of management: The recognition and use of LEK may reduce resource management conflicts and improve communication among scientists, managers, and resource users. When LEK is not written off as "anecdotal," but accepted as a legitimate knowledge system alongside scientific knowledge, resource users may be less likely to attack the process (or the science) and more likely to approve of the resulting policy decisions. Calheiros et al. (2000) found this to be the case in their study of participatory wetland research in Brazil.

Local Ecological Knowledge and U.S. Natural Resource Management: Opportunities and Challenges

Given the history of resource management in the U.S., integrating LEK into the knowledge base with which management decisions are made could address a number of the problems of conventional resource management. It is certainly not a cure-all. For example, improving the quality and accuracy of the knowledge base used for management decision-making does not directly address *how* decisions are made, and with what values—precautionary and protective or cornucopian—or in whose interest they are developed. However, in theory, LEK could provide a balance to the top-down, broad scale vision of conventional management. Considering and integrating LEK could bring to the fore important local ecosystem dynamics, impacts and other nuances, which are typically overlooked with the conventional approach. By supplementing the management knowledge base, the vision of management could become more holistic, as well as more responsive and sensitive to " local practices, concerns, priorities, and sensibilities" (Davis and Wagner 2003). Finally, by acknowledging that resource users and other local communities "know," and treating that know-how as legitimate and credible, policy makers could reduce some of the conflict, anger, and political stalemates that surrounds current management decisions (Robertson and McGee 2003).

Furthermore, although the conventional approach to management is still dominant in the U.S., there has been a clear shift over the past decade toward new paradigms, such as ecosystem-based management and adaptive management. Ecosystem management recognizes that management must be approached more holistically by taking into account ecological, social, and economic linkages and their relevant scales, while adaptive management suggests that management be treated as an experiment, with continually learning and readjustment (Holling 1978). Both approaches recognize the importance of managing and monitoring at different spatial and temporal scales. Ecological research has shown that activity and events at fine scales can have effects that ripple outwards and impact the system at much broader scales (Levin 1992). However, given that current management institutions and their management vision and tools were developed under the Enlightenment program paradigm and typically focus on a single scale, such as a single species, it is unclear how this shift will be made; with limited time and resources, how will agencies be able to monitor activity and feedbacks at the various scales these new approaches demand? The integration of LEK could be essential to this endeavor. Resource users are privy to fine-scale information and events that large-scale monitoring misses. If this information could be integrated with the current coarser scientific data, a more comprehensive picture of the system could emerge to guide management decisions.

Its putative benefits notwithstanding, in reality, LEK is rarely used (Bart 2006, Huntington 2000). As Huntington (2000) has written LEK is frequently discussed in the future tense: LEK "'*will* be of use,' somewhere, sometime." Using LEK presents a number of challenges. As one writer has noted, its important not to get "too dewey eyed" over LEK as it—like scientific knowledge—it is sometimes wrong (Edwards 1998), and there are many examples of "traditional" communities destroying their environment (Diamond 2005). Furthermore, because it is a mix of discrete chunks of knowledge, as well as theories, methods, and expertise, all unwritten and unevenly distributed in a community, it is far more challenging to obtain and understand than knowledge that is codified or quantified. Thus to "use" LEK for decision making, rigorous (and often time-consuming) qualitative methods (such as questionnaires, interviews, or workshops) are typically developed and applied to locate, elicit, substantiate, and document LEK

(Huntington 2000, Robertson and McGee 2003). Huntington (2000) argues that a mixture of resistance to using these social science methods, to working with "non-experts," and general "inflexibility" to changing the modes of operation have prevented the acceptance of LEK.

In the U.S. these barriers also exist, but equally challenging is the fact that numerous statutes require that management agencies use only the "best available science" and technical reasoning when promulgating their environmental regulations. As Ozawa (1996) notes, these requirements are intended to serve as a form of "accountability": "As long as decision-makers [are] constrained by the technical experts' interpretations of the physical conditions and alternative actions," Congress assumes that "raw politics," or the interests of a few, cannot intervene and corrupt the development of laws to protect the good of many. Whether or not these requirements produce the desired disinterested rulemaking, they have important implications for the use of LEK in management: To be perceived as useful to natural resource management and policy in the U.S., LEK has to be integrated into a scientific framework—one guided by established scientific methodology that, generally, entails observing phenomena, formulating and testing hypotheses for given phenomena, and recording the process. In the following, I present two U.S. case studies, and seek to build on the ideas explored thus far by examining how and why, in each case, LEK was—and was not—integrated into the relevant management science, and to what affect.

THE SONORAN DESERT CONSERVATION PLAN

Introduction

This case looks at the role of LEK in the development of a conservation land system (CLS), the backbone of Pima County, Arizona's sweeping Sonoran Desert Conservation Plan (SDCP). The case illustrates how the team of scientists charged with designing the reserve was able to design a more accurate CLS by incorporating the LEK of individuals with varying levels of connection to the scientific community. However, the case also shows how scientists determined what LEK was useful and credible by defining an expert community, based on a shared scientific literacy as well as common conservation values. Two major barriers discouraged the scientists from directly drawing on other sources of LEK. The first barrier was a language divide: because most "non-expert" LEK was communicated in non-scientific language, scientists could not understand its relevance nor confirm its accuracy. The second barrier was that of conflicting interests: although local ranchers had some of the most extensive LEK in the County, much of it quantified, they were also the SDCP's most vocal; scientists saw the potential risks of including ranchers' knowledge (particularly risks to the team's perceived credibility) as outweighing the potential benefits to their knowledge base. Furthermore, some ranchers did not want to reveal their LEK to scientists for fear that it would be used against them. Finally, the case demonstrates how certain individuals with a foot in both the local and scientific communities could bridge the language divide and serve as translators. However, the inability for conflicting interests to be overcome in a similar fashion suggests that this the obstacle of conflicting interests may require a more strategic intervention that directly addresses the risks associated with using and divulging LEK.

Background

1998, spurred by the Endangered Species Act (ESA) listing of the tiny pygmy owl, Pima County, Arizona, embarked on a planning process to address growth and biological conservation in the region comprehensively (Figure 2). Until this time, like much of the rest of Arizona and the Sunbelt, Pima County had been on a growth binge. In fact, since the 1950s, Tucson (the largest city in the County) has been one of the fastest growing urban areas in the entire country, exploding from a population of around 50,000 to over half a million by the year 2000. All of Pima County lies within the vast Sonoran Desert, one of the most biologically diverse deserts in North America, and by the 1990s, an acre of desert was being lost every two hours (The Conservation Fund 2005). The ESA listing was a wake-up call for the County; many were concerned that the pygmy owl was going to be for Pima County what the spotted owl was for the Pacific Northwest (Kloor 2005).

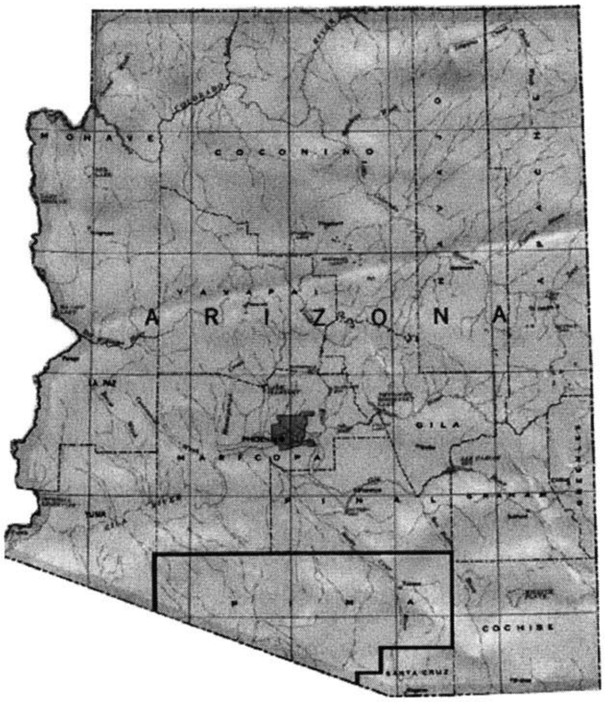

FIGURE 2. Arizona and Pima County (outlined in black).

It was this possibility that prompted the County to consider developing a Habitat Conservation Plan (HCP)—the only way to receive some leniency from Section 9 of the Endangered Species Act (ESA), which prohibits any entity from "taking" (harming, harassing, killing) a federally listed endangered species or adversely modifying its habitat.

Few HCPs are developed with long-term goals of environmental protection and conservation. Instead, most simply seek to avoid the scenario of stalled economic activity and vociferous conflict between resource users and environmentalists by nabbing the Section 10 permit that allows species take. Initially, Pima County thought it would be no different (Behan 2007). However, the combination of growing public demand to curb sprawl, a shift in power within the Board of Supervisors, which between 1996 and 1998 went from "being staunchly predevelopment to being strongly proenvironent," and a potent coalition of environmental organizations resulted in a much grander conservation vision to comprehensively address growth and protect the richness of the surrounding environment (Layzer 2008). This vision became known as the "Sonoran Desert Conservation Plan" (SDCP).

When the Pima County Board of Supervisors approved the SDCP in 1998, the concept represented a fairly unusual "science-based" approach to regional planning that would use natural "resource assessment...as a necessary first step in determining the urban form" (Huckleberry 2002). The SDCP development process would still spawn a HCP for a Section 10 Permit, but would also be used to identify the most ecological sensitive or valuable land in the County and guide growth and development away from these regions and towards less biologically important ones.

Following its approval, the County established five advisory committees: a citizen Steering Committee of over 80 self-appointed members of public, a ranch technical team, a cultural resources technical team, a recreational advisory team, and a science technical advisory team (STAT). Although all the groups developed final reports and recommendations for the County, the STAT team was charged with developing the reserve system of biologically sensitive areas, later called the Conservation Land System, or CLS, which would form the core of the SDCP and HCP. The County was aware that similar "collaborative" HCP processes, which brought together industry, scientists, government, and citizens, were fraught with problems. Some collaborative processes crumbled from internal conflict before a plan could be formed; others produced plans that were influenced more by politics than environmental science and were not biologically protective. Instead of following these models, the County took its cue from the recommendations of conservation biologists (See: Noss et al 1997) and wanted the foundation of the reserve to be created without initial consideration of economic or political constraints, and instead be built on credible science. Thus, STAT was only composed of scientists (County, academic, and agency) with various, relevant biological expertise and was co-chaired by two respected local scientists: Dr. Bill Shaw, a professor of Natural Resources at the University of Arizona, and Julia Fonseca, a scientist with the County's Flood Control District. For the three years following its formation, the team would remain insulated—in fact "fire-walled"—from the heated politics that surrounded that SDCP (Behan 2007).

Incorporating Expert Local Ecological Knowledge into a Reserve Design

At its inception in 1999, the STAT team reaffirmed the County's intent not to design a reserve simply for ESA legal compliance and a take permit. The team did not want to develop a plan by doing the bare minimum required by law and simply "check[ing] off the boxes" needed for an HCP (Shaw 2007). "We had no interest in providing a loophole to avoid ESA," Shaw has said. STAT instead chose to follow the spirit of the ESA and adopt a conservation goal: "To ensure the long term survival of the full spectrum of plants and animals that are indigenous to Pima County through maintaining or improving the habitat conditions and ecosystem functions necessary for their survival" (SDCP 2001, 2).

STAT wanted to plan above the "species level", at which the ESA is written, and protect ecosystem communities and processes—essentially engage in ecosystem management instead of conventional management—but they needed a starting point. What they settled on was the following: if they could develop a reserve that would protect the vulnerable species in Pima County, these species would serve as a surrogate for the larger picture of biodiversity, and protect other valuable ecosystem elements such as important biologic communities or genetic diversity (Shaw 2007). Thus STAT would not only provide a strong foundation for conservation based land-use planning, but it seemed certain that a permit based on their multi-species HCP would follow.

Another unusual aspect of STAT's modus operandi was that, although it worked intimately with the consultant RECON, the consultant was really under the guidance of STAT, not the other way around, as is more typical (Fromer 2007). This inversion of usual positions meant that while RECON provided essential supplementary information and expert vetting of data and models, ran GIS simulations, and wrote most key reports, STAT provided the bulk of the direction, data and, in particular, the species expertise that fed the that GIS modeling and reserve mapping.

Because Pima County is extremely large—the equivalent, as locals will tell it, of a Connecticut, a Rhode Island, and several other small Northeastern states combined— the ten-member STAT team could not provide all the necessary expertise on its own. As the team was committed to developing the reserve with the best information and know-how available, they mined the area for sources of local expertise at every step of the reserve planning process. As Shaw (2007) has said, they could have "hired a team of experts, from Harvard or MIT…to apply planning without local knowledge," but who better to provide information about Pima County and its biological communities than the people who lived there and worked in the field— many for decades, if not their whole lives? Shaw himself has worked in Tucson for 33 years and dedicated his research to many local environmental concerns such as urban wildlife and the socio-politics of its management.

There is, of course, a difference between getting scientific data and studies from locals and using their local ecological knowledge, that hard-to-pin down know-how that arises from a mixture of known facts, experience, and, as one scientist put it, "gestalt" (Falk 2007). The STAT team did both, and (as will be explained later) the use of LEK turned out to be a critical component of the reserve design. However, because STAT's process had to be scientifically defensible in all respects, the "locals" who provided LEK had to be part an "expert" community. This did not mean that they held PhD, or even that they were working as a so-called scientist (although many were) — one person who provided expertise to STAT worked a day job as a parole officer (Fonseca 2007).

No STAT member could explain in any clear terms what gave a person the appropriate credentials to be considered an "expert". However, they all shared three important traits. First, these experts had extensive field experience and gained their credibility through an informal vetting by the scientific and naturalist community in Tucson and the rest of Pima County. In Pima County, there is an expansive network of field biologists, ecologists, natural resource scientists and naturalists, working at the University of Arizona, in government agencies, in educational and research organizations, or associated with certain societies, such as the Tucson Herpetological Society. Although they are clustered by species or interest, they are all linked through their fascination with and dedication to learning about the natural resources and species of the Sonoran Desert. As part of this network, STAT scientists knew who to go to within the network for the "best" information.

Second, for STAT to consider someone an expert, STAT also had to perceive that person as "credible". Although no one said it directly, by using terms like "self-serving" and "disruptive" to describe people they would avoid, STAT clearly linked credibility to more than extensive experience and vetted know-how, but also to perceived shared conservation interests, or, at the very least, neutrality. However, the majority of STAT's experts, who *donated* their time, did so because they supported the team's mission.

Third, although not all of STAT's experts were professional scientists they all understood the language and methods of science and were able to frame their LEK in scientific terms (Falk 2007). That is, all of them could present and, if pressed, defend their experiential knowledge in the scientific language of the STAT team. For example, experts understood the importance of repeat observations for reliability and how to distinguish significant versus chance phenomena. In this way, the STAT team did not have to develop a way to elicit or confirm the expert LEK; they could have a peer-to-peer conversation, and if an expert's experiential knowledge struck them as questionable, the provider of the information could typically explain, in a common scientific language, why or how they had developed that understanding.

STAT used expert LEK in several capacities. They elicited expert opinion via personal interviews while formulating their list of priority vulnerable species (PVS), around which STAT would design the CLS. STAT also used the expert opinion to assist in prioritizing vulnerable species from a much longer list of potential vulnerable species.

For example, STAT wanted to screen out species that did not meet certain local criteria—such as those for whom conservation would best be accomplished elsewhere (RECON 2000)[3]. The expert LEK provided information on local species' status that could not be ascertained through available studies or reports.

However, STAT and RECON relied most heavily upon expert LEK for the first and most crucial stage in the development of the CLS: mapping the land that the designated vulnerable species needed to survive and persist. In a typical HCP process, the most straightforward way to do this is to gather existing data on where the species, during their lifecycle, nest; where they forage; and which corridors they use to travel—essentially, where they are on the landscape (Fromer 2007). The problem was that for many of the species the data didn't exist there or was spotty at best, nor were there funds or time to initiate costly surveys for a 9,000 square mile area. Furthermore, STAT did not want to overlook areas where species *had been* in the past, and thus *could be* in the future if restoration was undertaken. Instead, STAT and RECON gathered what data they could and turned to the next best option: habitat modeling.

The habitat modeling STAT and RECON did can be explained in relatively simple terms (much to their credit). Where a certain species, say a reptile, can persist is constrained by a number of environmental variables, such as temperature, vegetation, or rainfall. RECON and STAT chose several environmental variables—including hydrology, vegetation/landcover, and soil type—that they believed were central to determining vulnerable species' habitat. They divided each of the variables into sub-categories, a total of 115 for all. For example, vegetation/landcover was subcategorized: "mixed-scrub," "creosote bush," "cattail," and so forth. Then they gathered as much of the most accurate and most detailed spatial data on these variables that they could find and fed them into a GIS system, creating a map of Pima county with vegetation types, hydrology, soils, and so forth, all overlaid. They also used the most accurate vulnerable species data they could find from natural histories and other studies to rate the importance

---

[3] The jaguar, which did not make it to the final Vulnerable Species list, is a good case of this. Although many environmental groups argued that it should be planned for, it only enters the county periodically and the majority of its range is in Mexico. After expert review, STAT contended that the conditions in Pima County had a very limited impact on its survival.

of each sub-variable (from 1-3) in determining the species' distribution: For the pygmy owl, "mixed paloverde cacti" (under the variable vegetation) scored a 3 and 401-600 feet (under the variable elevation) scored a 2 (SDCP 2000). They developed these models for each species. The idea was, for any particular species, where its most highly rated sub-variables lined up on the map, the higher the value of that land for its habitat, which would be delineated by a color gradient across the map.

A favorite argument of the SDCP skeptics, who don't always quite understand what STAT did, is that the entire habitat reserve is based on "models" and "extrapolations"—not "reality". Although STAT's habitat modeling and ecosystem planning was based on well-established concepts from conservation biology, because of data gaps, such critiques would actually have had some merit had not expert LEK played such a central role in the mapping. The initial habitat maps, modeled without local expert input, were fraught with error. One of STAT's experts recalled his reaction when he saw the first runs of the models for several of the species: "You were getting a negative image! I mean, maybe they were starting with field guides, but the distribution [of the species] they were getting was almost the opposite, in some cases, of the actual distribution." Not all the initial maps were this inaccurate, but STAT and RECON were well aware that they were working with major data gaps: their vegetation/landcover and soil data was far less detailed in some areas than they would have liked, and very little was known about their habitat needs.

To remedy the inadequacy of the data, STAT developed an iterative process, where they brought in their local experts, who were intimately familiar with the distributions and habitat needs of the PVS in Pima County, to help critique and tweak the models. As Mima Falk (2007), a member of the STAT team and the plant ecologist with the U.S. Fish and Wildlife Service, described:

> The local expert groups that we brought in were made up of anyone we knew who was an expert, regardless of whether or not that person was a quote-un-quote scientist. So, there are a lot of people in Tucson who work on tortoises and they do not all work in the agencies—or whatever it means to be a 'scientist'— so based on our personal contacts and people we know to be knowledgeable, those groups were brought together to look

> at the species information and then to have those discussion of: what do you think is the appropriate habitat here? Are these the parameters to be looking at?... We tried to bring in a range of people…Lots of amateur people are great at natural history; they see things out there that the quote-un-quote scientists does not because they are driven by certain questions; it's really rare to find someone [like that] who sees the big picture… Once the model was done, it actually came back to the group and we asked: does this look right, based on what you know about the species? So there was a lot of information that was used that way: that could not necessarily be quantified. it was sort of a species expert review, where we sat down and sort of went on people's knowledge—or gestalt, if you will.

If the distributions of potential habitat appeared "off", the experts would recommend changes to the models: decrease the value of soil type or weight vegetation more heavily than altitude. The models would be altered and the maps re-drawn. This was done iteratively for every species map, blending the technical, data driven GIS model with the experiential know-how of the local experts, until STAT and the panels were satisfied (Figure 3).

To add a further dose of reality, a separate team of 19 local experts (all from agencies, consulting firms or the University of Arizona) added additional layers called "priority conservation areas" (PCAs). Drawn onto paper maps and then digitized, these areas were based on their experiential understanding of local conditions and demarked habitats that they deemed absolutely essential for species persistence.

These finalized maps were then compiled to produce one map, based on where three or more species' "high quality" habitats overlapped; this became the base map of the CLS, although other important shaping of the map, such as improving connectivity between patches, was performed later (Figure 4). And, as they did throughout the process, STAT, RECON and outside peer reviewers vetted all the information to ensure accuracy to the greatest extent possible.

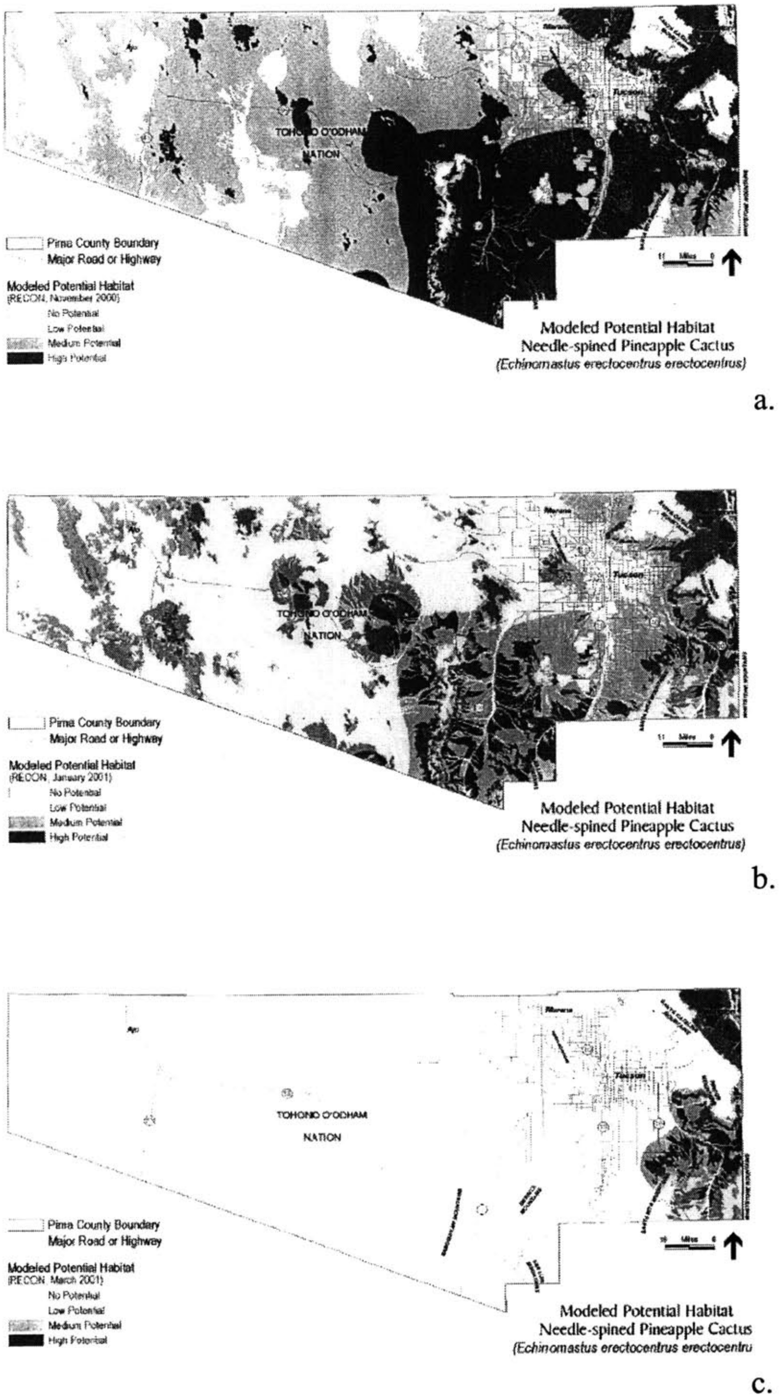

FIGURE 3. Three RECON models of potential habitat for the needle-spined pineapple cactus. Maps rendered by "high," "medium," and "low" potential habitat. Run "a" was conducted in November, 2000. Runs "b" and "c" were conducted following consultation with species experts in January and March of 2001. Run "c" represents the final, accepted habitat model. (Image source: SDCP 2001)

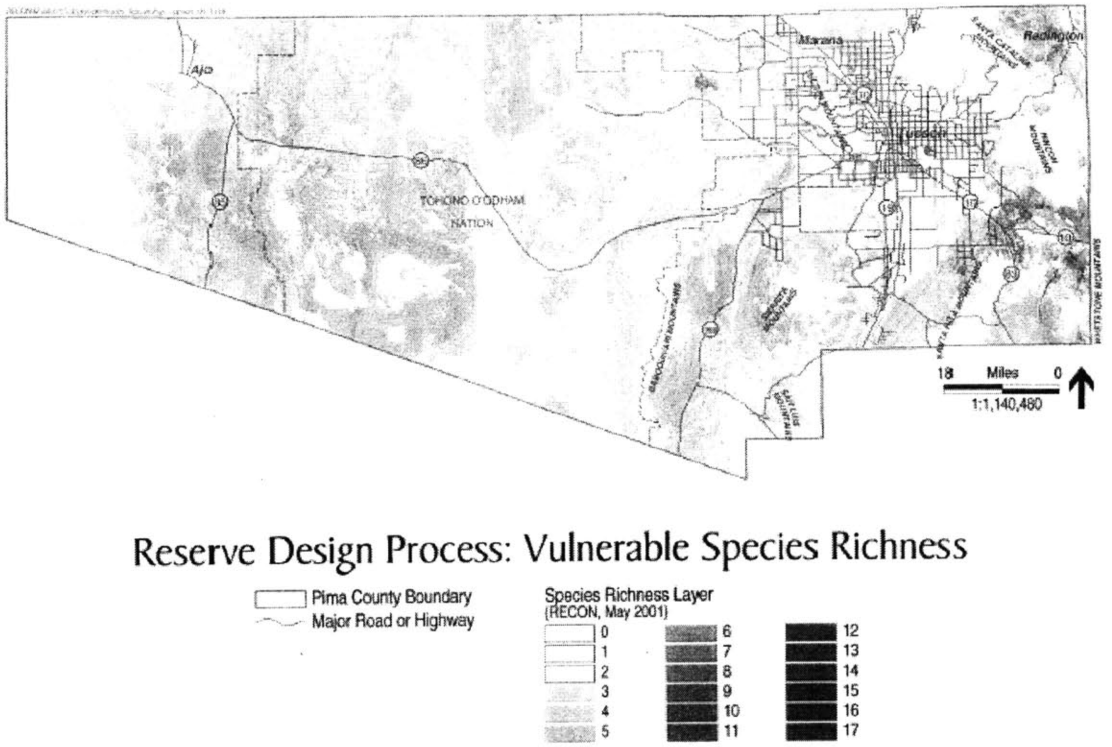

FIGURE 4. Early habitat map based on priority vulnerable species richness. (Image source: SDCP 2001)

By all accounts, STAT's use of expert LEK greatly increased the accuracy of the CLS mapping effort, and very likely the future effectiveness of the CLS. However, the development of the CLS still required quantitative modeling. The two perspectives were complementary. While the extensive local expertise grounded the technical approach in on-the-ground realities and greatly improved the map's accuracy, the modeling effort allowed the local experts to consider the potential habitat value of areas they were less familiar with. The modeling also increased the credibility and defensibility of the map's development, as it ensured uniformity in approach and also allowed replication—key aspects of any scientific endeavor

Non-Expert Local Ecological Knowledge: The Language Divide and the Role of a Translator

Because STAT limited its use of LEK to that of an "expert community", it represented only a portion of the LEK that existed in Pima County. Although not all the

experts were professional scientists, they all shared a common conservation culture and scientific language. In this sense, the LEK that STAT relied on was easy to access and integrate. STAT had a much more difficult time handling LEK from those outside of its own expert network, which was proffered through hundreds of phone-calls and at STAT's meetings, all of which were open to the public. A major cause of this difficulty was a language divide. For example, non-experts did not have the scientific literacy to frame their knowledge for scientists, so the LEK they presented was not in scientific terms, quantified, or even codified; STAT, therefore, perceived the knowledge to be anecdotal and therefore unusable. The language divide was also manifest in the public's frequent misinterpretations of the team's research methodologies. Citizens who were earnestly interested in contributing their biological knowledge rarely possessed enough scientific training to understand STAT's assumptions, scope, procedures, or goals. Thus the LEK locals offered was rarely directly useful or relevant to STAT's work. For example, many locals had detailed information pertaining to a very small land area, whereas STAT was modeling over an enormous land mass; locals would tell the team about the biological richness of 15 acres, while STAT was looking at an area of 5.9 million acres and a specific 56 species.

Although the STAT team recognized that some of the information locals offered might have been credible and valuable, there were risks associated with attempting to bridge this language divide. STAT would have had to thoroughly investigate each of the locals' claims before accepting them. With limited time and budget, the effort of confirming the LEK's accuracy, coupled with possibility it would be inaccurate, made such ventures risky and impractical.

Citizen informants were similarly discouraged from attempting to translate their knowledge into scientific language, as it would have required considerable investment of time and money: they would have to attend STAT meetings, understand STAT's process, and possibly hire or have access to a scientist or surveyor to complete a study, write a compelling report, and so forth. The investment required was beyond most individuals' capacity. Furthermore, it was not guaranteed that such an effort would have any impact on STAT's work. In fact, in the hopes that their local knowledge would be incorporated into STAT's modeling, several conservation-minded local groups developed scientific reports and funded local land assessments for STAT review. However, none of the handful of these community-developed reports influenced STAT's CLS—either because STAT was already aware of the information, or, more often, because the study was not relevant to STAT's pre-determined scope and methodology.

However, a method did emerge to bridge the language divide: Several of STAT's species experts worked with non-expert locals when conducting field research and acted as "translators" between the two communities and their knowledge bases. Among Pima botanists, birders, and other field researchers, many of whom were STAT experts, tapping local knowledge was not unusual. Researchers and naturalists spoke to locals when in the field, or maintained relationships with a handful of informants who supplied them with information and field updates. One botanist described these informants as a small group of people that she could call up and ask: Have you been out in the field recently? What has been going on out there? What have you seen? In addition to providing LEK, these informants were useful to researchers because they were not burdened by institutional paper work and could circumvent the "red-tape" that may face government or academic researchers (Caldwell 2007). Furthermore, local informants were frequently provided access to private lands, such as ranches, that may be closed to government employees. Because STAT relied so extensively on local experts, these experts also were passively providing entry points for non-expert LEK to filter up in a form that was scientifically framed and credible, either as scientific studies or embodied in the expert's own knowledge and judgment, to inform STAT's work.

For example, one of STAT's experts was Phil Rosen, a professor at the University of Arizona who studies reptiles and amphibians in Southwest Arizona. From the year 2000 and on, he has worked in an urbanizing region of Tucson, southwest of downtown, known as the West Branch. He went to the area following a lead on a very rare lizard—the giant spotted whip-tail, one of STAT's priority species—and his presence piqued the interest of a small coalition of long-time residents who had been working with little success to protect the West Branch ecology, first from flood control engineering and then from encroaching development. A handful of the group's most vocal members established a rapport with Rosen and provided him with several types of LEK. One particularly valuable form was historical. They were able to tell Rosen the story of the landscape's natural history: what had happened on the land that may have had effects that he was interested in. This was detailed information he could not have acquired anywhere else and assisted him in formulating causes for ecological change and restoration strategies. A second form of LEK was "location specific knowledge": Since the locals knew the area well, they were able to help Rosen locate particular animals, plants, or landforms. For example, during the first summer Rosen worked in the West Branch, he was with one of the neighbors and heard a specific toad call; the neighbor able to take him through the clearing to where she knew toads were living. Sometimes he would show her a picture of a particular species, and she would recognize it and be able to catch it for him (Baker 2007). A final type of LEK that the locals offered was real-time information on changes in the system or species: When Rosen was working on a frog study, some informants who had become interested in his study would call him up to tell him when a breeding explosion had occurred, which he could not know from his office or home.

When I asked one of the West Branch informants if she and the neighbors knew that specific species, such as the whiptail lizard, were in her environment, she explained: "We didn't know the nitty gritty; we saw the area as a unit… We saw what would happen when developers would go in and scrape out two feet of soil; we saw the erosion and the flooding…It was our home, and we knew it was an unusual area and had many plants and animals were being destroyed elsewhere; we didn't need to do a study to know what was there and that it was valuable" (Baker 2007).

Rosen, however, was able to bridge the divide in how he and the locals learned and thought about the landscape, and draw out their knowledge through informal interactions such as conversations or assisted fieldwork. As Rosen (20007) put it: "I learned to know what they know…[and] it facilitated the work I had to do out there, which was to document the natural history and conservation status of the species." At the same time, Rosen taught them about the ecology of the area, the names and natural histories of species, and educated them about how, as a scientist, he worked; through this co-teaching they established a common language and understanding. In this way, Rosen was able to incorporate LEK into his scientific research.

In 2001, Rosen and a plant ecologist completed a detailed survey of the area, and confirmed what the neighbors had been arguing for decades, though not in the scientific terms or comprehensive framing that Rosen was able to articulate. Within the nearly 2-mile stretch of the community's wash, Rosen found a host of important riparian plant and animal species, including two more vulnerable species. When 15 acres of the river bottom was slated for use as a bus barn, Rosen and his studies were instrumental in preventing the construction. Instead the land, and many other parcels, were purchased with mitigation funds for conservation, and will connect to several Priority Conservation Areas in the CLS.

Non-Expert Local Ecological Knowledge: Ranchers and the Challenge of Conflicting Interests

A language divide, however, does not explain why STAT never tapped the knowledge of the community with the most extensive LEK: Pima County ranchers. As anthropologists, managers, and even a few STAT experts attested, it would not be an exaggeration to say that the ranchers of Pima County know their land inside and out. Although some of the ranchers have only recently acquired their business, often as a lifestyle choice, a number of outfits are multi-generational; some are even run by descendants of the original homesteaders, who claimed territory when the West was first opened to settlement. Particularly in the latter case, where families have been on the land since the late 1800s, ranchers have acquired substantial ecological know-how, pertaining to a landscape that may span 50,000 acres. In addition to understanding its history and landscape scale changes, they have a practical, day-to-day, knowledge of the land's elements, species, and dynamics. Ranchers have had to manage the land through drought, under federal regulations (particularly the Endangered Species Act), and with the ever-present threat of environmentalists' lawsuits. Furthermore, this knowledge applies to the nearly one-third of the county that qualifies as ranchland: a mosaic of private land, as well as State Trust and Federal land that is grazed in accordance with grazing leases.

To explain why STAT did not draw on ranchers' LEK, scientists instead offered two main reasons. First, they suggested that the ranchers' knowledge was related to land management, and not useful for the design of the CLS, which largely required species related expertise. Second, they argued that ranchers' interests in supporting a cattle business (and not biodiversity) biased the type of knowledge they had. There is certainly truth to both these statements. Unlike researchers, ranchers are land managers, and they have historically managed the land for a commodity: beef. And they have not always even done a good job managing for that. By the late 1890s, the cattle industry had so degraded the range that cattle starvation was common, and the effects of erosion from overgrazing are still visible. Furthermore, many unsustainable practices are still in use today, and some scientists even question whether ecosystem health and cattle grazing are compatible goals in semi-arid grasslands (Layzer 2006).

These issues aside, ranchers did have knowledge—some of it quantified— that STAT was interested in using. For example, a coalition of ranchers in the Altar Valley, the County's largest, unfragmented land mass, had been working with the Natural Resources Conservation Service (NRCS) to improve range productivity, restore degraded areas, and document landscape health and change. The ranchers had internalized much of this information, but the NRCS conservationists had also worked with ranchers to quantify and record it. The STAT team expressed interest in accessing some of the NRCS' rangeland data, which included landcover mapping and repeat photographs. However, privacy laws prevent the NRCS from divulging information, even that collected on public lands, without a rancher's permission. Once STAT realized this, they ceased pursuing the data.

The fact that STAT was only willing to work through the NRCS for data on range conditions suggests that the reason STAT did not draw on ranchers knowledge had less to do with the type of knowledge ranchers had, and more to do with the type of interests ranchers represented: Along with developers, ranchers were the primary public critics of the SDCP, and, from their perspective, they had numerous reasons to be skeptical. In general, ranchers value privacy, are wary of government regulation, and are averse to policies that threaten to undermine their property rights. Most ranchers are also land rich and money poor. While few approve of encroaching development, ranchers simultaneously recognize that should their businesses fail, the land and its development rights are their "nest-egg." The SDCP, and thus the STAT team's work, appeared to be a threat on all these fronts. In particular, it would reduce the possibility of intensive future development in the majority of ranchlands, which, with their lack of fragmentation and riparian corridors, are some of the County's most biologically rich regions. Additionally, ranchers perceived the SDCP to be unduly influenced by environmentalists, and feared that STAT would recommend the removal of cattle from public lands— as several locally-based environmental organizations, such as the SW Center for Biodiversity, had been doing for decades. Ranchers were heatedly engaged in the Steering Committee's political battles, and were staunch opponents of environmentalists, arguing for a far less protective version of the CLS. In a scenario that is likely to be repeated across the U.S., the holders of one of the largest funds of LEK—the resource users—were the same people who were liable to politically oppose any attempts to regulate or place restrictions on the resource.

Thus, although no scientists said it directly, STAT believed that including ranchers and their LEK in the science of the CLS was a risky enterprise. In particular, because ranchers were adversarial advocates, STAT could not credibly draw on the ranchers' LEK. Scientists further perceived the risk of politicizing their work after struggling to maintain their political "fire-wall." STAT was forced to weigh potential risks and benefits and, as one scientist obliquely said: "In this case, the principles of transparency and accountability may be more important than new information."

Because of the risks scientists perceived, there were scant ways to bridge the divide between the ranchers' LEK and the management science. Unlike a language divide, conflicting interests could not be overcome through translation, as risk was embedded in the very act of eliciting and using the LEK. Thus, even efforts to translate ranchers' knowledge into "objective" scientific reports introduced interest-related risks. Although it was important for ranchers to make sure that the STAT team was working with accurate data (they were particularly frustrated when they perceived mistakes in species or landcover mapping on their own land), some were wary of revealing their own hard data, particularly related to endangered species, in the chance that it could be used against them. STAT also faced the difficult decision of whether or not to use scientific studies that they had not commissioned, especially when offered by individuals who might be motivated by self-interest. For example, in 2000, several members of the Altar Valley Alliance shared a resource assessment (vegetation and soils) with the STAT team that provided much finer-scale data than STAT had been using. As one STAT scientist noted: " If the data had come from one rancher, we probably would not have taken it, for the same reason we would not take a developer commissioned environmental assessment and just plug it in." Ultimately, the STAT team accepted the assessment because it was conducted by an individual who known to the STAT team and deemed "credible."

Discussion

In this case I have argued that the scientists charged with developing the CLS were able to design a more accurate CLS by drawing on LEK. However, the LEK that scientists used was drawn a defined expert community who shared a scientific language and conservation interests. The case revealed thus two major obstacles to integrating LEK into management science: language divides and conflicting interests. Both obstacles introduce risk into the act of drawing on or attempting to communicate LEK; in the case of the language divide, risk is associated with the effort required to bridge the divide, either through scientists spending time and resources to work with locals and understand and confirm LEK, or through locals trying to express their LEK in scientific terms. This case suggests that one way this effort and risk can be overcome is through a "translator" who can bridge both communities. However, the process of translation that is revealed in this case is passive. That is, locals were not able to actively translate their LEK, nor was STAT able to actively seek out LEK. The communication and integration of LEK hinged entirely on one individual and his or her decision and ability to draw out LEK from a local community or individual. Though revealing of the characteristics required to accomplish LEK translation, the bridging that occurred in this case is somewhat tentative.

This case also shows that even if translation methods are developed to bridge the language barrier, such methods cannot bridge the conflicting interests (between scientists and resource users) that are likely to arise wherever natural resources are being extracted.

Conflicting interests involve very different risks than language divides. As shown in this case, risk is perceived to be embedded in the very act of sharing knowledge and interacting: scientists fear their science will be politicized and resource users fear their LEK will be used in ways they cannot control and that are potentially harmful. This suggests that to incorporate LEK from locals with different interests than scientists, incentives must be created through structural or systemic changes to overcome these risks, or align the communities' interests. This was not accomplished in Pima County, but it is unclear if such an effort would have been beneficial to the SDCP. Given that the scientists had only one opportunity to develop a CLS, an act with even the slightest risk of compromising the research would, and probably should, have been avoided. The following case, however, begins to suggest how conflicting interests in other instances might be overcome and with what outcomes.

THE NEW ENGLAND GROUNDFISHERY

Introduction

This case study examines role of LEK in fishery management throughout the latter part of the 1900s, as groundfish stocks in the Gulf of Maine declined precipitously and conflict between scientists and fishermen raged. The case demonstrates how advancements in fishery science and technology and increasingly precautionary science and rule-making created both a language, and, in particular, an interest divide between fishermen and scientists that prevented fishermen's LEK from being incorporated into management science—although the region has had a rich history of cooperative research. The case further shows how these divides have been, and are being, bridged. As was seen in Pima County, this case demonstrates that an individual with a foot in both the local and scientific world can act as a translator between the two communities' knowledge bases, and can bring to light new visions of ecological systems by drawing on LEK. However, this case also begins to provide a model for how interest conflicts between scientists and locals can be overcome. This model is provided by the collaborative research initiatives that have been developed in the Gulf. These initiatives have created incentives for cooperative research and aligned scientists and fishermen's goals in joint research projects, thus overcoming many of the risks that have prevented such cooperation in the past.

Background

Tucked between the coastlines of Maine, New Hampshire and Massachusetts and the underwater shallows that sweep off Cape Cod and eventually rise to form George's Bank, lies the Gulf of Maine (Figure 5). For thousands of years its waters supported one of the world's richest fishing grounds, sustaining pre-American tribes, and later the European settlements that by the 19th century would grow into New England's wealthy coastal communities. Among the Gulf's many marine riches, the catch that fishermen most coveted were the abundant groundfish, a complex of bottom dwelling species including flounder, haddock, halibut and—most prized of all—cod.

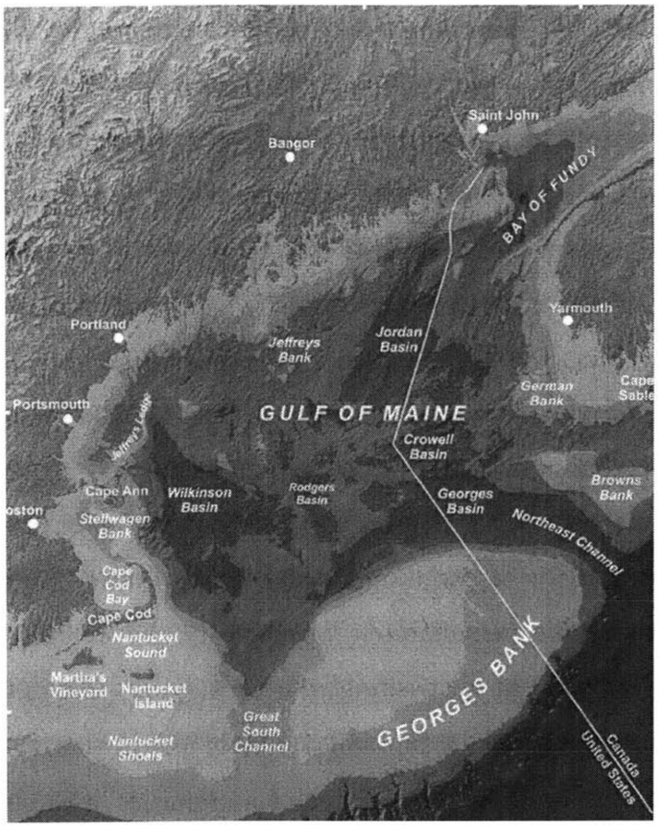

FIGURE 5. Gulf of Maine. (Base map courtesy of: The United States Geological Survey/Woods Hole Field Center)

Aside from several narrow international agreements, for the majority of the 20th century there was no comprehensive federal strategy to manage the Northeast fisheries—or, for that matter, any marine resources outside of state waters. However, the need for management of the vast commons was evident as early as the 1930s. At this time, technological advances in the fishery, such as the introduction of trawling vessels, coupled with increasing seafood demand began to expose the edges of the seemingly limitless system, in the form of several temporary commercial extinctions. Then in 1950, enormous foreign factory ships from Asia and Europe began to enter the Gulf. These vessels could stay out on the water for many months to years, and engaged in a systematic targeting of abundant species, gradually working their way down the food-chain (Murawski 2001). For the next two decades, concern among New England fisherman escalated to a fever pitch as they witnessed systems-wide declines in stocks and demanded that the U.S. government take action. By the time Congress responded with the Magnuson Fishery Conservation and Management Act of 1976 (also known as the Magnuson Act), groundfish stocks had collapsed, in some cases to less than 30% of their original numbers, and were followed by massive declines in essential prey, such as herring and mackerel (Murawski 2001).

With the Magnuson Act, Congress legislated a number of major changes in U.S. fishery management. First, the Act expelled foreign boats from the Gulf of Maine and other waters by demarking an exclusive fishing zone within 200 miles of all U.S. coastlines. Second, it sought to grow and modernize the nation's fishing fleet by providing financial incentives. And third, it established a comprehensive framework for U.S. fishery management and research intended to support the twin goals of environmental and economic sustainability. Specifically, the Act mandated that management measures "prevent overfishing while achieving...the optimum yield from each stock" and simultaneously " be fair and equitable to all fishermen" while minimizing "adverse economic impacts on such communities" (Magnuson Act 1976). To carry out this mission, Congress created eight regional fishery management councils, to be composed of state and federal managers, scientists, and industry. The councils would manage and develop regulations for their local waters, while the National Marine Fisheries Service (NMFS) a federal agency in the National Oceanic and Atmospheric Administration, would ensure regulatory compliance and provide stock assessments and projections.

Crisis and Conflict

In the Northeast, the Magnuson Act succeeded in relieving the pressure of foreign fleets in the Gulf of Maine; however the financial incentives, such as government backed boat-building loans, worked far too successfully. In fact, banks were so eager to provide these loans, that some fishermen would joke that if one "opened a savings account, the bank would either give you a free toaster or a free fishing boat; and they were all out of toasters" (Dobbs 1999, 104). The New England fleet quickly ballooned to fill the place of the Asian and European ones, and was soon catching nearly double what NMFS scientists deemed sustainable (Dobbs 1999, 59). Meanwhile, the New England Fisheries Management Council (hereafter "the council"), overwhelmed by the complexity of balancing both environmental and economic wellbeing in an uncertain social and ecological landscape, acted slowly and clumsily (Dobbs 2000, Murawski 2001). Furthermore because the council was composed largely of industry interests, who knew "a lot more about catching fish…than marine biology or natural resource management," members were reluctant to impose too stringent regulations (Layzer 2006, 255). The rules the council did promulgate were met with ire among fishermen, who saw them as too harsh and unfairly "democratic," as they applied equally to all fishermen, even those with different gear and boats sizes. The regulations were also met with consternation among scientists, who argued that they were inadequate. As the actors argued and the council waffled, the groundfish stocks plummeted.

The changes wrought by the Magnuson Act and the deteriorating conditions in the groundfishery produced another unfortunate and inadvertent outcome that only exacerbated the mismanagement of groundfish stocks: fishermen were pitted against government scientists and the gap between the two communities and their knowledge bases slowly widened. This had not always been the case. Although by the 1980s and 1990s few could imagine it, in the early half of the 1900s, scientists frequently worked collaboratively with fishermen. Such partnerships were borne both out of necessity—fishermen had the boats scientists needed to conduct their research—as well as their common interests in more productively exploiting the Gulf's seemingly infinite marine resources. Furthermore, scientists recognized that fishermen's expertise, based on decades of inherited and experiential knowledge, was unparalleled. Fishermen had, and continue to have, extensive LEK, some of which is passed down through family-lines, or shared laterally among fishing colleagues. Fishermen know where fish congregate, seek cover, spawn, and migrate, and how fishing practices or specific equipment affects this behavior. They have knowledge about interactions between species and with their habitat. They know bottom depths, type (rocky or smooth) and cover (eel grass, sponges, sand dollars) over vast areas—largely from what their nets pull up or get caught on. They are also aware of cycles of change and have knowledge about historical baselines that may precede scientific data collection. Some of this information is written down in detailed logs; most is stored into fishers' minds and integrated into their practices (Hall-Arber and Pederson 1999, Pederson and Hall-Arber 1999, Dobbs 2000, Ames 2006). Thus, at a time when the Gulf was a virtual unknown to the scientific community, fishermen knew it quite well. And some of the regions' greatest marine scientists, such as Henry Bigelow, who conducted the first, and still cited, scientific investigations into the Gulf, relied on fishermen's accounts and expertise to supplement and confirm his findings (Hartley and Robertson 2006, Dobbs 2000).

However, the passage of the Magnuson Act inspired several developments that presented two major challenges to the integration of fishermen's knowledge in fisheries science. The first development occurred in fisheries science and the ways and means by which scientists and fishermen learned about and understood the Gulf diverged: By requiring the unit of management to be single-species stocks, over their "full range", the Magnuson Act encouraged the narrow path of research that scientists had recently embarked on: estimating, modeling, and predicting stock sizes and composition (i.e. "stock assessments"). In 1963, NMFS scientists, working out of the New England Fisheries Science Center (NEFSC), initiated the first groundfish trawl survey. Surveys were conducted bi-annually (using identical procedures for statistical accuracy) and the resulting data was input into mathematic models to produce NMFS' stock assessment. Because of Magnuson's science-based standards and the council's need for immediate answers on how many fish were in the Gulf, and how many could be removed "sustainably", these assessments became the primary scientific analyses on which the council made and explained their management decisions (Dobbs 2000). In turn, NMFS's research budget shifted away from "biological science, gear research, and extension activities" to support the surveys and the increasingly complex and statistically rigorous assessment models, leaving fishermen with "few opportunities to contribute the knowledge they possessed" (Hartley and Robertson 2006).

In addition to being angered by the abstruse nature of NMFS's models, fishermen also found fault with the vision of the natural world that underlay them; it was a vision that was utterly at odds with fishermen's own understanding of the Gulf's dynamics.

NMFS models assumed a system linearity, a predictable, causal relationship between fishing effort and population size. They also assumed a relatively "constant context" across a broad-scale (Acheson et al. 1998, Smith 1995). Fishermen saw things much differently. Far more attuned to fine-scale phenomena and system interconnections, fishermen argued that NMFS methodologies and approach were misguided and even mistaken.

At times fishermen's complaints were a result of misunderstanding how the scientific models corresponded to what fishermen saw on the water. For example, during early 1980s, NMFS assessments showed a serious decline in stocks, while fishermen, boosted by "Magnuson-driven fleet modernization" continued to have relatively consistent catches (Hartley and Robertson 2006). As NMFS' claims did not match their experience on the water, fishermen took what was really a relic of technological advancement to mean the assessments were wrong. However, fishermen also noted problems that would later be reiterated by scientists, even within NMFS itself). For example, they argued that NMFS' models misunderstood and downplayed the effects of localized events—behavioral and distributional changes in stocks and small-scale disturbances—and wrongly ignored interactions between generations as well as between species. Furthermore, they complained that scientists' (and managers') assumptions about fishermen's practices were wrong. For example, gear changes, did not always work as expected, or solved one problem while creating another. However, fishermen's expertise was rarely presented in scientific terms and frequently challenged NMFS' scope of work, thus, for NMFS, the relevance of the information fishers provided as well as its accuracy was uncertain. Instead, NMFS deemed fishermen's LEK "anecdotal" and subjective.

In addition to the widening divide between how fishermen and scientists envisioned and understood the Gulf and its fish populations, a second development in the latter half of the 1900s further divided the groups: NMFS scientists became far more precautionary in their analyses and recommendations (Layzer 2006). While many fishermen continued to cling to the belief that the Gulf's resources were inexhaustible, or simply resisted any attempt to limit their activities, scientists—witnessing yearly declines in their stock surveys—argued for the NEFMC to impose stricter conservation measures.

The days when fishery scientists and fishermen were united in a mission to maximize exploitative effort and efficiency had long past. Thus, in addition to being separated by a language divide, the expertise of scientists and fishermen was shrouded by mutual mistrust. Scientists viewed fishermen and their LEK with suspicion: how could fishermen, who were facing large economic losses from regulation, possibly be "objective" in their analysis of stock conditions? (Wilson 2007). Fishermen on the other hand, accused NMFS of using bad science to try and put them out of business.

Any hope for collaboration between industry and scientists appeared dashed by the events of the 1990s. In 1991, the Conservation Law Foundation sued the Secretary of Commerce[3] for failing to protect New England Groundfish from overfishing: In 50 years, the Gulf of Maine cod stock had declined by 90%, and represented less than a 20th of the biomass extant in the 1850s (Hartley and Robertson 2006). Overall groundfish biomass levels were at their lowest in two decades and would continue to decline to an all-time low in 1999 (NMFS—cite). The lawsuit "empowered conservation minded-oriented managers on the council and within NMFS" and effectively put an end to the influence that industry had wielded over the Council (Layzer 2006). Any channels, via Council representation or congressional intervention, that may have existed for fishermen to influence decisions or offer their expertise shut-down. The Council turned to NMFS' scientists for guidance, and all rules were submitted to NMFS lawyers before they were promulgated (Hall-Arber 2007). Beginning in 1994, the Council began passing exceedingly strict regulations, compensating for 20 years of inadequate action. While deemed necessary by NMFS and the Council, the rules were economically disastrous for many small fishing fleets and coastal communities. Council meetings devolved into grim events where industry attendees shouted, wept, and threw punches and unleashed their frustration on those "bearing the bad news"—the scientists—inflaming an already adversarial and defensive relationship (Dobbs 2001). As the journalist David Dobbs has written: " In the blurring of boundaries and denial of limits that the spectacularly dysfunctional council process encouraged, [the] louder angrier sector of the fishing community didn't want to bother distinguishing between NMFS's science and policy branches, and found some pleasure in the idea of killing the messenger" (Dobbs 2001, p. 60).

Bridging Visions of the Gulf: Mapping Historic Cod Spawning Grounds and Migration Patterns with LEK

Not everyone believed that the visions of fishers and scientists were as irreconcilable as Council meetings or industry diatribes in the widely read *National Fisherman* suggested. Some contended that fishers' LEK could complement fishery science, and vice versa. For example, NMFS assessments accurately perceived changes at the broad-scale, they ignored potentially significant local nuances and phenomena—the type of information that was embodied in fishers' LEK. At the same time, fishers' conclusions were often skewed by their limited view of the system; this explained why some fishermen were convinced that fish populations were growing, while others believed the stocks were virtually wiped-out (Wilson 2007). The application of scientific methodology to fishers' insights was necessary, particularly if the ideas were to be useful to the council, which was required to abide by the Data Quality Act and Magnuson's mandate that regulations be based on "best available science."

As seen in the Pima County case study, the individuals who saw both the potential for using LEK in fishery science and the *means* to translate it into science straddled both the world of the locals and the world of the scientists. As intermediaries, they could see the relevance of LEK and the value of applying it in fisheries science. Furthermore, as intermediaries, they understood how to bridge the language divide that plagued New England fishers and scientists in the 1990s, and blend the two groups' expertise.

One such individual was Ted Ames, a life-long New England fisherman and lobsterman, from a family of fishers that went back 250 years to Stonington, MA, as well as a trained scientist, with a master's in biochemistry and a nearly completed PhD in Oceanography. Ames disagreed with those who discounted fishermen's LEK as "subjective," "anecdotal," and generally of little use except as an "historical footnote" (Wilkinson 2006, Ames 2006). Ames was also critical of those who claimed (as a National Research Council report did in 1999) that the crisis in the groundfishery was the result of "too many fishers chasing too few fish." Although he agreed that a high catch rate had led to the decimation of groundfish stocks, he also believed that the statement simplified the complexity of managing a sustainable fishery. In particular, Ames was interested in how the lack of historical baselines and consideration of fine-scale changes in populations may have "aggravated attempts to manage New England's commercial fisheries," and how the LEK of fishermen, which, he argued, provided the only source of "local, historical, place-based fisheries information," could begin to fill those gaps (Ames 2006).

In the mid-1990s, Ames embarked on research that would fuse his background in science, his decades on the water, and his interest in improving the sustainability of the groundfishery. It started in 1994, when he joined a state commissioned study, looking at the feasibility of establishing several cod and haddock hatcheries in Maine's in-shore waters, where groundfish populations had collapsed in the 1950s and, curiously, failed to rebuild, even as off-shore populations rebounded. His commission found that a more efficient approach would be to release young fish into once productive spawning grounds and nursery sites. There was, however, one large obstacle: no one knew where those grounds were. They had been "fished-out"—effectively cleared of fish—decades before. As he pondered a solution, Ames began to think about the grounds he and other fishermen had fished out in the 1970s, and realized that by interviewing retired fishermen (fishers of his father's or grandfather's generation), he could patch together their knowledge of relic spawning grounds and potentially identify the disappeared sites. In the late 1990s, Ames received funding to complete such a study, and began to track down and interview fishers.

Had Ames simply been a scientist, he may have had a much harder time gathering the information he needed for his study. But because he was a fisherman, he was able to communicate in a common tongue and knew to use media that fishers would be familiar with, such as nautical maps to elicit data. Because of his fishing experience, Ames also understood the effects different gear types would have on catch; he knew, for example, that cod do not feed when they are spawning, thus fishermen who used trawlers, which drag nets through the water, would provide better data on spawning sites than hook and line fishermen (Ames 2006). He was also prepared for certain challenges that someone from outside the fishing community may not have been, and was able to respond appropriately. For example, when he began, Ames did not know the names of retired in-shore fishermen but was able to draw on his connections with several coastal groundfish organizations to recommend and locate relevant fishers (Ames 2006).

Although his background as a fisher was vital to his recognizing the potential of LEK and the means to responsibly and efficiently elicit it, Ames' training as a scientist and his connections to the local scientific community gave him the tools he needed to undertake a rigorous study and convey his findings in a manner that would resonate with scientists and managers. Ames carefully validated his data; he only recorded sites that were independently identified by more than two fishers and that also bore physical traits that were characteristic of cod spawning grounds. He further verified his work with other scientific research, such as studies of extant spawning grounds and sonar scans of the ocean bottom, which he found lent credence to his interviewees' LEK. Finally, his work was assisted and peer reviewed by some of Maine's leading ecologists (Dobbs 2000).

At the study's end, Ames had identified over 2,800 km^2 of cod and haddock spawning grounds from fishers' LEK, over half of which were no longer active (Ames 1997). The work further established that cod and haddock had once spawned "along the length of the Gulf of Maine's coast" (Ames 2006). In addition to locating these forgotten sites, the research offered clues to why the coastal spawning grounds had never rebounded, and instead blinked out. If cod, like salmon, exhibit site fidelity—that is they only return to their birthplace to spawn—once a spawning site is fished-out, it will remain so, perhaps indefinitely. Other populations will not move-in to repopulate, and the empty grounds can not be "reseeded by eggs floating in from elsewhere…as the Gulf's current pattern prevents eggs laid offshore from finding their way into the bays" (Dobbs 2000).

In 2001, Ames discovered research by the fisheries biologist Joe Wrobelewski that confirmed belief that cod were faithful to their birth-site and returned there, year after year, to spawn. With this confirmation, the LEK collected from his previous study, and several other early data sources, he began developing what he would later refer to as a "proto-type database for Atlantic cod from fishermen's knowledge" (Ames 2006).

Essentially, he set out to "reconstruct the Gulf of the past" (Wilkinson 2006). Using the spawning grounds of the 1920s (when cod populations were healthier) as "points of origin", Ames was able to track the seasonal movements of the Gulf of Maine cod during that time (Ames 2006). What he found was startling. Although NMFS divides the cod of the Gulf of Maine into two stocks, Gulf of Maine and George's Bank, and the council develops regulations based on this model, the migration patterns in Ames' mapping showed three distinct sub-populations that moved from spawning grounds to feeding grounds in annual cycles (Ames 2004).

Drawing on the LEK of fishermen, Ames has produced another vision of the Gulf, one that takes into account the system nuances that heretofore have been absent from fisheries science. The growing influence of systems ecology in the fisheries, with its attention to scale and non-linearities, has only increased the importance of his work. Should his conclusions find wide acceptance, they have substantial implications for fishery management. While the Gulf of Maine cod have been managed as one homogenous stock, Ames' findings suggest that such management will fail to detect and account for local extinctions, and perpetuate the fishery's decline. Ames, number of other scientists, as well as several fishers' and environmental organizations have lobbied the council to institute what is referred to as "area-based management", which would divide the gulf into three separate management regions corresponding to the three cod sub-populations. Although the council had thus far refused to agree to this option (Wilson 2007), the plan would create:

> ...three ecologically discrete subdivisions...accessible only to fishers who agreed to fish in one of the areas for five years, making it imperative that they would develop a good rebuilding program...harvesting [would] be restricted to modest levels that allow the development of a sustainable fishery that provides long-term benefits to the local economies of the area (Ames 2006, 360).

Shifting the Incentive Landscape: The Return of Collaborative Research and the Aligning of Interests

Although Ames' research supported fishers' claims that their knowledge could "help manage a fishery if it was collected with appropriate rigor and judgment," individuals with his translation skills were rare. Furthermore, the research of Ames, and other intermediaries like him, could not address on a large-scale the systemic failures that had led to the dysfunctional relationship between fishermen and scientists. Efforts to translate LEK could not overcome the interest and value conflicts that continued to divide scientists and fishermen; indeed it is notable that Ames relied primarily on retired fishermen's LEK, as active fishermen were far less likely to participate in scientific research studies, often out of mistrust and fear that information could be used against them. By the late 1990s, this breakdown in relations had revealed the need to find ways to productively deal with divergent visions and work towards re-establishing trust. In 1998, for example, a National Research Council panel of independent fishery scientists (directed by Congress to investigate the accuracy of NMFS's science and assessments), produced the report: *Review of Northeast Fishery Stock Assessments.* Even as they exonerated NMFS scientists of industry charges of scientific inaccuracy, the panel also cited the need to "improve relationships and collaborations between NMFS and harvesters by providing, for example, an opportunity to involve harvesters in the stock assessment process and using harvesters to collect and assess disaggregated catch per unit effort data" (NRC 1998).

The conflict was not only taking its toll on the scientists and fisher communities, but congressmen and women were increasingly fielding complaints from industry interests and acting as "referees" to the conflict, while litigation had become the primary tool of environmental groups, as well as industry and concerned citizens, to challenge council decisions (Goethel 2007). NOAA accounted for well over 50% of all lawsuits filed against government agencies, and NMFS had created a "tailored fisheries litigation database to track the thousands of cases" it received (Hartley and Robertson 2006, Goethel 2007).

In recognition that something needed to be done, in the late 1990s, Congress and NOAA initiated two major funding programs that shifted the incentive landscape to favor collaborative research and the integration of LEK into a scientific framework. The first program was established through a $5 million dollar emergency relief effort, passed by congress to assist New England fishers after the council instituted rolling closures across the Gulf. Largely due the wise political maneuvering of Senator Judd Greg of New Hampshire, the relief fund transformed from a "check-writing exercise" to the "linking of economic assistance with collaborative research" (Hartley and Robertson 2006). In 1999, the operation coalesced into what is now known as The Northeast Consortium (NEC). Through the input of a multi-stakeholder advisory committee, the NEC established four main objectives. In addition to its original goal of providing economic relief to industry, the NEC sought to: foster partnerships between fishers, researchers, and managers; enable the participation of industry in research; integrate LEK and fishery science; and equip commercial vessels for research and monitoring use (Hartley and Robertson 2006). In 1999 the Northeast Regional Office of the NOAA Fisheries Service established a similar funding program to support collaborative work within the agency and regional council. Known as the Cooperative Research Partners Program (CRPP), the goal of the program is to establish cooperative partnerships to "enhance the data upon which fishery management decisions are made as well as to facilitate communication and collaboration among New England commercial fishermen, scientists, and fishery managers" (NOAA 2006).

The introduction of collaborative research programs created incentives that have encouraged many fishermen and scientists to engage in cooperative scientific assessments of the Gulf. These programs have accomplished this by making the benefits of cooperative research outweigh the risks that were frequently associated with such work. The first incentive these programs provide is financial. Fishermen are drawn to the economic support provided through the grant money—NEC funding, for example, mandates a 75%-25% split between industry and researchers, respectively. Scientists are also drawn to the funding, but even more attractive is the easy access to a research platform. Chartering vessels is the most expensive part of oceanic research, and through these programs the fishermen partners provide the research boats (Goudy 2007).

Another incentive is the opportunity for fishermen to offer LEK and for scientists to have access to it. Because involvement in the research is also voluntary, the scientists and fishermen who work together choose to do so, and are often equally invested in the research. Thus their goals and interests are aligned and both parties exercise control over the experiment and the use of knowledge in it. This aligning of interests and sharing of control reduces risks to both the scientists and fishermen. For scientists, the risk that their work will be politicized by conflict is enormously reduced. Furthermore, because fishermen have control over how their knowledge is used, they are less protective of their hard-earned LEK and more willing to share and apply it in research. By overcoming the risks associated with conflicting interests, collaborative research permits a freer exchange of knowledge, where benefits can accrue through the eliciting and divulging of LEK.

Of course not all the collaborative projects offer equal opportunities to integrate fishermen's expertise. In some cases, the extent of the collaboration goes no further than scientists and fishers sharing the same vessel (Atkinson 2007). However, even in some of the more "top-down" projects, such as NMFS cod-tagging program, where fishers have had almost no role in shaping the scope or methods of the project, LEK plays a vital role: fishers know where the fish are, when they will be there, and how and where to set the gear (Goethel 2007).

However, on the other end of the spectrum, a number of projects, particularly those funded by the NEC, are actually driven by fishers' research questions. When fishermen—as opposed to NMFS—are able to determine the research questions and scope of the project, a new vision of the Gulf, with potentially important management implications, can materialize. For example, the Cape Cod Commercial Hook Fishermen's Association (CCCHFA), an association established by a group of hook fishermen (some of whom are also scientists) in 1991, is active in a number of NEC and CRPP funded collaborative projects. Every one of their studies integrates fishermen's input in initial brainstorming, the design, execution, analysis, reporting, and management recommendations (Parker 2007, Rudolph 2007). In 2001, they initiated a study on herring populations based on a local fisher's concern that populations were declining and may be impacting the cod that feed on them. In another study, funded by the CRPP, at the urging of a local fishermen, CCCHFA teamed up with scientists from the NMFS' New England Fisheries Science Center to examine possible genetic differences between spawning cod in the east and west parts of George's bank. The result of the study found that the two spawning components were genetically distinct, indicating that they be separate sub-populations.

Discussion

This case confirms many of the findings from the Pima County case. Two similar obstacles to integrating LEK in management science emerge. The first is a language divide that has developed as fisheries science has become more complex and inaccessible to fishermen. The second obstacle is that of conflicting interests, which so often arises between precautionary scientists and more cornucopian resource users (Layzer 2006). As seen in Pima County, this case has shown that individuals, who straddle both the scientific and local world and can translate between them, has been able to overcome these divides between the fishing and the scientific community. However, as seen in the previous case, the translator is in control of what question is asked, how the scope of research is defined, what methods are used, and how results are interpreted. For others involved, the process is a passive one.

This case has also provided a model for how interest conflicts between scientists and locals can be overcome. This model is provided by the collaborative research initiatives that have been developed in the Gulf. These initiatives have created incentives for cooperative research and aligned scientists and fishermen's goals in joint research projects, thus overcoming many of the risks that have prevented such cooperation in the past. However, a number of questions remain. First, although cooperative research has indeed succeeded in creating incentives that encourage and support collaborative enterprises between fishermen and scientists, it is not a stable, self-sustaining arrangement. In fact, it is currently uncertain if money will be available from the NEC for future projects (Goudy 2007). As one of the largest funders of collaborative of research, this could be a major blow to the future of collaborative research in the Gulf. Furthermore, the introduction of collaborative research does not change the management structure with which so many fishermen find fault. Indeed, it is the management structure itself that makes sharing some of the most valuable LEK risky. Fishers can provide real-time information, based on what they see and experience on the water, which is some of the most useful information to have in management. However, the current management regime has established competition between fishers and discourages them from sharing this short-scale knowledge. With this in mind, a more lasting way to overcome conflicting interests might be what Ames and others have in mind: an area-based management regime where fishers exercise a form of "property rights" in the commons and are actively engaged in management. In this case, fishers might be more encouraged to share real-time LEK and work with scientists to maintain a sustainable and healthy fishery.

CONCLUSION

Conclusions: A Summary of the Findings

The case studies analyzed in this thesis confirm the theory regarding the benefits of incorporating LEK into resource management science. In both Pima County and the Gulf of Maine fisheries, LEK supplemented and at times corrected management science; in the New England Groundfishery, LEK also provided new visions of the Gulf's ecological system that may eventually lead to more nuanced and sustainable management, based on the system complexity that LEK is revealing. This will, of course, also depend on the values that guide management decisions, and specifically whether or not rulemaking remains precautionary. Accurate knowledge and nuanced understanding alone can only help, not create, a healthy fishery.

However, my goal in analyzing these cases was to understand why LEK is so infrequently used in practice: what is preventing scientists on the ground from using LEK? And when scientists do draw on LEK, why do they choose to do so and how do they overcome the related obstacles. Indeed, understanding what are the obstacles to using LEK should be the first step in developing ways to increase its accessibility and its incorporation into management science. The conventional wisdom in most LEK literature is that "language" is the major obstacle preventing the uptake of LEK in management science. With this belief as an operating assumption, many researchers have already begun to develop methods of eliciting and translating LEK. This study confirms that a language divide presents an obstacle to incorporating LEK into management science. The language divide prevents scientists from recognizing the relevance or accuracy of LEK, and with limited time and research budget, scientists rarely can afford to invest energy in understanding and confirming LEK. From the standpoint of untrained locals, scientific methods and assessments are often too complex and time-consuming to understand, and they are unable to engage productively in the research. This study further shows how individuals with standing in the both the local and scientific communities can translate across this divide.

But this study also demonstrates that if one hopes to facilitate the integration of LEK into management science, simply developing methods to overcome the language divide is not enough. The knottier challenge to incorporating LEK into U.S. natural resource management science is that of conflicting interests between scientists and locals. As the case analyses demonstrate, such conflicts are to be expected between those who extract resources—and have some of the most extensive LEK—and the scientists responsible for advising managers on how that extraction should occur. Whereas resource users tend to hold utilitarian values and resist any attempts to limit their access to the resources they extract, natural resource scientists have become increasingly precautionary and conservation-minded over the past several decades. Such contradictory interests and values make knowledge sharing a risk-incurring exercise for both scientists and resources users. And unlike the risks associated with bridging the language divide, these risks or potential costs are not related to the effort required to undertake translation; rather the risks are embedded in the very act of working together and sharing knowledge. Scientists fear that by involving adversarial resource users they will politicize and compromise their science. Resource users fear that if they divulge LEK, it will be used to limit their access to resources, or somehow compromise their livelihood.

The case of the New England groundfishery provides one model for overcoming the obstacle of conflicting interests. It shows that in order to do so, incentives must be provided that make knowledge sharing and cooperative work beneficial, and simultaneously reduce the potential risks involved. The cooperative research programs in the Gulf of Maine ingeniously achieved this shift in incentives by providing financial incentives, supporting research alliances between fishermen and scientists, and encouraging the alignment of fishermen and scientists' interests in service to the research projects goals. There are drawbacks to this model. They include the programs' financial instability, as well as its inadequacy in addressing the problems of the Gulf's management structure. However, the program does offer a model for how one might shift incentive structures so that benefits of cross-community work outweigh the associated risks.

It is worth reiterating the point that more LEK is not always better. There are instances when LEK is wrong, where it does not provide desired benefits, or where the risks involved in incorporating it may outweigh potential gains. However, given the conclusions of this thesis, the following section presents a number of policy recommendations for different institutions and individuals who may be interested in expanding the availability and use of LEK in natural resource management.

Policy Recommendations for Agencies

I. Establish the right incentives

This is the most fundamental recommendation for management agencies. Incentives must be established that provide benefits and overcome the risks associated with collaborative work. What these incentives are may depend on the communities involved. However, incentives may include, but are not limited to, financial incentives for collaborative research; written assurances that locals will control what happens with their knowledge and how it is interpreted in studies in policy; financial support for time locals spend with scientists or on projects; and written agreements between scientists and locals that outline expectations and commitments.

II. Foster relationships between agency scientists and locals

The more scientists interact with locals, the more knowledge they gather and the more they dismantle barriers of mistrust that inhibit cooperation. Agency scientists in Pima County provide an excellent model for this type of close engagement: Many of the of them work in the field and speak extensively with locals, as well as the naturalist organizations that network with locals. Furthermore, agencies can foster these relationships through partnership programs, such those as run by the Natural Resource Conservation Service that work with ranchers on common projects, such as range restoration and the documentation of landscape health and function.

III. Involve local field scientists in management research programs

Many agencies have field scientists who have already established strong bonds of trust and understanding with locals, particularly resource users. These scientists are vital links to the local community. In Pima County, for example, the field scientists who served as STAT's experts also served as conduits to the larger local community and could facilitate the interaction between the communities. It is important to have at least one such individual engaged in management programs.

IV. Establish methods to store the LEK that is acquired

Not all LEK can be codified and still retain its meaning. However, it is important that the knowledge that is acquired through interactions with locals not disappear when the agency employee or local leaves. A number of institutions have established LEK oral history projects, which collect oral histories related to the ecology of important sites. Histories are recorded and stored for future research and reference. Published research papers written on collaborative research or LEK may also serve a similar function.

Recommendations for Resource Users and Other Bearers of LEK

I. Be assertive about needs and requirements

Individuals with LEK should be clear about what they need to feel comfortable sharing LEK (e.g. what written agreements, what form of compensation, and what role in the research or policy formation they need) as well as what expectations they have for how that knowledge will be used. Establishing requirements early will prevent misunderstanding and also ensure that LEK is put to use in a manner with which its originator feels comfortable.

Recommendations for Academia

I. Train knowledge translators

This study has illuminated the need for individuals who have the ability to straddle scientific and resource dependent communities and clearly translate between them. This suggests a need for academies to train individuals who are versed in science, ecology, mediation, and anthropology. Such individuals would be essential to facilitating the translation of LEK and its integration into management science.

II. Train scientists to work with locals

Although scientists in most universities are now taught the skills of knowledge translation for the purpose of educating the lay public, they should also be taught to use the public as a resource. That is, biology students could be educated about LEK, what its benefits are, and how to elicit it. LEK from locals could then be integrated into research projects. At the University of Arizona, some professors are already doing this. For example, in one study of roadrunner distribution, part of the methodology for mapping the birds included setting up an answering machine for the public to call in sightings. After a day the machine had to be thrown out; it had filled to its capacity of 500 messages (Shaw 2007).

REFERENCES

Acheson, J. M., Wilson, J. A. and Steneck, R. S. 1998. Managing chaotic fisheries. Pages 390-413 *in* F. Berkes and C. Folke, eds. Linking Social and Ecological Systems. Cambridge: Cambridge University Press.

Agrawal, A. 1995. Dismantling the divide between indigenous and scientific knowledge. *Development and Change* 26, (3) (JUL): 413-439.

Ames, T.. 2004. Atlantic cod structure in the Gulf of Maine. *Journal of the American Fisheries Society* 29, (1): 10-27.

———. 2006. Putting fishers' knowledge to work: reconstructing the Gulf of Maine cod spawning grounds on the basis of local ecological knowledge. Pages 351-361 *in* N. Haggan, B. Neis, and I.G. Baird, eds. Fishers' Knowledge in Fisheries Science and Management. Paris: UNESCO.

Atkinson, Jen. In person interview. January 28, 2007.

Baker, Beryl. Phone Interview. February 16, 2007.

Bäckstrand, K. 2003. Civic science for sustainability: Reframing the role of experts, policy-makers and citizens in environmental governance. *Global Environmental Politics* 3, (4): 24-41.

Bart, D. 2006. Integrating local ecological knowledge and manipulative experiments to find the causes of environmental change. *Frontiers in Ecology and the Environment* 10, (10) (DEC): 541-546.

Behan, Maeveen. In person interview. January 26, 2007.

Berkes F, Folke C, editors. 1998. Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. Cambridge (England): Cambridge University Press. of tropical biodiversity. New York: Oxford University Press.

Berkes, F., J. Colding, and C. Folke. 2000. Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications* 10, (5) (OCT): 1251-1262.

Brint, S. 1994. In an Age of Experts. Princeton, N.J.: Princeton University Press.

Caldwell, Dennis. Phone interview. February 15, 2007.

Calheiros, D. F., A. F. Seidl, and C. J. A. Ferreira. 2000. Participatory research methods in environmental science: Local and scientific knowledge of a limnological phenomenon in the pantanal wetland of Brazil. *Journal of Applied Ecology* 37, (4) (AUG): 684-696.

Colding, J., and C. Folke. 2001. Social taboos: "invisible" systems of local resource management and biological conservation. *Ecological Applications* 11, (2) (APR): 584-600.

Conservation Fund, The. 2005. Green Infrastructure Case Series: Sonoran Desert Conservation Plan, Pima County, Arizona, viewed January 18, 2007. www.greeninfrastructure.net/sites/greeninfrastructure.net/files/6-sonoranfinal11.16.05.pdf

Corburn, J. 2003. Bringing local knowledge into environmental decision making - improving urban planning for communities at risk. *Journal of Planning Education and Research* 22, (4) (SUM): 420-433.

———. 2002. Combining community-based research and local knowledge to confront asthma and subsistence-fishing hazards in Greenpoint/Williamsburg, brooklyn, new york. *Environmental Health Perspectives* 110, (APR): 241-248.

Davis, A., and J. R. Wagner. 2003. Who knows? On the importance of identifying "experts" when researching local ecological knowledge. *Human Ecology* 31, (3) (SEP): 463-489.

Diamond, J. M. 2005. *Collapse : How Societies Choose to Fail or Succeed.* New York: Viking.

Dobbs, D. 2000. The Great Gulf. Washington, D.C.: Island Press.

Drew, J. A. 2005. Use of traditional ecological knowledge in marine conservation. *Conservation Biology* 19, (4) (AUG): 1286-1293.

Falk, Mima. In person interview and email communication. 30 January and 18 April, 2007.

Fazey, I., J. A. Fazey, J. G. Salisbury, D. B. Lindenmayer, and S. Dovers. 2006a. The nature and role of experiential knowledge for environmental conservation. *Environmental Conservation* 33, (1) (MAR): 1-10.

Fazey, I., K. Proust, B. Newell, B. Johnson, and J. A. Fazey. 2006b. Eliciting the implicit knowledge and perceptions of on-ground conservation managers of the macquarie marshes. *Ecology and Society* 11, (1) (JUN). [online] URL: http://www.ecologyandsociety.org/vol11/iss1/art25/

Fischer, F. 2000. Citizens, Experts, and the Environment: The Politics of Local Knowledge. Durham, NC: Duke University Press.

Fonseca, Julia. In person interview and email communication. January 25 and April 17, 2007

Fromer, Paul. Phone interview. March 13, 2007.

Geertz, C. Local Knowledge : Further Essays in Interpretive Anthropology. New York: Basic Books.

Geiser, U. 2002. Knowledge, knowledge management, and sustainable natural resource use: An introduction. Pages 157-180 *in* M. Flury and U. Geiser, eds.. Local Environmental

Management in a North-South Perspective : Issues of Participation and Knowledge Management. Amsterdam, IOS Press: Zürich.

Gilchrist, G., M. Mallory, and F. Merkel. 2005. Can local ecological knowledge contribute to wildlife management? case studies of migratory birds. *Ecology and Society* 10, (1) (JUN). [online] URL: http://www.ecologyandsociety.org/vol10/iss1/art20/

Goethel, David. Phone interview. February 25, 2007.

Goudy, Cliff. In person interview. May 23, 2007.

Habermas, J. 1970. Toward a Rational Society. Boston: Beacon Press.

Hall-Arber, Madeline. In person interview. March 15, 2007.

Hall-Arber, M. and Pederson, J. 1999. Habitat observed from the decks of fishing vessels. *Fisheries* 24, (6): 6-13.

Hartley, T. and R.A. Robertson. 2006. Emergence of multi-stakeholder-driven cooperative research in the Northwest Atlantic: The case of the Northeast Consortium. *Marine Policy* 30, (5): 580-592.

Holling, C.S. 1978. Adaptive Environmental Assessment and Management. New York: John Wiley & Sons.

Huckleberry, C. 2002. The Sonoran Desert Conservation Plan. *Endangered Species Bulletin* 27, (2): 12-15.

Huntington, H. P. 2000. Using traditional ecological knowledge in science: Methods and applications. *Ecological Applications* 10, (5) (OCT): 1270-1274.

Jasanoff, S. 1995. Science at the Bar: Law, Science, and Technology in America. Cambridge, MA: Harvard University Press.

Kloor, K. 2005. Score one for the desert. *Audubon* 107, (3) (MAY-JUN): 38-43.

Layzer, J. A. 2006. The Environmental Case: Translating Values into Policy. 2nd ed. Washington, D.C.: CQ Press.

———. 2008. Natural Experiments: Ecosystem Management and the Environment. Cambridge, MA: MIT Press (Forthcoming).

Lele, S., and R. B. Norgaard. 1996. Sustainability and the scientist's burden. *Conservation Biology* 10, (2) (APR): 354-365.

Levin, S.A. 1992. The problem of pattern and scale in ecology. *Ecology* 73, (6) (DEC): 1943-1967.

Lynn, F.M. 1986. The interplay of science and values in assessing and regulating environmental risks. *Science, Technology, and Human Values* 11, (2): 40-50.

Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, resource exploitation, and conservation - lessons from history. *Science* 260, (5104) (APR 2): 17-36.

Ludwig, D. 2001. The era of management is over. *Ecosystems* 4, (8) (DEC): 758-764.

Magnuson-Stevens Fishery Management and Conservation Act of 1976. PL 94-265, 90 Stat. 331; 16 U.S.C. sections 1801-1882.

Meine, Curt. 1995. The oldest task in human history. Pages 7-35 *in* R. Knight and S.F. Bates, eds. A New Century for Natural Resources Management. Washington, D.C.: Island Press.

Milliken, Henry. Phone interview. June 4, 2007.

Murawski, S.A. 2001. Statement to the House of Representatives, Subcommittee on Fisheries Conservation, Wildlife and Oceans Committee on Resources. *Ecosystem-based management.* 14 June, viewed 24 February, 2007. http://www.legislative.noaa.gov/Archives/2001/murawskitst061401.html

Murphy, D. D., and B. D. Noon. 1991. Coping with uncertainty in wildlife biology. *Journal of Wildlife Management* 55, (4) (OCT): 773-782.

National Research Council. 1998. Improving Fishery Stock Assessments. Washington D.C.: National Academy Press.

Neis, B., D.C. Schneider, L. Felt, R.L Haedrich, J. Fischer, J.A. Hutchings. 1999. Fisheries assessment: what can be learned from interviewing resource users? Canadian Journal of Fisheries and Aquatic Science 56, (10): 1949-1963.

Niamir-Fuller, M. 1998. The resilience of pastoral herding in Sahelian Africa. Pages 250-284 *in* F. Berkes and C. Folke, eds. Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. Cambridge, UK: Cambridge University Press.

Noss, R. F., and A. Cooperrider. 1994. Saving Nature's Legacy: Protecting and Restoring Biodiversity. Washington, D.C.: Island Press.

Ozawa, C. 1996. Science in environmental conflicts. *Sociological Perspectives* 39, (2): 219-230.

Parker, Paul. Phone interview. March 28, 2007.

Pederson, J. and Hall-Arber M. 1999. Fish habitat: a focus on New England fishermen's perspectives. American Fisheries Society Symposium 22: 188-211.

Petts, J., and C. Brooks. 2006. Expert conceptualisations of the role of lay knowledge in environmental decisionmaking: Challenges for deliberative democracy. *Environment and Planning A* 38, (6) (JUN): 1045-1059.

Policansky, D. 1993. Uncertainty, knowledge, and resource-management. *Ecological Applications* 3, (4) (NOV): 583-584.

Popper, K. 1965. Conjectures and Refutations: The Growth of Scientific Knowledge. New York: Harper and Row.

Robertson, H. A., and T. K. McGee. 2003. Applying local knowledge: The contribution of oral history to wetland rehabilitation at Kanyapella Basin, Australia. *Journal of Environmental Management* 69, (3) (NOV): 275-287.

Rosen, Phil. In person interview. January 26, 2007.

Rudolph, Tom. Phone interview. March 30, 2007.

Sarewitz, D. 2000. Human well-being and federal science—what's the connection? Pages 87-102 *in* D.L. Kleinman, ed. Science, Technology, and Democracy. Albany, NY: SUNY Press.

Sarewitz, D., and A. Pielke. 2000. Prediction in science and policy. Pages 11-22 *in* D. Sarewitz, R.A. Pielke, Jr., R. Byerly, Jr., eds. Prediction: Science, Decision Making, and the Future of Nature. Island Press, Washington, D.C.

Scott, J. C. 1998. *Seeing Like a State : How Certain Schemes to Improve the Human Condition Have Failed.* Yale agrarian studies. New Haven Conn.: Yale University Press.

SDCP. 2000. Priority Vulnerable Species Habitat Data Analysis (Draft), viewed 13 February, 2007. http://www.pima.gov/cmo/sdcp/reports\d16\051PRI.pdf.

———. 2001. Reserve Design Process Update (Draft), viewed 23 January, 2007. http://www.pima.gov/cmo/sdcp/reports\d17\068RES.pdf.

Shaw, Bill. In person interview. January 25, 2007.

Sillitoe, P., A. Bicker, and P. Pottier, editors. 2002. Participating in Development : Approaches to Indigenous Knowledge. London ;   New York : Routledge.

Smith, E.S. 1995. Chaos, consensus, and common sense. *The Ecologist* 25, (2/3) (March/April): 80-85.

Stevenson, M. G. 1996. Indigenous knowledge in environmental assessment. *Arctic* 49, (3) (SEP): 278-291.

Walker, B., S. Carpenter, J. Anderies, N. Abel, G. Cumming, M. Janssen, L. Lebel, J. Norberg, G. D. Peterson, and R. Pritchard. 2002. Resilience management in social-ecological systems: A working hypothesis for a participatory approach. *Conservation Ecology* 6, (1) (JUN): 14.

Ward, G. C. 2000. The West. New York: Little, Brown and Company.

Weeks, P., and J. M. Packard. 1997. Acceptance of scientific management by natural resource dependent communities. *Conservation Biology* 11, (1) (FEB): 236-245.

Wilkinson, A. 2006. The lobsterman: how Ted Ames turned oral history into science. The New Yorker 82, (23) (JUL 31): 56.

Williams, N. 1997. Philosophy of science - biologists cut reductionist approach down to size. *Science* 277, (5325) (JUL 25): 476-477.

Wilson, James. Phone interview. March 14, 2007.

Yli-Pelkonen, V. and J. Kohl. 2005. The role of ecological knowledge in sustainable urban planning: perspectives from Finland. *Sustainability: Science, Practice, and Policy* 1, (1): 3-14.

Zuckerman, H. 1988. The sociology of science. Pages 541-564 *in* N.J. Smelser, ed. Handbook of Sociology. London: Sage Publications.

7106-20