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LINKING KNOWLEDGE AND ACTION FOR SUSTAINABLE DEVELOPMENT

Lorrae van Kerkhoff[1] and Louis Lebel[2]
[1]*National Centre for Epidemiology and Population Health, The Australian National University, Canberra, Australian Capital Territory 0200, Australia; email: lorrae.vankerkhoff@anu.edu.au*
[2]*Unit for Social and Environmental Research, Chiang Mai University, Muang, Chiang Mai 50202, Thailand; email: louis@sea-user.org*

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■ **Abstract** It is now commonplace to assert that actions toward sustainable development require a mix of scientific, economic, social and political knowledge, and judgments. The role of research-based knowledge in this complex setting is ambiguous and diverse, and it is undergoing rapid change both in theory and in practice. We review conventional views of the linkages between research-based knowledge and action, and the early response to concerns that these links could and should be improved, through efforts at translation and transfer. We then examine the range of critiques that challenge those conventional views by highlighting different aspects of the relationships between science and society, focusing on the implications for action toward sustainable development. We then review the theories and strategies that have emerged in the attempt to improve the linkages between research-based knowledge and action in the context of sustainability across four broad categories: participation, integration, learning, and negotiation. These form a hierarchy with respect to how deeply they engage with the various critiques. We propose that the relationships between research-based knowledge and action can be better understood as arenas of shared responsibility, embedded within larger systems of power and knowledge that evolve and change over time. The unique contribution of research-based knowledge needs to be understood in relation to actual or potential contributions from other forms of knowledge. We conclude with questions that may offer useful orientation to assessing or designing research-action arenas for sustainable development.

CONTENTS

1. INTRODUCTION

Scientists are readily recognizable at the forefront of environmental issues, such ozone depletion, climate change, biodiversity loss, urban air pollution, and agricultural nutrient depletion. Perhaps less readily recognizable, but nonetheless significant, researchers have also been central to understanding and promoting human needs, such as access to clean water, safe living environments, health, and sufficiently productive livelihoods. In short, researchers have played, and continue to play, an important role in shaping our understanding of the need for sustainable development and generating public awareness of the challenges this poses to society. Yet generating awareness is not enough. Generating *actions* to counteract these problems, the essential next step, has proven to be a far more difficult task and one in which the role of science is not nearly as straightforward.

Over the past few decades, several different approaches to linking scientific, research-based knowledge with action have emerged. These vary in scope, influence, and their underlying assumptions, forming a complex, fragmented and often contradictory set of ideas and processes. As a result, there are few unambiguous lessons or tool options for either researchers or practitioners who attempt to foster change for sustainable development. As more and more researchers, governments, international agencies, research funding bodies, and nongovernmental organizations are confronting the real-world complexities of attempting to achieve sustainability, increasing attention is being paid to the question of how research can be harnessed more effectively to the task.

This review aims to provide some orientation in this complex area by presenting the conventional models of the linkages between research-based knowledge and action, critiques of these approaches, and four main classes of response to these

critiques that represent different approaches to the key issues raised in the critical literature. Our coverage of these diverse and complex topics is necessarily incomplete. In particular, we do not cover the large literature concerned with commercial technological development and private sector innovation in development because this topic has been recently covered elsewhere (1). We have focused our review on the "public good" areas of sustainability, that is, those with no clear or immediate financial incentives for action but with characteristics essential for sustainable development. There is, of course, no clear line of demarcation between public and private benefit, and we do venture into the gray zone between them, for example, when addressing issues such as sustainable livelihoods and actions that have both public and private benefits. We try point this out where relevant.

We have approached this review as an effort to capture the main challenges and controversies while retaining a focus on the practical implications for researchers and practitioners as well as those at the interface between them. Following the review sections, we analyze the literature and draw out the main themes that cut across this diversity. We conclude by suggesting key questions that may be usefully considered by those concerned with improving linkages between research-based knowledge and action to achieve—or at least, move toward—sustainable development. We hope that this will serve as a platform for selecting, assessing, and designing tools and methods for linking research-based knowledge and action and also for challenging those involved in this work to think more deeply (or broadly) about those choices.

1.1. Definitions

In an effort to deal with such broad, open concepts as knowledge, action, and sustainable development, definitions are needed. Knowledge is defined here as justifiable belief (2). Different forms of knowledge emerge as different sets of criteria for what may constitute justification. Scientific knowledge, for example, must be justifiable according to the standards set by adherence to accepted scientific practice and peer review. Local knowledge must be justifiable according to claims of connection with a particular place. Practical knowledge is justifiable on the basis of experience in practice, and political knowledge must be justifiable according to experience within the political process.

In this review, we focus on what we have called research-based knowledge. Research-based knowledge is a wider category than scientific knowledge because it includes all areas of systematic inquiry that are justified by their adherence to a research process as defined by peers. As such, it includes knowledge generated from within both the natural and social sciences as well as areas that need not be regarded as scientific, e.g., history or philosophy. It also accommodates research oriented toward practice rather than theory. In this review, we do not make judgments regarding whether research-based knowledge is better as a result of adopting alternatives to the conventional model.

Although research-based knowledge is our main focus, this is not to the exclusion of other sources or types of knowledge. Indeed, as we will show, it is the interaction between research and other sources of knowledge that is often crucial for understanding the role of research-based knowledge in action.

By action, we mean doing something that has physical or behavioral repercussions. Actions include purposefully changing practices and environments as well as implementing or changing regulations, policies, and institutions. Key challenges in this review are the different ways we can think about and represent the separation and independence (or not) of research-based knowledge from action. We return to this issue at the conclusion.

The classic definition of sustainable development was made by the World Commission on Environment and Development who described it as development "that meets the needs of the present without compromising the ability of future generations to meet their own needs" (3). However, as many have commented, sustainable development is ambiguous because it can be invoked to meet a wide variety of goals (4). Some have even argued it is an oxymoron, a convenient political device that has stifled robust political debate over differing ethical and political stances with respect to global inequalities (5). Our approach is that sustainable development is the process of ensuring all people can achieve their aspirations while maintaining the critical ecological and biophysical conditions that are essential to our collective survival. We have tried to ensure that our analysis is global in scale (addressing low-income country issues as well as high-income country issues and the interactions between them when appropriate), and we regard sustainable development as including issues of well-being (health, aesthetics, livelihoods) and environmental management.

1.2. The Focus of This Review

This review focuses on approaches to linking research-based knowledge with actions that have been developed since 1990 in the context of sustainable development. In order to contextualize these, we briefly review conventional understandings of the links between research-based knowledge and action in Section 2. Although these understandings may seem mundane or obsolete to some readers, these views are still commonplace within research institutions, as well as holding a fairly broad commonsense appeal in the practitioner community, and those that sit at the interface between researchers and practitioners. Such understandings also form the backdrop to much of the formal institutional structure that governs research, including the incentives and rewards for academic output. Nevertheless, these conventional models have been the subject of widespread, multifaceted critique, which we outline in Section 3. These two sections form the backdrop to the methods, techniques, and approaches we examine in Section 4. These are synthesized in Section 5, where we present key themes and a conceptual framework to distill some of the features of the diversity presented in Section 4. We conclude in Section 6 with observations regarding how we can more usefully approach

the challenge of linking research-based knowledge and action in the context of sustainable development.

2. CONVENTIONAL VIEWS OF LINKS BETWEEN KNOWLEDGE AND ACTION

We regard conventional views as those wherein the linkages between research-based knowledge and action are held to be either unproblematic or resolvable by relatively straightforward add-on measures. The science community is seen as an arena separate from those that might use the products of research, that is, a "two-community" concept of the problem of linking knowledge with action (6). With respect to connections across these two communities, we recognize two variants: the "trickle-down" and the "transfer and translate" models.

2.1. Trickle Down

The trickle-down view of the linkages between research-based knowledge and action, adapted from Latour (7), holds that good research will be taken up by practitioners without additional effort required by the research community. Bringing research into the public domain by publishing in peer-reviewed journals is implicitly regarded as the end of the researcher's responsibility. This perspective is deeply embedded in the scientific enterprise, manifested not only in attitudes but also in incentive structures that reward peer-reviewed publications and other academic output.

Although the trickle-down approach is often regarded as the natural or default relationship between researchers and those who might use research, it is important to note that this approach is not accidental or inevitable. The science policy that emerged in the United States following World War II, and emulated by many other countries, effectively created this distanced relationship between academia and the communities research was perceived to ultimately serve (8). Some science policy analysts have argued the freedom and independence granted to researchers over the ensuing 50 years are historically anomalous, rather than inevitable or natural (9).

The trickle-down model may be a good characterization of basic research; however, in the context of research that aims to inform or influence sustainable development decision making, it is now widely recognized that reality is somewhat different. In some instances, there is a seemingly straightforward link, as when there is widespread agreement that a current practice is unsustainable and solutions are in hand or potentially forthcoming. The Montreal Protocol to phase out the use of ozone-depleting substances is a case where action in response to scientific discoveries was relatively swift and effective. This well-known example gives the impression that science is an effective agent in bringing about change. But such cases tend to be the exception rather than the rule and tend to apply

more to narrow, straightforward, technically defined issues than the more diffuse, ambiguous, public good–oriented issues that pervade sustainable development.

2.2. Transfer and Translate

The failure of trickle-down approaches to influence social policy led to the development of a new field of study in the 1970s, concerned with "research utilization" (6). The defining characteristic of these approaches is that they are founded on the one-way transfer of science to users. Research is characterized as a product that needs to be taken up by the relevant user communities. Activities to facilitate this transfer often include efforts to translate technical, jargon-laden science into terms that can be understood by the layperson. Solutions to the challenge of linking knowledge with action are commonly framed in the language of products, bridges, translation, and transfer (10).

The transfer of technology approach to linking research-based knowledge and action is perhaps the best known and appears in several different sectors, especially manufacturing and agriculture. It is based on the idea that, rather than passively relying on uptake of research, problem-oriented research generates knowledge that needs to be actively transferred to users.

The transfer of technology model is essentially a linear research and application process, as outlined in Figure 1.

The transfer of technology model embodies a particular way of thinking about the role of science, the relationship between research-based knowledge and other sources of knowledge, and the relationship of both with action. In agriculture, this has been widely manifested in the idea of extension officers, the use of specialized intermediary agents to transfer field station research findings into farmer practices. As Scoones & Thompson (11, p. 18) write: "The superiority of 'rational science' is assumed and the pursuit of change (development) is derived almost exclusively from the findings of the research station and transmitted to the farmer through hierarchical, technically oriented extension services. Farmers are seen as either 'adopters' or 'rejectors' of technologies, but not as originators of either technical knowledge or improved practice."

As such, the traditional transfer of technology model assumes an objective truth that the scientists pass on to the farmers via extension officers, and farmers

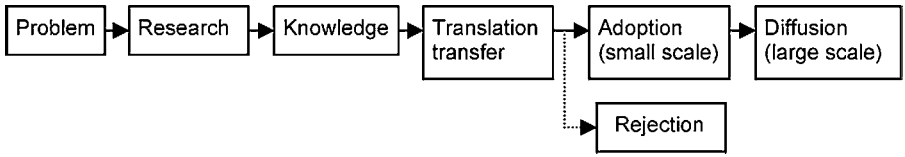

Figure 1 The linear model of the transfer of technology. Scientists set the research agenda, do the research, and then transfer the results to the users. The results then diffuse through the practice community.

are assumed to make decisions independently on a technical basis. It is perhaps unsurprising then that although agricultural extension is effective in disseminating new technologies for increased production or profitability, it is far less successful in convincing farmers to prevent or ameliorate land degradation (12) or for farmers facing complex, diverse, and risk-prone contexts (13).

In the health sector, the transfer and translation model is manifested in the concept of evidence-based health care. Proposed in the late 1990s by a group of epidemiologists (14), the aim of evidence-based approaches is to integrate current best evidence from research with clinical policy and practice, public health programs, and health policy. It is based on the view that the findings from health and medical research are often slow in filtering through to professional practice communities and that as a consequence there is a gap between the technically rational policies and those actually in place. The centerpiece of the evidence-based movement are evaluations and syntheses of existing scientific literature. These syntheses aim to meet the challenge of translating research into useable clinical or public health polices, facilitating the uptake of those policies in practice (15).

From within the health care sector, evidence-based approaches have been criticized for attempting to mechanize and standardize health care provision, downplaying consideration of important contextual factors and the experience and skill of practitioners (16). Its practical usefulness has also been questioned. An empirical study in Australia, for example, found that the syntheses that form the centerpiece of the evidence-based health care solution have been accessed or used by only 4% of general practitioners (17). Regarding sustainable development, the evidence-based medicine movement has not been highly effective in addressing the challenges of health care in developing countries. Plant (18) has argued that this is not due to the lack of evidence or to practitioner confusion surrounding what form of clinical care is needed but results from the lack of knowledge of how to provide it.

The similarities between evidence-based health care and transfer of technology in agriculture are strong. There is a perception that practice can and should be based more systematically on recognized research evidence, with associated (often assumed) gains in efficiency and production or patient outcomes. The main barrier to improved outcomes is characterized as ignorance of practitioners, fuelled by poor access to high-quality research results. Consequently, improvement is best achieved by making efforts to translate scientific findings and improve research products. Practitioners are assumed to make rational choices in light of new information and change their practices accordingly.

It is somewhat ironic that despite widespread evidence of the failure of transfer and translation models to achieve sustainability-oriented outcomes in agriculture, health, and other sectors, they still hold appeal in the imaginations of researchers and policy makers alike (19). The Report of the World Summit for Sustainable Development held in Johannesburg in 2002 described "knowledge transfer to developing countries" as a key component of poverty eradication and frequently cites the importance of technology transfer for sustainable development (20). Although

widespread uptake of technologies that enhance the prospects of sustainable development is obviously important, the role of research goes well beyond developing commercially viable products. In essence, the success of the idea of transfer in the commercial arena (through product promotion, for example) is presumed to extend to the entire range of actions needed to move toward sustainable development. The appeal of this model is that it does not require a great deal of change on the part of the research community, does not conflict with academic goals or incentives, or challenge the view that technical solutions will provide the answers to sustainable development.

3. CRITIQUES OF THE CONVENTIONAL MODEL

The linear views of the relationship between research-based knowledge and action described in Section 2 have come under close scrutiny in recent years. This scrutiny has, in part, been concerned specifically with science and research but has been featured also in broader social critiques. These critiques have generated a decades-long debate about the nature of science, knowledge, and their relationships with society that has generated much controversy and acrimony (21) but relatively little productive guidance for people who want to improve those relationships (22). In this section, we do not review those debates as such [see, for example, Sardar (23)] but draw from them those insights that help inform our understanding of the relationships between research-based knowledge and action toward sustainable development.

3.1. Science is Socially and Institutionally Embedded

The first critique is that scientists' work is shaped by the social and institutional structures and processes in which it is embedded (24). From the research perspective, decisions regarding what is a suitable problem to work on are made both with consideration of the state of the world that is of interest or concern to the researchers, but also with consideration of who will fund it (how should it be pitched?), how much they will pay (which parts of the ideal project can be trimmed?), where the work will be conducted (which field sites are feasible?), whether the work will advance one's standing with peers (where can it be published?), and so forth (25). Essentially, this critique highlights that research-based knowledge is not derived (solely) through a neutral, objective process of unfolding scientific discovery—it is the result of constructing a feasible balance between a range of personal, scientific, institutional, and practical considerations.

Classic anthropological studies of research laboratories have highlighted these personal and practical dimensions of research work (26, 27). This picture is further complicated by the present-day need for government- or university-employed researchers to find external funding to support their research, as researchers' financial interests are now often ambiguous, rather than simply public or private.

The challenges to scientific authority that often characterize environmental politics often point to researchers' ties to political and economic interests (28).

Larger social and political processes can also stimulate new research agendas, where not enough is known about issues that people want to act on quickly. Taylor et al. (29) for example show how SO_2 regulations acted as spurs to innovation, even before they were implemented, by encouraging firms to invest in research and development. International agreements for biodiversity and attempts to go beyond national regulation of forests illustrate similar patterns of how institutional changes can precede and stimulate research, encouraging practitioners to seek alternative strategies and thereby increasing demand for innovative, action-driven research (30). In this way, social and political forces shape both problem setting and the conduct of research, as much as the other way around.

In terms of the relationship between research-based knowledge and action toward sustainable development, this critique has two main implications. The first is that these considerations can serve as mechanisms through which power and influence interact with research, a point that will be taken up later. The second is that it particularly focuses attention on the potential for mismatch between the knowledge researchers generate and the knowledge needs of practitioners. Sustainable development is characterized by complex interrelationships between the natural and social spheres, whereas science is dominated by fragmented, specialized areas of investigation (31). Under such circumstances, it is likely that mismatches are the norm, rather than the exception.

The argument that research is shaped by considerations that are external to the unfolding of scientific discovery is hardly news to practicing researchers; however, the trickle-down, transfer and translation models do not acknowledge these influences. Focused on the research product, the social, political, and economic forces that led to its development are regarded as irrelevant. Although these forces can be largely ignored when that product is a new, fully developed technology seeking a market, they cannot be ignored in the context of action toward sustainable development. The political and social history and context of the research are central to the question of who will regard it as a valid basis for action (32).

3.2. Scientific Knowledge is Socially Constructed

Second, there is the more controversial argument that science and research cannot uncover truth—the actual knowledge researchers produce is not an accurate reflection of the world, but rather is a lens that offers a particular picture of the world at a particular point in time. Supporters of this perspective adhere to the claim that "[n]o body of knowledge, nor any part of one, can capture, or at least, can be known to capture, *the* basic pattern or structure inherent in some aspect of the natural world" (33). In simpler terms, knowledge is always uncertain because observations are subject to interpretation. The same issues, events, and things observed by people with a different lens will generate different knowledge, and arguments that one is more valid than another are simply that—arguments.

This stance has been the main wellspring for the acrimonious debates mentioned earlier, and many researchers (who take great care to expose and challenge their assumptions) reject this extreme point of view. Viewed from a science perspective, the key controversy regarding the social construction of scientific knowledge is about the nature of reality and our capacity to know and understand it. Viewed from the perspective of the role of research in action toward sustainable development, the key controversy is about the authority to make claims that should be acted upon, and the interactions between research-based knowledge and other knowledges. Imagine, for example, the different knowledges held by a soils scientist and a farmer, confronting, say, an eroded landscape. Although the researcher may know the physical and chemical soil processes that led to the view before them, the farmer may know the history of stocking the land that led to that same view. Both forms of knowledge may prove to be relevant—perhaps even essential—to reversing the degradation process.

In the context of understanding the role of science with respect to actions toward sustainable development, the implications of the social construction of science are profound and not necessarily negative. In particular, it opens up the possibility that other people with other knowledges may have useful contributions to make toward actions for sustainable development—that research does not have to provide the answers but rather needs to hold a clear understanding of its own lens. We return to this issue in the conclusion.

3.3. Boundaries Between Science and Society

The third main argument that is particularly relevant to the role of research-based knowledge in action for sustainable development is that the boundary that distinguishes science from the rest of society is not a natural boundary but is created by social and political processes that are permeable, changeable, and contestable (34). These boundaries emerge through controversies over where legitimate authority lies and, important to this review, which claims of knowledge should be acted upon and which should not. As Gieryn writes, "When credibility is publicly contested, putatively factual explanations or predictions about nature do not move naked from lab or scientific journal into courtrooms, boardrooms, newsrooms, or living rooms. Rather, they are clothed in elaborate *representations* of science—compelling arguments for why science is uniquely best as a provider of trustworthy knowledge, and compelling narrations of why my science (but not theirs) is bona fide" (35).

These boundaries are not, by definition, one sided and are subject to strategic maneuvering by researchers, by those on the other side of the boundary, and by those who operate across or in between. This maneuvering is central to sustainable development, as it is one of the processes through which questions of what counts as good or adequate science (including what can be considered science at all, which problems are political and which are technical, and who has authority in decision making) are decided. Bocking (28), for example, notes that politicians are adept

at characterizing environmental controversies as technical puzzles, allowing them to draw on the authority of science and research in decisions that go against popular demand. This "depoliticization" strategy has also been noted in development work, wherein aid agencies, political leaders, and experts have often collectively emphasized the technical aspects of crises, rather than the social and political ones. Mitchell (36), for example, describes how in the early to mid-twentieth century the characterization of Egypt's development problems as "natural" (too many people crowded into a narrow river valley) rather than political (concentration of around one third of the arable land into the hands of a small number of large landowners) pushed questions of inequality into the background and brought technical solutions to expand the amount of arable land available to the fore, culminating in the construction of the Aswan Dam.

In terms of the relationships between research-based knowledge and action, the idea of boundaries and their construction and maintenance highlights that the authority of research-based knowledge in any given decision-making scenario is negotiated through the interaction of researchers and decision makers. At the global scale, for example, analysts have shown that society has sometimes reached agreement on collective action to address pressing environmental issues before major uncertainties in underlying causes and details of impacts were well understood, whereas in other cases, well-established science has failed to generate action (37–40). Authority is not, as the trickle-down, transfer and translation models assume, inherent in the research itself. Where the social construction of science and its social embeddedness discussed in the previous two subsections focused on the characteristics of problem setting and research, boundary work draws attention to the importance of the decision-making contexts in the ways research-based knowledge is used for sustainable development.

3.4. Science and Power

The previous three sections have described research as less autonomous, less certain, and more controversial than the conventional model portrays, and these attributes are all the more acute in the context of action for sustainable development. Implicit in these more fluid characterizations of research, and in need of expansion, is the role of interests and power in shaping the linkages between research-based knowledge and action toward sustainable development. This is important because interventions and actions for the public good often run counter to established private good regimes (41) and thus involve reconstructing power relations.

Issues of power with respect to research-based knowledge and action for sustainable development are ambiguous, complex and—not surprisingly—fraught with ideological conflict. In perhaps overly simple terms, this can be regarded as a "glass half-empty, glass half-full" situation. Analysts with a critical orientation emphasize the role of scientific and technical knowledge in the exploitation of the poor and vulnerable, supporting those power relations that perpetuate such

exploitation for private gain (36, 42). Others point to successes in health and environmental management, where research has been a powerful ally in looking beyond immediate interests of firms and states and in challenging the status quo (11, 39, 43). Both need to be taken seriously in attempting to understand and enhance the role of research-based knowledge for sustainability because they point to the value judgments that are embedded in both research and action toward sustainable development (44).

Technical-rational ways of approaching policy, management, and development—including particularly the natural sciences and economics—have long been a subject of criticism for concentrating power in those who can lay claim to scientific knowledge and its interpretation and implementation in practice (45). Scott (46) argues that the appeal of modernist (technical, rational, scientific, evidence-based) ideals in development has favored the centralization of state activity, a major shift in power from distributed, local political regimes. Science and research that focus on creating universal, generalized knowledge complement the centralized state by providing the technical tools that allow this "management at a distance." The outcomes of such management can, of course, support or run counter to sustainable development. Scott gives numerous examples of failure, including the forced settlement of nomadic peoples in Tanzania, which effectively rendered their local knowledge, and the adaptive capacity embedded within it, useless to their new surroundings. In contrast, however, centralized schemes can work to the benefit of the entire population. Cuba, for example, has basic health statistics comparable to (some superior to) those of the United States, on less than 3% of their gross national income per capita, through an effective centralized health care system (47).

Alongside the questions of when research has a positive or negative influence on action, one also needs to examine when research has no notable influence at all—or has not effected the change that is intended. In climate change, for example, a worldwide effort by researchers to consolidate scientific and technical understanding, generate technical consensus, and actively lobby on the world stage has not convinced key nations such as the United States and Australia to endorse the Kyoto Protocol (48). However, as noted earlier, these failures have been countered by successes in other areas such as ozone-depleting substances and pollution control. The contingent nature of whether science can influence policy is in direct contradiction to the trickle-down model.

The use of science to enhance or challenge power structures points to an important question of responsibility for change: under the conventional trickle-down, transfer and translate models, researchers are not responsible for the uses to which their research is put. Both critical and supportive accounts of the role of research in reshaping power relations in sustainable development challenge this lack of responsibility. As the previous critiques have also shown, the line between research-based knowledge and its application in action is not so clearly drawn that responsibility for the effects of redistributions of power can lie solely outside the domain of research.

3.5. Science Reflects Cultural Biases and Inequalities

Although it is relatively easy to point to instances where funding or other identifiable interests could have influenced the selection of research topics, appropriate evidence, or recommendations, the more subtle and arguably more pervasive influence is that of the broader culture within which research is embedded. We have already noted in the previous section the dominance and shortcomings of technorational ways of thinking and attempting to address complex development issues. Research agendas, approaches, and world views inevitably reflect the biases, attitudes, and inequalities characteristic of the society that supports them.

Feminist critiques have pointed to the gender biases that are evident in science. Kohlstedt & Longino (49) point to three main areas of feminist investigation: historical analyses of the (limited) participation of women in science, gendered language and imagery in scientific communication, and the effects of gender imbalances in the practice of science for the ways we conceptualize knowledge.

In the context of sustainable development, the need for gender equality was a prominent theme in the Report of the World Summit for Sustainable Development (20). Yet the effects of gender inequality in science (and other inequalities, such as low participation by minorities and the overwhelming dominance of wealthy Western countries in academia globally) on the linkages between research-based knowledge and action have received little attention. In the U.S. context, a study of gender in two agricultural land grant universities shows differences regarding links with the private sector, with male faculty more likely to have collaborations with industry and more accepting of close ties between universities and industry than female counterparts (50). This indicates that gender may be a significant factor in how research-based knowledge is linked with action.

Similarly, proponents of the value of indigenous or local ecological knowledge claim that efforts to manage ecological systems that did not take local knowledge into account were missing a vital and rich source of knowledge about complex interactions. As Olsson & Folke describe it, "Locally evolved resource management systems can be looked upon as natural experiments; they are experiential through learning-by-doing rather than experimental in the scientific sense" (51). Authors argue that these knowledges are often denigrated in comparison to scientific knowledge, when they should be regarded as complementary (52, 53). These critiques emphasize both the substantive knowledge of local actors via their experience as well as the ethical dimension of the need to include the knowledges of those people who are likely to be affected by the outcomes of decision making.

In a more reflexive vein, Nygren (54) has noted that many analyses of local and indigenous knowledges have been based upon a number of dichotomies of knowledge: tacit versus scientific, folk versus universal, indigenous versus Western, and traditional versus modern. She argues that the presumption that indigenous and local knowledges are distinct from other forms of knowledge, including science and research, is not well supported. In her studies of forest-edge communities in Nicaragua, she found that knowledge was often controversial and changing, with

new ideas being integrated into their day-to-day actions (54). In other words, the presumption that indigenous knowledge is disconnected from scientific knowledge is not necessarily the case.

Gender and local knowledge by no means represent the full extent of actual or potential cultural bias. Indeed, underlying both is the major inequality in the production of research itself—heavily concentrated in wealthy Western countries. The implications of this inequality are yet to receive the attention they deserve in the context of sustainable development. The effects of deeply embedded cultural biases and inequalities in the relationships between research-based knowledge and sustainable development are significant because they include questions of who gets to define which problems are most important as well as what should be done about them.

3.6. What Lies Beyond the Trickle-Down and Transfer Model?

The critiques discussed in this section, although by no means a complete account of the ways in which people have challenged the trickle-down and transfer models of science, do point to several key issues. First, critiques have come from different practical and ideological backgrounds—from those who see science and research as a hegemonic cog in the machinery of global oppression through to practicing researchers who have been frustrated in attempts to get what they see as important findings acted upon and those who examine the hybrid spaces in between. Second, the linkages between research-based knowledge and action are institutionally enabled and constrained; that is, the use of research is shaped by the explicit and implicit rules that govern social decision making, such as democracy, and the delegation of decision-making power.

The core insight is that the conventional models for linking research-based knowledge, founded on the idea that there is a research product that is independent of the processes that have gone into creating it, are unraveled in every critique. If we locate each critique with respect to the original transfer and translate model presented in Figure 1, we can see that the different critiques individually target different parts of that process. Yet taken *as a group*, they offer a comprehensive suite of challenges that leave no part of that model unscathed, shown in Figure 2.

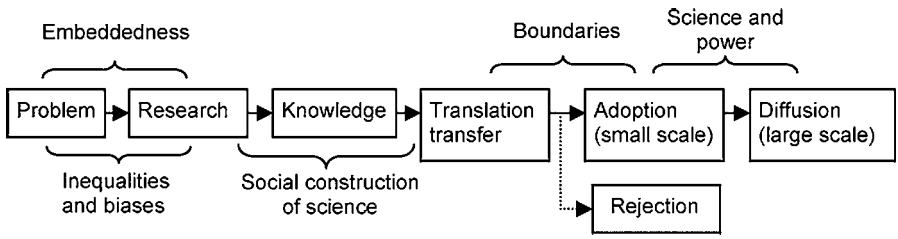

Figure 2 Critiques of the transfer and translate model.

These critiques posit that in the context of sustainable development, the work that goes on prior to the actual research—in setting the problems to be investigated, as well as the actual research itself—matters to the eventual application (or not) in practice. Adoption or rejection of research does not flow automatically from understanding generated by well-translated findings but is a product of political context and how research findings align, conflict with, or transform existing power structures. The authority of research emerges from the *interaction* of the research process with the political processes of decision making and change.

Yet research itself has by no means remained static and passive in the face of these critiques and other shifting forces. Indeed, although some have expended their efforts on defending conventional ideas of scientific authority, others have begun to explore and exploit the opportunities that these alternative ideas have offered. New ways of thinking about research, action, and sustainable development, as well as new ways of doing research, have emerged as a result. The next section examines a range of these new approaches to tackling the challenges of linking research-based knowledge with action for sustainable development.

4. MAJOR RESPONSES TO CRITIQUES

There have been many attempts to overcome some or all of these challenges in improving the linkages between research-based knowledge and action. The responses are many and varied, and any attempt to group them into a handful of categories necessarily rides roughshod over the subtleties and crossovers between them. Nevertheless, in this section, we examine the main responses to the critiques discussed in Section 3 under four headings: participation, integration, learning, and negotiation. In these four categories, we have tried to draw key distinctions between them, but we must note that our use of these four titles does not always neatly correspond with the ways these terms are used in the literature.

4.1. Participation

Participation refers to the wide range of mechanisms and techniques by which nonresearchers become involved in research or governance. Enhancing public participation has been touted as crucial to informed decision making and taking action toward sustainability for several reasons. Randolph (55), for example, cites four reasons for taking a participatory approach to environmental management: to gain access to alternative, less easily available, sources of knowledge relevant to solving particular problems; to build support for decisions by addressing common problems and resolving disputes; to mobilize resources and share management responsibility for actions; and to develop agency, organization, or community capacity. Others focus on the rights of people to know and be involved in processes that may affect them (56). In practice exactly what constitutes participation and how it is to be achieved are often not clearly spelled out. Here we focus on weak

levels or degrees of participation or consultation (57–59) because other models will be incorporated in sections below.

The failure of the transfer of technology model to address land degradation and the needs of poor farmers left a gap that was largely taken up by the concept of participation. As Richeleau describes it, participatory research proposes to "join together people and institutions with very distinct traditions of acquiring knowledge, in order to develop sustainable land use practices of interest to both" (60).

In some cases, participation evolved as extension services started to listen to farmers and as farmers began actively commissioning research and consultants. This led to the emergence of more collaborative models of research, validating experimental findings and making observations in practice that shifted the nature of the relationship between researchers and practitioners and emphasized process as well as output. For example, a study of the factors influencing adoption of integrated pest management of durian fruit growers in Thailand revealed that the collaborative approach between farmers and agricultural extension workers—wherein farmers learned from each other and extension agents learned things about durian farming—was more important to participants than the detailed content of instructional material (61).

These emergent participatory practices were supported and strengthened by a range of other forces. In a review of the catalysts driving the move toward participatory land management research, Keen (62) noted four distinct forces for change. These were (*a*) policy developments, embracing the ideas of sustainable development; (*b*) institutional catalysts, including changing conditions for government research funding; (*c*) academic developments, with new methodologies and changing theoretical paradigms; and (*d*) community catalysts, such as advocacy and changing community expectations of research.

Participation has also sought to address the exclusion of traditional knowledges noted in the critiques section. This is illustrated by the recent history of Karen land-use systems in northern Thailand, where participatory approaches recast and strategically connected traditional knowledges with technical alternatives to extraction forestry, such as community forests and rotating swidden agriculture in an effort to maintain access by the Karen to their land (63).

Another major route for participation has been in participatory governance and assessment processes that include both citizens and researchers as participants. Rayner has observed the way in which social scientists and policy entrepreneurs have created increasingly elaborate techniques which "re-establish a role for non-experts in scientific, environmental and technological decision making" (64) via focus groups, citizen juries, consensus conferences—all of which have a much greater emphasis on public participation alongside expert participation.

Participatory approaches have challenged the dominance of natural sciences and economics as foundations for decision making and have demonstrated that innovative relationships can generate innovative solutions to sustainability challenges (65). Others, however, argue that the actual outcomes of these approaches

are uncertain and ambiguous. Petkova et al. (66), in a nine-country review of environmental governance, found that participation opportunities ". . . tended to occur too late to meaningfully affect the scope and nature of the decision, and did not continue through the implementation phase of the decision making cycle." Some take this further to argue that participation has become a new democratic disguise for persistent power inequalities (67). These controversies suggest that participatory processes need to be carefully designed and executed to fulfill their promise in sustainable development.

4.2. Integration

A second response to the challenge of linking research-based knowledge and action took the form of calls for greater integration of interested parties, both within science and between researchers and decision makers. Although there are many variations on this theme of integration, this very variation is a response to the many ways in which relationships between researchers and their user communities are fragmented. A review by van Kerkhoff (68) has noted that calls for integrated research have often been initiated by people or groups who are not active researchers—particularly research funding agencies. Consequently, one feature of the integration literature is that it tends to focus on the structural, institutional, and governance issues surrounding the linkages between different parties in connecting research-based knowledge and action, rather than the microlevel interactions of researchers and practitioners that characterize the participatory approaches. Here, we cover three arenas for integration: scale, jurisdiction, and researcher-user chains.

Action for sustainable development is stretched over the entire range of geographic scales, from global regimes and conventions to regional, national or provincial policies, and local, on-the-ground decision making (41). Efforts to integrate across scales include linking global-scale science with local-scale actions and vice versa as well as enrolling science in struggles between global, national, and/or local politics and power. As noted in the Karen example above, in the field of forest management, growing interest in biodiversity conservation and community resistance to conventional extraction approaches focused on harvest and yield has forced policy makers and scientists to examine alternative models (30), wherein some form of comanagement among actors operating at different levels and interplay among institutions is now regarded as essential (69).

Another major context of integration has been the need to integrate research-based knowledge and action across jurisdictions (70). This has been particularly prominent in water management, where the effects of the actions of one jurisdiction (nation, province, town) can have important effects on others who rely on that water source. The engineering approach to water management, which has been dominant since the start of the twentieth century, was typically tied to a particular jurisdiction. This approach was criticized on the grounds that it failed to account for the negative effects of large-scale projects such as dams, including dispossession of people and loss of fertile cropland upstream. It also generated political

problems because water management projects initiated by one jurisdiction often had important ramifications in others.

Since the late 1970s, this scientific-technocratic process has been countered by a variety of integrated watershed management approaches. The integration of water management includes linking different disciplines (hydrology, agronomy, social sciences) and creating governance structures whereby landholders, researchers, and government representatives participate in priority setting and decision making within a watershed. It also includes integration of different political units involved in or affected by water management efforts (71). This approach to linking knowledge and action sought to expand the concept of water management to address key failings in approaches dominated by technical sciences.

A third major axis for integration has been along the research production-to-use axis. Institutional innovations, such as cooperative research programs, integrated projects, and other mechanisms for connecting academic research with the users of research, have flourished over the past decade. These typically involve cofunding and oversight arrangements in which users (particularly industry, but also farmers, policy makers, and land managers) jointly set research agendas and participate in the development of research findings. For a review of current approaches to integrated research between research producers and users, see van Kerkhoff (68).

4.3. Learning

A third response to the critiques noted in Section 3 has been to develop models of research-practice interaction based on the concept of learning. These have a number of different origins, from participatory, power-sharing bases through to deliberation techniques and adaptations of private sector models. Here, we will draw on insights from studies in three different areas: knowledge sharing and management initiatives, agricultural knowledge systems and social learning, and adaptive management.

Knowledge sharing and management initiatives at the organizational level originated in the private sector. Early literature in the late 1970s (72–74) on knowledge management and organizational learning generated an avalanche of business programs over the following decades. The theoretical work by Nonaka and colleagues (75–77) is particularly noteworthy for bringing together practical, but hard to codify, knowledge that lies within employees and their relationships with conventional manuals and product- or process-based knowledge that is easier to articulate and share. This literature aimed to help organizations gain better financial returns from the knowledge they already possess and a more strategic approach to their ongoing learning and development to build their knowledge base. There is typically a strong emphasis on technical systems to facilitate access to this knowledge base.

These ideas have also been taken up in the public sector and international agencies. In the mid-1990s, The World Bank initiated a new program of organizational reform around the idea of knowledge sharing, a concept based on knowledge

management and organizational learning (78). This effort was soon emulated by other major development agencies (79).

Agricultural knowledge and information systems and social learning are approaches to learning based on engagement between researchers and farming practitioners to build ecologically sound farming practices (80). The agricultural knowledge and information system model examines farming change as a process of innovation in which knowledge and learning are central, but institutions, policies, and facilitation also play key roles. This model has been generalized to a broader concept of ecological knowledge systems, noting that other forms of knowledge systems (notably, the transfer of technology and farm management development models) have been ineffective in the development of ecologically sound farming practices (81). A particularly distinctive feature of this approach to linking knowledge with action is the idea that participants need to learn to see themselves as a knowledge system; that is, innovation emerges through the interaction of social actors and can be enhanced as those actors begin to understand their role within a knowledge system. As this vision develops, either spontaneously or through facilitated processes, those involved in the system become more purposive, directed, and deliberate in their actions and interactions to support learning and innovation (82).

Adaptive Environmental Assessment and Monitoring (83) was proposed as a model for integration between researchers and policy makers. It has been an influential model that spawned several variations that can be more loosely grouped under the title "adaptive management." Adaptive management models and approaches also draw on systems theory to suggest that policy interventions, or environmental management more broadly, should be regarded as experiments with concomitant assessment and monitoring as a basis for ongoing learning. More recently, proponents emphasize building flexibility and resilience in the face of uncertainty rather than grand experiments (84). Other versions of adaptive management productively combined the more quantitative dimensions of adaptive management with social and organizational learning concepts, broadening the integrative scope of the models to include social factors (82, 85, 86). In all cases, however, research is an essential component. Dovers & Mobbs (87), for example, describe the important features of adaptive management approaches as "information is central, the focus is on integrating natural system and institutional/social dimensions, and it is absolutely and inevitably interdisciplinary." Adaptive management approaches are significant because they insist that researchers and managers can work together in productive, ongoing relationships in which research and management activities dovetail and strengthen each other.

4.4. Negotiation

Although the previous approaches to improving the linkages between research-based knowledge and action have focused on improving linkages at interpersonal, and institutional levels, our final category examines approaches that have focused

on power sharing. Negotiation-based models acknowledge that researchers are political actors and provide a space for different political interests to be considered. In this section, we discuss three models based on negotiation and power sharing: advocacy coalitions, boundary work, and mode 2 research.

Work in the early 1990s, primarily by Sabatier & Jenkins-Smith (88), showed that research informed policy through researchers' participation in advocacy coalitions. These coalitions are formed by actors, including researchers, from government and private organizations who share a set of beliefs regarding policy and seek, over time, to influence government institutions accordingly. This work represents a major departure from previous concepts of research-policy linkages by differentiating groups according to their affiliation to a set of ideas or ideology rather than by their affiliation to a particular institution (the basis of the two communities idea) (10).

The idea of contested boundaries between science and society was introduced earlier. "Boundary work" is a concept that directs attention to the actual work that researchers and others engage in to demarcate research and establish its authority, both within science (boundaries between different disciplines or points of view, for example) as well as between science and society.

With regard to sustainable development, boundaries have been shown to be created as a result of public controversy and perceptions of risk. Bickerstaff & Simmons (89), for example, have examined the scientific contest between epidemiologists and academic veterinarian researchers over appropriate policies for controlling infectious animal-borne disease. They argue that the boundary work between these disciplines reflects different spatial practices, with different recommendations for disease control policy. When there are multiple authoritative sources of advice, policy makers can readily select those recommendations that are the most politically or practically feasible. Cash et al. (90) emphasize the importance of managing the boundaries between knowledge and action. Building on work with the Social Learning Group (38) on international assessments they proposed that "efforts to mobilize science and technology for sustainability are more likely to be effective when they manage boundaries between knowledge and action in ways that simultaneously enhance the saliency, credibility and legitimacy of the information they produce." They and others also suggest that institutional change and other mechanisms are often needed to facilitate negotiation across such boundaries (86). The danger, however, as Guston (91) points out, is that the very flexibility of these boundaries generates questions: How much blurring of these boundaries is enough, and how much might be too much? He suggests that organizations that are "tethered" to both scientific and political interests (i.e., are accountable to both) are best able to maintain a balance. The appeal and usefulness of the idea of boundary work are that it highlights the presence of multiple realities and thus reframes sustainable development as a negotiation among the groups involved at a particular boundary.

In the mid-1990s a new discourse began that started with the observation of Gibbons et al. (92) of newly (or recently) emerging research structures ("mode 2")

that are different from conventional scientific structures of knowledge production and dissemination ("mode 1"). The aim of their analysis was to "clarify the similarities and differences between the attributes of each [mode], and help us understand and explain trends that can be observed in all modern societies." Mode 2, in contrast to the conventional mode 1, actively involves society (particularly research users and those affected by the outcomes of research) in the research process. In mode 2, negotiation between scientists and society becomes the norm, as governments, industry, and citizens demand a greater say in scientific processes, and science is deeply embedded in many—perhaps all—forms of day-to-day decision making. Nowotny et al. (93) have described this as the emergence of a new space, an "agora," where science and society, markets, and politics comingle.

The mode 1/mode 2 research distinction is an interesting contrast to the other models of negotiation because its proponents claim that the changes implied or carried out by implementing these models are the result of broader social, political, and scientific forces. They argue that the ability to cross boundaries, learn, and negotiate is increasing as education levels increase, civil society strengthens and organizes, and researchers are forced by ever-shrinking pools of public funding to seek new relationships outside academia.

5. KNOWLEDGE, ACTION, ENGAGEMENT, AND POWER

Our examination of the conventional model of how research-based knowledge is linked with action in Section 2, the various critiques of that model in Section 3, and the responses to those critiques discussed in Section 4 has covered very diverse territory, but two themes have persisted throughout. The first is the idea of engagement—whether, when, and how research and action are, or should be, connected and working together. The second has been the exercise of power, both in the service of and to the detriment of sustainable development. The interactions between knowledge, action, and power have been approached differently in the five critiques we listed in Section 3 as well as in the major categories of response we discussed in Section 4. In this section, we look more closely at the different approaches to the relations between knowledge, action, engagement, and power in the four types of responses.

Engagement and direct interaction between researchers and practitioners have been a feature of each of the models we presented in Section 4, although taking a somewhat different form in each. The importance of engagement can be understood in relation to the critiques of the conventional, disengaged models of science discussed in Sections 2 and 3. In very simple terms, if the problem was lack of connection between research and practice, then the solution is surely to build up those connections. This is, however, where the simplicity ends. With the authority of research-based knowledge at least partly grounded in its independence from other interested groups, any efforts to engage with those groups must be approached carefully.

Issues of power are often regarded with some discomfort by researchers because they form an implicit challenge to the idea that research should be based on neutral, disinterested application of scientific method. However, as soon as researchers become concerned with action, decision making, and change, power can no longer be ignored as it is intimately entwined with the ability to act. Power relations are fundamental to institutional enabling and constraining conditions that form the context of action both of individuals and groups. But how can it be applied usefully in this context? In sociological literature, power is often used as a synonym for domination and oppression. As we have noted in the critiques, science has been held by some to support such domination by legitimizing acts of violence and discrimination. Yet power is inherent in every organized society and is not always wielded to the detriment of citizens or against goals of sustainable development. Participatory and learning models have illustrated that research that shares power and authority between researchers and practitioners can lead to improved outcomes for livelihoods and sustainability. International regulatory regimes have illustrated that global power can be harnessed to the task of sustainable development.

The varied approaches to linking research and action that were discussed in Section 4 offer different interpretations of power and engagement and of the interactions between them. These are summarized in Table 1.

Table 1 shows that the structure of the engagement processes between research and action is deeply entwined with the ways decision-making power is formally allocated. Participation and integration, with their focus on particular, discrete activities (projects, events, decisions), tend to have clearly but narrowly defined avenues for sharing decision-making authority. They typically share efforts to define problems but not their resolution. In contrast, negotiation and learning are open-ended processes (at least in theory, but the practicalities of funding may lead them to project-oriented work) and have more diffuse, fluid arenas for decision making, both in defining problems and resolving them.

5.1. Implications for Linking Knowledge and Action for Sustainability

Power, engagement, knowledge, and action are general and abstract terms. What do the observations noted in the previous section mean in the context of efforts to achieve sustainable development? What is it that people do differently to shift power balances, challenge the status quo, or resolve specific sustainability problems?

In examining implications for practice, both for researchers and practitioners, it is important to note that either group may take responsibility for improving the linkages between research-based knowledge and action. Practitioners may seek out research-based knowledge to help their decision making; researchers may seek out practitioners to gain influence or bring new issues to their attention. The question of who takes the lead is significant because it is typically the initiator who has the greatest say in how the engagement is structured and, consequently, how power is

TABLE 1 Engagement and power in participation, integration, negotiation, and learning

Approach	Engagement	Power
Participation	Individual- or small-group level engagement occurs around specific topics or issues. Terms of engagement are set by authorities (researchers, policy makers) for specific issues.	Personal empowerment (increased capacity to act) occurs through becoming a more informed participant, with some power to define problems. No higher-level decision-making authority is granted to participants.
Integration	Organizational level engagement occurs to set shared agendas and aims and to create supportive institutions for specific projects.	Problem definition is shared. Research becomes more powerful by formally engaging with influential decision makers but is less able to challenge their power.
Negotiation	Strong engagement occurs within coalitions and exists when there is political polarization (disengagement) on controversial issues, an ongoing process.	Researchers are powerful actors in their own right, adding the authority of science to particular political positions; autonomy from decision makers is often preferred.
Learning	Strong engagement occurs within groups that may emerge or be facilitated by researchers using specific methodologies, an ongoing process.	Researchers and practitioners both share learning experiences with equal power to implement them in their respective contexts.

shared. Specialist intermediaries such as knowledge brokers or new hybrid groups, who have experience and expertise in both research and action, can play important roles in facilitating these relationships. In Figure 3 we have tried to capture what the different approaches look like in practical terms, depending on who is driving the linkages, and note the intermediaries who may invoke these models using either or both of the strategies listed. We have included our original trickle-down and translation and transfer models for comparison.

Figure 3 shows that we can regard the two conventional models, plus the four response models, as forming a hierarchy with respect to engagement and power sharing. From the researcher's perspective, this hierarchy involves increasing interaction with practitioners, with ever-greater consideration of their perspective. From the trickle-down model, wherein no consideration is given, the translation and transfer models start to engage with the constraints faced by practitioners in accessing and understanding research-based knowledge. Science communication specialists may be employed to literally translate science into user-friendly formats. Participation steps up to actively involving practitioners in conceptualizing problem setting and problem solving, often using facilitators to manage the interactive process. Integration grants researchers and practitioners shared power

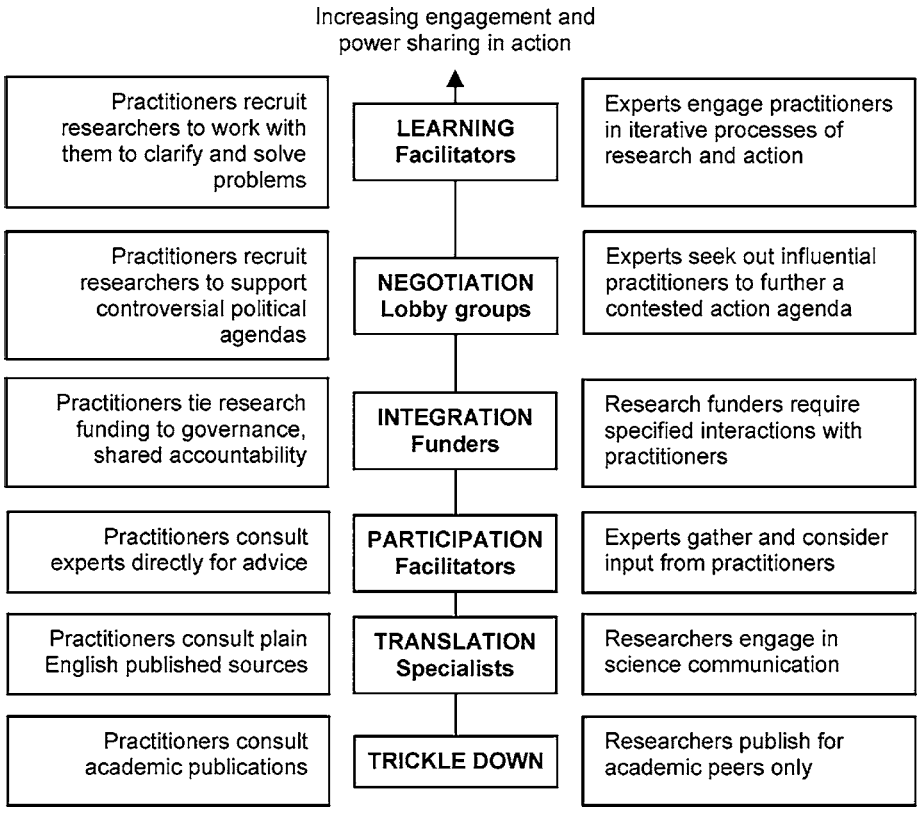

Figure 3 Knowledge, power, engagement, and action.

in setting research agendas, encouraged by research funding requirements. Under negotiation models, researchers seek out influential individuals or lobby groups to redefine or introduce new sustainability problems and work with them to further that agenda in political circles. Finally, in learning models, researchers invite practitioners to work with them throughout a research-action cycle, often managed by highly-trained facilitators, with responsibility for linking research-based knowledge and action formally shared.

From the practitioner's point of view, there is an equally increasing consideration given to research-based knowledge. Consulting academic sources is an option for those practitioners who have sufficient academic background to use them. Specific products created by the research community targeted at practitioners can reach a wider audience if practitioners seek them out (recall the 4% of medical practitioners who had consulted the evidence-based syntheses). Knowledge brokers can be useful intermediaries in helping practitioners identify and access research. Next, practitioners may consult or hire researchers to provide

input to specific decisions or strategies. When issues are highly technical, or the ability to make decisions is affected by scientific uncertainty, integrated research projects or programs may be initiated, which allow practitioners working with researchers to set a research agenda that has immediate practical implications. The terms of the relationship may be formalized via funding agreements and oversight arrangements, such as shared representation on steering committees. When particular issues are not finding purchase in political arenas, practitioners may recruit researchers who are working on those issues to lend both technical support and authoritative support to lobbying efforts. Finally, if practitioners have a strong commitment to research-based knowledge, they may initiate longer-term learning relationships with researchers, managed by facilitators with experience in both research and action.

As noted earlier, although we have characterized these models as separate, in practice, they are clearly interrelated. The descriptions we have just given are perhaps more stereotypical than highly accurate reflections of how relationships between researchers and practitioners actually unfold. However, such stereotypes can be a useful point of comparison in the otherwise foggy domain of linking research-based knowledge and action. In the next section, we restore some of the complexity and examine a series of tensions that emerge in trying to understand and develop effective relationships between research-based knowledge and action.

5.2. Tensions Between Knowledge, Action, Engagement, and Power

Although engagement and power were consistent themes throughout the literature we have examined, it is equally clear that there is no straightforward relationship between them. The contrasts and contradictions between research-based knowledge, action, engagement, and power may be better understood as a series of tensions, which may become productive sources of creativity and innovation, destructive sources of marginalization and violence, or stagnant domains of blame casting and inaction. These tensions include

- Tension 1: Democratic processes of engagement and dialogue share power across participants but assume power sharing will lead to action; authoritative processes of expert knowledge concentrate power but can challenge existing power structures that are blocking change.
- Tension 2: Every research-action scenario needs to be understood as unique and context rich, dependent on one-on-one relationships, but generalizations from research-action scenarios are needed to enable us to learn how to participate in these scenarios more effectively.
- Tension 3: Research-based knowledge is a special way of knowing that can make a unique contribution to sustainability, but actions toward sustainability are ultimately the result of social and political decisions.

- Tension 4: Efforts to link knowledge and action toward sustainable development are manifested in the changed behavior of individuals, but individual change may require altering powerful institutions or social relations first.
- Tension 5: Research-based knowledge can simplify causally complex situations to offer a clear course of action, but sustainable development is inherently complex, so simplification increases the risk that the course of action will be counterproductive.

There are, of course, no absolutely right or wrong approaches to deal with these tensions, nor is there much analytical work that takes us beyond the realm of best guesses and what seems opportune at the time. Despite the centrality of the dynamics between research-based knowledge, engagement, power, and action for sustainable development, we actually know very little about how these dynamics operate—especially in efforts that go beyond the trickle-down, translation and transfer models. How are these dynamics structured by institutional rules and conventions? How are these relationships mediated by the governance of research and action? And, most importantly, how might they be improved? Our review has shown that different methodological and institutional approaches to linking research and action can have a profound effect on the forms of engagement and the degrees of power sharing that can result.

One major implication of the review is that the way we conceptualize the connections between research-based knowledge and action can now be refined. As noted in the introduction, this was a key challenge for this review. The concept of linkages that we have used to this point implies a chain-like, disembodied, somewhat mechanistic relationship that is reminiscent of the transfer and translation models. The critiques and models we have reviewed have collectively destroyed any idea that such linkages are disembodied or chain-like, but as Gibson (10) has noted, the concept of two communities will persist while we continue to use the language that invokes it. We propose that the connections and relationships between research and action for sustainable development can be more usefully regarded as arenas. This allows us to point to specific instances where research-based knowledge and action are interacting but without necessarily implying that those interactions are simple or straightforward.

Finally, the different critiques and the responses to them also highlight the need for a system-wide perspective; that is, a perspective that examines the implications of the governance of research-action arenas that cover multiple scales and effects on groups beyond those immediately involved through direct engagement. This perspective would need to address three concerns: first, those microsolutions (for example, strong participatory or learning processes that are built up between specific researcher and practitioner groups) need not scale up to macrolevel results owing to systematic biases or incentives at more aggregated scales. The orientation toward direct engagement between researchers and practitioners, particularly around specific projects or events, comes at a cost of generality and the ability to offer sweeping solutions to pervasive problems. However, the inability or

unwillingness to see direct engagement within its broader context hampers efforts to learn across different activities. Second, just because processes encourage engagement, that does not mean they are necessarily immune from the cultural biases noted above. A systems perspective would need to consider (at least) issues of gender, minority interests, and representation of nontechnical knowledges. Third, a systems perspective would need to address concerns that any given effort to connect research with practice is embedded within a broader array of institutional structures and power relations that need not be immediately obvious. Robbins (94), for example, has written reflectively on his work with the middle-caste group in India. Although their relationship has been rewarding for both himself as a researcher and the group in maintaining their rights to access land, this has been at the expense of other lower-class groups, which are less powerful and therefore arguably in greater need of his support. There are, as he somewhat sadly notes, no easy solutions to this. Yet even this awareness of the broader system within which his work is situated and the connections between engagement, action, and power surely represents a positive standpoint from which to approach sustainable development.

6. CONCLUSIONS

In this review, we have outlined the shortcomings of conventional ideas of research utilization and provided some idea of the extent and breadth of present-day attempts to improve the linkages between research-based knowledge and action in the context of sustainable development. The two themes that most strongly emerged, engagement and power, both show that the responsibility and capacity to make useful links between these groups do not lie wholly within any particular group of actors, researchers, practitioners, or others. Rather they continually arise from engagement that brings critical tensions among those with different knowledges (and those with different capacities to act) to the fore.

Describing these tensions and the complexity of research-action arenas for sustainable development does not, unfortunately, make them easier to deal with. Indeed, as we noted in tension 5, there is often a trade-off between simple understandings that imply clear but inadequate courses of action and more complex understandings in which appropriate courses of action become far less clear. For those readers who have previously subscribed to the conventional model of the links between research-based knowledge and action, we acknowledge that the literature we have reviewed presents a far more complex picture. For those who have been involved in the critiques of that model or responses to them, we have most likely simplified the field, hopefully in a positive way.

As we noted above, research-based knowledge can and does make a unique contribution toward sustainable development, but this contribution needs to be understood in relation to actual or potential contributions from other forms of knowledge and to acknowledge that there are often no clear lines between "research" and "other" in this regard. Understanding these relationships is not easy in situations

that are socially, institutionally, and biophysically complex, with multiple layers of power and many contexts of action. Reconfiguring those relationships by adopting a notion of research-action arenas may be useful conceptually, but what might this mean in a real-world setting? Although it is not the purpose of this review to attempt to create a comprehensive guide, we do conclude with some suggestions of questions researchers may ask to gain some orientation to the issues of knowledge, action, power, and engagement from within a shared research-action arena.

1. Research-based knowledge

- How do participants in the research-action arena—both researchers and nonresearchers—understand the role of research-based knowledge for the particular decision-making scenario? (As authoritative solution provider? As a source of limited but useful knowledge? As a voice that can challenge power relations? As a guide to more detailed or disciplined learning?)
- Do various participants understand the role of research-based knowledge differently?
- Should any such differences be resolved, or can they become useful tensions for creativity and innovation?
- How might this be achieved?

2. Engagement

- Who is included in processes of engagement? Who is excluded? Why?
- What do these inclusions and exclusions say about the power relations that are in place? (Are efforts being made to share power? Could power relations be changed by changing who is in and who is out?)
- What do these inclusions and exclusions say about the actions that may result from engagement (Limited? Institutional change with uncertain application on the ground? Closely tied to a specific place?)

3. Power

- Who is funding participation in the research-action arena? (What are the formal channels of responsibility and accountability? What are the informal channels?)
- How is it governed? (Is there an oversight structure? Who is represented? Who is not?)
- How do these governance arrangements shape the research-action agenda?
- Are governance arrangements appropriate for sustainable development? If not, how might they be altered?

4. Action

- Who is responsible for action toward sustainability?
- Are all those holding responsibility involved in the research-action process?

- What knowledges are being brought to support decisions for action? (Are there any key participants missing?)
- What are the institutional constraints on what can be done (e.g., existing regulations? Lack of regulations?)
- Should institutional constraints be challenged? How?

We began this review with the goal of exploring ways of effectively linking research-based knowledge with action for sustainable development. By the end, we reached a contrary view of the world, one in which research, politics, researchers, and publics are intertwined in a constant struggle of justifications, explanations, and decisions in an uncertain and complex world. These questions encourage us to look at the relationships between research-based knowledge and action as arenas of shared responsibility, embedded within larger systems of power and knowledge that evolve and change over time. This conceptualization offers a more appropriate starting point for understanding the role of research in sustainable development than the conventional models of trickle-down, transfer and translation. It also serves as a point of comparison for the strengths and weaknesses of the many alternatives to that model. We hope it also offers richer possibilities for creating innovative, effective relationships between research and action in the pursuit of sustainable development.

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LITERATURE CITED

1. Juma C, Yee-Cheong L. 2005. *Innovation: applying knowledge in development*, Task Force Sci. Technol. Innov., UN Millenn. Proj., London
2. Rorty R. 1979. *Philosophy and the Mirror of Nature*. Princeton, NJ: Princeton Univ. Press
3. World Comm. Environ. Dev. 1987. *Our Common Future*. Melbourne: Oxford Univ. Press
4. Parris TM, Kates RW. 2003. Characterizing and measuring sustainable development. *Annu. Rev. Environ. Resour.* 28:559–86
5. Sachs W. 1999. *Planet Dialectics: Explorations in Environment and Development*. London: Zed Books
6. Booth T. 1988. *Developing Policy Research*. Aldershot, UK: Gower
7. Latour B. 1998. From the world of science

to the world of research? *Science* 280:208–9
8. Guston D. 1997. Critical appraisal in science and technology policy analysis: the example of "Science: the endless frontier." *Policy Sci.* 30:233–55
9. Weingart P. 1997. From "finalization" to "mode-2": old wine in new bottles? *Soc. Sci. Inf.* 36:615–40
10. Gibson B. 2003. Beyond two communities. In *Evidence-Based Health Policy: Problems and Possibilities*, ed. V Lin, B Gibson, pp. 18–30. Melbourne: Oxford Univ. Press
11. Scoones I, Thompson J. 1994. Knowledge, power and agriculture: towards a theoretical understanding. See Ref. 56, pp. 16–32
12. Ison R, Russell D. 2000. *Agricultural Extension and Rural Development: Breaking Out of Traditions*. Cambridge: Cambridge Univ. Press
13. Chambers R. 1993. *Challenging the Professions: Frontiers for Rural Development*. London: Intermed. Technol.
14. Sackett DL, Richardson SR, Rosenberg W, Haynes RB. 1997. *Evidence-Based Medicine: How to Practice and Teach EBM*. Edinburgh/New York: Churchill Livingstone
15. Haines A. 1998. Making better use of research findings. *Br. Med. J.* 317:72–75
16. Maynard A. 1997. Evidence-based medicine: an incomplete method for informing treatment choices. *Lancet* 349:126–28
17. Young J, Ward J. 1999. General practitioners' use of evidence databases. *Med. J. Aust.* 170:56–58
18. Plant A. 2004. Evidence-based health care and international health: good, but not good enough. In *Evidence-Based Medicine: In Its Place*, ed. IS Kristiansen, G Mooney, pp. 141–50. London: Routledge
19. Lavis JN, Robertson D, Woodside JM, MacLeod CB. 2003. How can research organizations more effectively transfer research knowledge to decision-makers? *Milbank Q.* 81:221–48
20. UN. 2002. *Report of the World Summit on Sustainable Development*, Johannesburg
21. Brown J. 2001. *Who Rules in Science: An Opinionated Guide to the Wars*. Boston: Harvard Univ. Press
22. Jasanoff S. 1998. Coming of age in science and technology studies. *Sci. Commun.* 20:91–98
23. Sardar Z. 2000. *Thomas Kuhn and the Science Wars*. Cambridge: Icon
24. Merton RK. 1973. *The Sociology of Science: Theoretical and Empirical Investigations*. Chicago: Univ. Chicago Press
25. Houck O. 2003. Tales from a troubled marriage: science and law in environmental policy. *Science* 302:1926–29
26. Knorr-Cetina K, Krohn RG, Whitley R. 1981. *The Social Process of Scientific Investigation*. Dordrecht, Neth.: Reidel
27. Latour B, Woolgar S. 1979. *Laboratory Life: The Social Construction of Scientific Facts*. Beverly Hills: Sage
28. Bocking S. 2004. *Nature's Experts: Science, Politics and the Environment*. New Brunswick: Rutgers Univ. Press
29. Taylor MR, Rubin ES, Hounshell DA. 2003. Effect of government actions on technological innovation for SO_2 control. *Environ. Sci. Technol.* 37:4527–34
30. Lebel L, Contreras A, Pasong S, Garden P. 2004. Nobody knows best: alternative perspectives on forest management and governance in Southeast Asia: politics, law and economics. *Int. Environ. Agreem.* 4:111–27
31. Kinzig AP, Carpenter S, Dove M, Heal G, Levin S, et al. 2000. *Nature and Society: An Imperative for Integrated Environmental Research (Exec. Summ.)*, Natl. Sci. Found., Tempe, Ariz.
32. Landry R, Amara N, Lamari M. 2001. Utilization of social science research knowledge in Canada. *Res. Policy* 30:333–49
33. Barnes B, Edge D. 1982. General introduction. In *Science in Context: Readings in the Sociology of Science*, ed. B Barnes, D Edge, pp. 1–12. Milton Keynes, UK: Open Univ. Press

34. Gieryn T. 1983. Boundary-work and the demarcation of science from nonscience: strains and interests in professional ideologies of scientists. *Am. Sociol. Rev.* 48:781–95
35. Gieryn T. 1999. *Cultural Boundaries of Science: Credibility on the Line*. Chicago: Univ. Chicago Press
36. Mitchell T. 2002. *Rule of Experts: Egypt, Techno-Politics, Modernity*. Berkeley: Univ. Calif. Press
37. Dimitrov RS. 2003. Knowledge, power and interests in environmental regime formation. *Int. Stud. Q.* 47:123–50
38. Soc. Learn. Group. 2001. *Learning to Manage Global Environmental Risks: A Comparative History of Social Responses to Climate Change, Ozone Depletion and Acid Rain*. Cambridge, MA: MIT Press
39. Haas PM. 2004. When does power listen to truth? A constructivist approach to the policy process. *J. Eur. Public Policy* 11:569–92
40. Mitchell RB, Clark WC, Cash DW, Dickson NM, eds. 2006. *Global Environmental Assessments: Information and Influence*. Cambridge, MA: MIT Press
41. Jasanoff S, Martello ML. 2004. *Earthly Politics: Local and Global in Environmental Governance*. Cambridge, MA: MIT Press. 356 pp.
42. Ferguson J. 1994. *The Antipolitics Machine: "Development," Depoliticization, and Bureaucratic Power in Lesotho*. Minneapolis: Univ. Minn. Press
43. Mitchell RB. 2003. International environmental agreements: a survey of their features, formation, and effects. *Annu. Rev. Environ. Resour.* 28:429–61
44. Forsyth T. 2003. *Critical Political Ecology: The Politics of Environmental Science*. London: Routledge
45. Dore J, Lebel L, Manuta J. 2004. Gaining public acceptance. *Rep. UNEP Dams Dev. Project*, Chiang Mai Univ. Unit Soc. Environ. Res., Chiang Mai, Thail.
46. Scott JC. 1998. *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed*. New Haven: Yale Univ. Press
47. World Health Organ. 2000. *World Health Report 2000 Health Systems: Improving Performance*. Geneva: WHO
48. Miller CA, Edwards PN, eds. 2001. *Changing the Atmosphere: Expert Knowledge and Environmental Governance*. Cambridge, MA: MIT Press
49. Kohlstedt SG, Longino H. 1997. The women, gender, and science question. What do research on women in science and research on gender and science have to do with each other? *Osiris* 12:3–15
50. Buttel FH, Goldberger JR. 2002. Gender and agricultural science: evidence from two surveys of land-grant scientists. *Rural Sociol.* 67:24–45
51. Olsson P, Folke C. 2001. Local ecological knowledge and institutional dynamics for ecosystem management: a study of Lake Racken watershed, Sweden. *Ecosystems* 4:85–104
52. Berkes F. 1999. *Sacred Ecology: Traditional Ecological Knowledge and Management Systems*. London: Taylor & Francis
53. Jodha NS. 2001. *Life on the Edge: Sustaining Agriculture and Community Resources in Fragile Environments*. New Delhi: Oxford Univ. Press
54. Nygren A. 1999. Local knowledge in the environment-development: discourse from dichotomies to situated knowledges. *Crit. Anthropol.* 19:267–88
55. Randolph J. 2004. *Environmental Land Use Planning and Management*. Washington, DC: Island
56. Scoones I, Thompson J. 1994. *Beyond Farmer First: Rural People's Knowledge, Agricultural Research and Extension Practice*. London: Intermed. Technol.
57. Arnstein SR. 1969. A ladder of citizen participation. *J. Am. Inst. Plan.* 35:216–24
58. Clayton A, Oakley P, Pratt B. 1997. *Empowering people—a guide to participation*. Prepared for Civ. Soc. Organ. Particip. Programme, UN Dev. Programme, New York

59. Int. Assoc. Public Particip. 2000. *Public participation spectrum*. (Accessed 11/20/05) http://www.iap2.org.au/spectrum.pdf
60. Richeleau D. 1994. Participatory research and the race to save the planet: questions, critique, and lessons from the field. *Agric. Hum. Values* 11:4–25
61. Elsey B, Sirichoti K. 2002. The learning facilitation role of agricultural extension workers in the adoption of integrated pest management by tropical fruit growers in Thailand. *Stud. Contin. Educ.* 24:167–80
62. Keen M. 1997. Catalysts for change: the emerging role of participatory research in land management. *Environmentalist* 17:87–96
63. Luangaramsri P. 2002. *Redefining Nature: Karen Ecological Knowledge and the Challenge to the Modern Conservation Paradigm*. Chennai, India: Earthworm
64. Rayner S. 2003. Democracy in the age of assessment: reflections on the roles of expertise and democracy in public-sector decision making. *Sci. Public Policy* 30:163–70
65. Kasemir B. 2003. *Public Participation in Sustainability Science: A Handbook*. Cambridge: Cambridge Univ. Press
66. Petkova E, Maurer C, Henninger N, Irwin F. 2002. Closing the gap: information, participation and justice in decision making for the environment. *Res. Rep.*, World Resour. Inst., Washington, DC
67. Cooke B, Kothari U, eds. 2001. *Participation: The New Tyranny?* London: Zed
68. van Kerkhoff L. 2005. Integrated research: concepts of connection in environmental science and policy. *Environ. Sci. Policy* 8:452–63
69. Lebel L. 2005. Institutional dynamics and interplay: critical processes for forest governance and sustainability in the mountain regions of northern Thailand. In *Global Change and Mountain Regions: An Overview of Current Knowledge*, ed. UM Huber, HKM Bugmann, MA Reasoner, pp. 531–40. Berlin: Springer-Verlag
70. Crabb P. 2003. Straddling boundaries: intergovernmental arrangements for managing natural resources. In *Managing Australia's Environment*, ed. S Dovers, S Wild River. Sydney: Federation
71. Lebel L, Garden P, Imamura M. 2005. Politics of scale, position and place in the governance of water resources in the Mekong region. *Ecol. Soc.* 10:18. http://www.ecologyandsociety.org/vol10/iss2/art18/
72. Argyris C, Schön DA. 1978. *Organizational Learning*. Reading, MA: Addison-Wesley
73. Argyris C, Schön DA. 1996. *Organizational Learning II: Theory, Method and Practice*. Reading, MA: Addison-Wesley
74. Liebowitz J, ed. 1999. *Knowledge Management Handbook*. Boca Raton, FL: CRC Press
75. Nonaka I. 1994. A dynamic theory of organizational knowledge creation. *Organ. Sci.* 5:14–37
76. Nonaka I, Toyama R. 2002. A firm as a dialectical being: towards a dynamic theory of a firm. *Ind. Corp. Chang.* 11:995–1009
77. Nonaka I, Toyama R, Konno N. 2000. SECI, Ba and leadership: a unified model of dynamic knowledge creation. *Long Range Plan.* 33:5–34
78. Gwin C. 2003. *Sharing Knowledge: Innovations and Remaining Challenges*. Washington, DC: World Bank
79. King K, McGrath S. 2002. *Knowledge Sharing in Development Agencies: Lessons from Four Cases*. Washington, DC: World Bank
80. Röling NG, Wagemakers MAE. 1998. *Facilitating Sustainable Agriculture: Participatory Learning and Adaptive Management in Times of Environmental Uncertainty*. Cambridge: Cambridge Univ. Press
81. Röling NG, Jiggins J. 1998. The ecological knowledge system. See Ref. 80, pp. 283–311
82. Leeuwis C, Pyburn R, eds. 2002. *Wheelbarrows Full of Frogs*. Assen, Neth.: Koninklijke Van Gorcum

83. Holling CS, ed. 1978. *Adaptive Environmental Assessment and Management*. New York: Wiley
84. Gunderson LH. 1999. Resilience, flexibility and adaptive management—antidotes for spurious certitude? *Ecol. Soc.* 3:7. http://www.ecologyandsociety.org/vol3/iss1/art7/
85. Lee KN. 1992. *Compass and Gyroscope: Integrating Science and Politics for the Environment*. Washington, DC: Island
86. Folke C, Hahn T, Olsson P, Norberg J. 2005. Adaptive governance of social-ecological systems. *Annu. Rev. Environ. Resour.* 30:441–73
87. Dovers SR, Mobbs CD. 1997. An alluring prospect? Ecology, and the requirements of adaptive management. In *Frontiers in Ecology: Building the Links*, ed. N Klomp, I Lunt, pp. 39–52. Oxford, UK: Elsevier Sci.
88. Sabatier PA, Jenkins-Smith HC. 1993. *Policy Change and Learning: An Advocacy Coalition Approach*. Boulder, CO: Westview
89. Bickerstaff K, Simmons P. 2004. The right tool for the job? Modeling, spatial relationships, and styles of scientific practice in the UK foot and mouth crisis. *Environ. Plan. D* 22:393–412
90. Cash D, Clark W, Alcock F, Dickson N, Eckley N, et al. 2003. Knowledge systems for sustainable development. *Proc. Natl. Acad. Sci. USA* 100:8086–91
91. Guston DH. 2001. Boundary organizations in environmental policy and science: an introduction. *Sci. Technol. Hum. Values* 26:399–408
92. Gibbons M, Limoges C, Nowtony H, Schwartzman S, Scott P, Trow M. 1994. *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. London: Sage
93. Nowotny H, Scott P, Gibbons M. 2001. *Rethinking Science: Knowledge and the Public in an Age of Uncertainty*. Cambridge: Polity
94. Robbins P. 2004. *Political Ecology: A Critical Introduction*. Malden, MA: Blackwell

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