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Synthesis

Bridging the Science–Management Divide: Moving from Unidirectional Knowledge Transfer to Knowledge Interfacing and Sharing

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ABSTRACT. Sustainable ecosystem management relies on a diverse and multi-faceted knowledge system in which techniques are continuously updated to reflect current understanding and needs. The challenge is to minimize delay as ideas flow from intent through scientific capability, and finally to implementation to achieve desired outcomes. The best way to do this is by setting the stage for the flow of knowledge between researchers, policy makers, and resource managers. The cultural differences between these groups magnify the challenge. This paper highlights the importance of the tacit dimension of knowledge, and how this renders the concept of knowledge transfer much less useful than the concepts of information transfer and technology transfer. Instead of knowledge transfer, we propose that "co-production" of knowledge through collaborative learning between "experts" and "users" is a more suitable approach to building a knowledge system for the sustainable management of ecosystems. This can be achieved through knowledge interfacing and sharing, but requires a shift from a view of knowledge as a "thing" that can be transferred to viewing knowledge as a "process of relating" that involves negotiation of meaning among partners. Lessons from informal communities of practice provide guidance on how to nurture and promote knowledge interfacing between science and management in R&D programs.

Key Words: *communities of practice; knowledge interface; knowledge transfer; science–management divide; R&D programs; shared understanding; tacit knowledge*

INTRODUCTION

> *The man who has the time, the discrimination, and the sagacity to collect and comprehend the principal facts and the man who must act upon them must draw near to one another and feel that they are engaged in a common enterprise.* (Woodrow Wilson, 1856–1924.)

Despite Wilson's early recognition of the need for scientist and manager to work in harmony, management of natural resources has suffered because of a long and entrenched legacy of disciplinary fragmentation and separation of the growth of scientific knowledge from its application. Today, more than ever, we recognize that sustainable ecosystem management depends strongly on the acquisition and use of integrated systems of knowledge that continuously replace outmoded techniques as our understanding evolves. Unobstructed knowledge flow between science (often considered the arena of the "experts") and management (similarly seen as the domain of "decision makers") is particularly important in times of significant change, such as policy reform and implementation.

One of the great challenges is to minimize the delays between publishing statements of intent (as embodied in policy or implementation objectives), developing scientifically sound concepts and management instruments, and finally ensuring the organizational capabilities that implement them. The alignment and co-evolution of capabilities to create, verify, absorb, and apply new knowledge is clearly at the heart of the sustainable management challenge. In South Africa, we face many such challenges as a wide range of new environmental legislation, compatible with an emerging democracy, replaces that of the Apartheid era (see MacKay et al. 2003). Much of the material in this paper has been drawn from these experiences and

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our application of general knowledge management theory to them.

The alignment, compatibility, and flow of knowledge between researchers, policy makers, and resource managers are often far from optimal. Instead, we often see misunderstandings, frustration, unhealthy forms of conflict, and significant misalignment. Although all parties are generally keen to contribute to the formulation and effective implementation of resource management policies, the synergy between them is frequently poor. Clearly, it is important for each party to understand what they can contribute to the process, and how best to integrate these contributions to achieve effective outcomes.

A number of strategies—often covered by the broad banner of knowledge transfer—are used in attempts to bridge the knowledge divide(s) between research, policy formulation, and operations in natural resources management. Although existing strategies may achieve some result, they often fall short of delivering proper alignment and a seamless flow of knowledge between groups. Success, on the other hand, comes most frequently from fostering an integrated progression from research, to design, adoption, diffusion, and sustainable implementation (see Roux 2001).

In this paper, we examine some of the key reasons why the effective implementation of knowledge transfer remains elusive. We emphasize the need to appreciate both explicit and tacit forms of knowledge, and to shift from a mode of unidirectional transfer, to the co-creation of knowledge. Given the shortcomings that are commonly experienced with knowledge-transfer efforts, knowledge interfacing and sharing is suggested as a conceptual framework for promoting and sustaining an effective science–management partnership.

THE HISTORICAL CLASH OF THE CULTURES

South African water scientists and managers have a reputation for working together (Postel and Richter 2003), but divisions still persist. This was highlighted during a recent conference in South Africa, where a prominent aquatic scientist, referring to a particular aquatic ecosystem, said: “Scientists have all the knowledge and managers should just ask; they have no excuse for making wrong decisions.” Two weeks later, at a strategic review of river research, a senior manager from the national Department of Water Affairs and Forestry commented: “Scientists have failed to provide any useful solution to current management challenges and managers have no options but to implement policy on their own.”

Such reports of misunderstandings and friction between ecosystem researchers and managers have also been recorded frequently in the literature (e.g., Cullen 1990, Aumen and Havens 1997, Baskerville 1997, Rogers 1997, Norton 1998, Rogers 1998, Walters 1998, Grayson et al. 2000, Havens and Aumen 2000, Asher 2001, Cullen et al. 2001, Ewel 2001, Kinzig 2001, Ludwig 2001). Many reasons for this have been suggested, but the most common theme to emerge is the difference in operational cultures and working philosophies.

Many managers hold the view that:

- Science peer-review and reward systems enforce an inward-looking, self-serving culture.
- Scientists are arrogant.
- Scientists produce fragmented information that seldom addresses “real” problems.
- Scientists do not work at appropriate or useful spatial and temporal scales.
- Scientists have little regard for application contexts, and are driven only by intellectual curiosity.
- Scientists do not communicate effectively to non-scientists.
- Scientists are unable to contribute to the value-based debate that usually governs problem solving in the real world.

Scientists’ views of managers testify to similar biases in disciplinary and cultural understanding:

- Managers work within a system that rewards organizational and individual interests rather than ecosystem interests.

- Managers have a poor understanding of scientific processes.
- Managers do not articulate their needs effectively, and often do not know what they want.
- Managers are caught up in day-to-day operations, and spend little time in intellectual reflection and longer-term R&D planning.
- Managers do not appreciate ecosystem complexity.

These examples show a deep rift that has been perpetuated by years of misunderstandings and misconceptions of each other's roles and responsibilities. Stereotyping of both managers and scientists is sometimes used in a humiliating or manipulative way, further exacerbating the problem. Although it is true that the behaviors of scientists and managers over the years have justified certain generalizations, the irony is that as each party criticizes the other, it acknowledges their mutual dependence. In recent years, it is interesting to note that increasing numbers of scientists and managers are breaking out of the traditional mold, and are making a concerted effort to develop more professional interaction at the science–management interface.

PUSH-AND-PULL INTERVENTIONS

The diffusion of new knowledge would be simple if there were no social and cultural divides between the suppliers and prospective adopters of knowledge; yet there must be some social or cultural differences between them to drive the need for new knowledge (Rogers 1995). To take this irony further, the more technologically advanced a knowledge supplier and the more technologically deprived a potential adopter, the bigger the scope for introducing new knowledge but the lower the chance that the transfer of knowledge will be successful. Hence, knowledge vendors (e.g. consultants) generally prefer to work with clients that have levels of technological advancement similar to their own, and in so doing tend to work with those clients that least need their help. This phenomenon, where an increase in technological, educational or economic disparity results in a decrease in transfer potential, can occur between individuals, organizations or countries (see Li-Hua 2003).

Given this reality, scientists and managers have tended to adopt contrasting strategies to bridge the knowledge divide brought about by their cultural differences. Scientists have focused on strategies to "push" new knowledge from the science to the management domain, whereas managers have developed strategies to "pull" the knowledge needed from the science to the management domain. At first glance, these strategies seem to be complementary, but more detailed analysis exposes important limitations.

Pushing Knowledge across the Divide

Three strategies are commonly used to push knowledge across the divide between science and management.

Involve end-users in the knowledge creation process

All too often researchers will develop a product and pass the final report, publication, or design on to managers with the expectation that it will be embraced with enthusiasm and implemented immediately. Implementers are presented with a product for which they have little ownership, and which may not suit their particular needs, capabilities, or resource realities. Despite this, researchers often continue to refine their "solution" or move on to another project bemoaning the fact that their work was not put into practice. An obvious way to speed up the adoption of new technological solutions and associated knowledge is to more closely align such solutions with actual problems, and therefore, the needs of the day. This can only be achieved by involving those parties who will deploy the knowledge at the earliest possible stages of research and development; but this is easier said than done.

Early and ongoing interaction with end-users is the surest way to increase compatibility between knowledge innovations and resource management needs (Poff et al. 2003). Prospective users should be involved up front, be encouraged to participate in the new technology's development, and help apply it at a pilot scale before it is finally adopted.

Such interaction helps scientists to more fully grasp, and respond to, implementation realities, such as the management agency's capability and resource constraints. At the same time, managers can personally experience the new knowledge and technology in action, and help to shape the ultimate product and develop ownership. In this way, they develop "user readiness," a lack of which commonly constrains knowledge and technology adoption (Grayson et al. 1999). This pilot-scale interaction is fundamental for effective knowledge interfacing because adoption of a new technology is generally not based on rational analysis of what is needed, or on choosing the "best available," but rather on user-defined criteria such as affordability, familiarity, and availability of the necessary infrastructure and skills (Steele 1989, Van Vliet and Gerber 1992). Both scientists and managers need to internalize this important concept if they are to be successful in resource management.

Improve scientist credibility

There is a positive relationship between a knowledge supplier's credibility in the eyes of a potential adopter, and the successful transfer of knowledge between them. This credibility has two components, competence and safety (Rogers 1995). Competence credibility describes the degree to which an individual, group, or organization is perceived to be knowledgeable or expert in a specific field. It is a function of their collective record of accomplishment, of originality, of technological superiority, and of the relevance of their projects, as well as of their perceived experience and their ability to communicate clearly and unambiguously (Cullen et al. 2001).

Safety credibility, on the other hand, is the degree to which the adopter is comfortable in the scientist's presence and not intimidated by possible perceptions of his or her "superior knowledge." This trust is often influenced by similarity in educational status, technical capability, cultural background, recreational activities, and work ethos/philosophy (Rogers 1995). Scientists are usually very aware of competence credibility, but often overlook, or trivialize, safety credibility. A simple way for scientists to improve their safety credibility in the eyes of managers is to spend time with them so as to understand their challenges, rather than trying to press home their own independent perspective. Role reversals, where scientists work for resource management agencies for a period (Walters 1998), have much potential to improve safety credibility, but there is probably no substitute for simply trying to understand the other's perspective.

Scientists face a tough compromise when simultaneously trying to improve both competence and safety credibility. Scientific advances and breakthroughs often require periods of intense focus and relative isolation. Although these intellectual indulgences can increase their competence credibility, scientists also need to balance them with reality checks and "socialization" within the relevant application domain. The more frequent and sustained the interaction between scientists and managers, the greater the mutual understanding and trust that develop.

Information packaging for managers

Although scientists may be good communicators within their peer groups, they often struggle to translate the scientific message to reach managers, and therefore, have little influence on management behavior. There are various reasons for this: e.g., undue emphasis may be placed on single, lengthy outputs for a homogeneous audience (as seen in research reports or journal publications), and research findings are surrounded with conditions and qualifications (e.g., Cullen 1990, Baskerville 1997, Walters 1998, Saywell and Cotton 1999, Cullen et al. 2001, Kinzig 2001).

Managers, on the other hand, meet this knowledge "push" strategy with their own set of realities and constraints. They often experience information overload, and perceive scientific messages as promoting a particular viewpoint that is driven by undue self-interest; they know they cannot trust all information sources equally, and contradictory information makes it harder for managers to assess the risk of embracing, or ignoring, a particular message (Cullen et al. 2001). To managers, scientific information can be useful, but only if is packaged to be unambiguous, is not excessively complex, and is compatible with existing planning models (Westley 1995).

Pulling Knowledge across the Divide

Where scientists use "push" strategies to get their findings across the divide, managers can use a number of "pull" strategies to obtain the information they require.

Uncover and articulate real information needs

The identification and articulation of a portfolio of information needs is very often far more complex and elusive than it may sound, partly because the future is uncertain. Easily identifiable needs may constitute only the visible tip of the proverbial iceberg—above the surface of awareness (Miller and Morris 1999)—and may change more quickly than scientists or funding organizations are able to respond.

A number of forward-thinking processes are used to elicit the deeper information needs, such as scenario planning (van der Heijden 1996), and science and technology roadmapping and foresighting (Galvin 1998). The information needs of a resource management agency can also be identified through the formal development of clear purpose coupled with an explicit implementation strategy (Rogers 2003). This strategy can be used to compare current capabilities with requirements, and to identify information gaps. If these gaps are properly communicated, scientists and funding agencies, with a desire to find application for their research outcomes, are able to respond appropriately to these information gaps.

The value of uncovering and communicating a framework of information needs has been well demonstrated in the Kruger National Park (KNP), South Africa. During the early 1990s, an analysis of historical research showed that certain areas of major importance had been researched poorly or not at all. This started to change in the mid-1990s after the introduction of the KNP's objectives hierarchy (Braack 1999, Biggs and Rogers 2003). Several previously unattended areas now receive attention simply because KNP managers have made their revised information needs explicit and communicated them widely. Many external research institutes have responded to these needs, either spontaneously or through solicitation, and the benefits to managers are already becoming evident (Biggs 2003).

Become involved in "upstream" activities

A common situation is the fact that most of a resource manager's time is allocated to the urgent affairs of day-to-day operations and so-called "fire-fighting" activities. Managers generally prefer these operational activities because the results are tangible and measurable, but in the process, long-term strategic issues are neglected. For example, time spent with scientists co-designing and co-managing a strategic research program would improve the chances of securing appropriate information to guide future decisions (Miller and Morris 1999). However, it is a rare institution that engages in such activities in a way that leads to both parties sharing the responsibility and risk of planning for the future. If responsibility and risk are not shared, the science–management partnership will usually be transient, unproductive, unsatisfying, and ineffective.

Improve information seeking and filtering ability

Access to knowledge and information sources at a global scale is becoming easier, but for many this pool of information is intimidating, partly because of the difficulty in discriminating between useful and useless information. Hence, more sophisticated searching strategies are required to obtain the right information in a timely manner, and assess its validity and quality.

Filtering information with an ability to avoid being distracted by inaccurate and non-critical information is becoming an important survival mechanism. Such filtering skills receive remarkably little attention, and are underdeveloped in most managers who will often:

- Seek only until they find the first acceptable answer, regardless of how good it is.
- Give up searching relatively quickly.
- Seek knowledge from someone who is easily accessible and trusted (high safety credibility).
- Prefer face-to-face communication—that which builds trust and puts an obligation on the provider.
- Seek broad-scale information that can be more easily understood (e.g., synthesis) rather than original research sources (Johnson 1996, as cited in Cullen et al. 2001).

Several barriers inhibit resource managers from seeking and gaining information. Many feel that they are already overloaded with information, and lack the time and energy to seek more. They may have poor access to knowledge infrastructure, or poor searching skills, or feel they have sufficient knowledge to do the job at hand, and do not want to admit ignorance or uncertainty (Cullen et al. 2001). As straightforward as these issues seem, unless they are explicitly managed, a knowledge system will have limited success.

Development of a professional network is a specific mechanism that can be used to improve knowledge seeking. Such networks commonly have "structural holes" (Cullen at al. 2001), for instance, when water engineers communicate with other engineers about managing an algal bloom, but do not consult algologists. They may not know such people exist or how to contact them. The depth and breadth of a manager's professional network are critical elements in ensuring access to the appropriate knowledge when needed.

MOVING BEYOND PUSH AND PULL

True knowledge transfer will end with adoption, where the adopter has both the absorptive capacity (understanding), as well as the emotional and financial commitments to allow sustained use of the acquired knowledge. Knowledge transfer efforts that do not result in adoption are failures. Although the pushing and pulling strategies described above are increasingly practiced and achieve some success, we still see too many failed transfer attempts. Why? We believe that there is a missing ingredient that has much to do with perceptions of what knowledge transfer comprises. In this section we emphasize two issues related to the character of knowledge that are critical to understanding the requirements for effective knowledge transfers.

Valuing the Tacit Dimension

We often fail to discriminate between information and knowledge. In general, information refers to organized data, data endowed with relevance and purpose, or interpreted data (e.g., Drucker 2001). These definitions point to the fact that information includes human participation in the purposeful organization of raw data. The end product, information, is explicit and can be readily transferred to another party. Scientists do this all the time by means of research or consultancy reports and peer-reviewed publications.

Knowledge, on the other hand, is defined as a mix of experiences, values, contextual information, and intuition that provides a framework with which to evaluate and incorporate new experiences and information (Davenport and Prusak 1997). It is this knowledge that gives people their capacity for effective action (Dawson 2000). A significant component of knowledge exists in tacit form (Polanyi 1983).

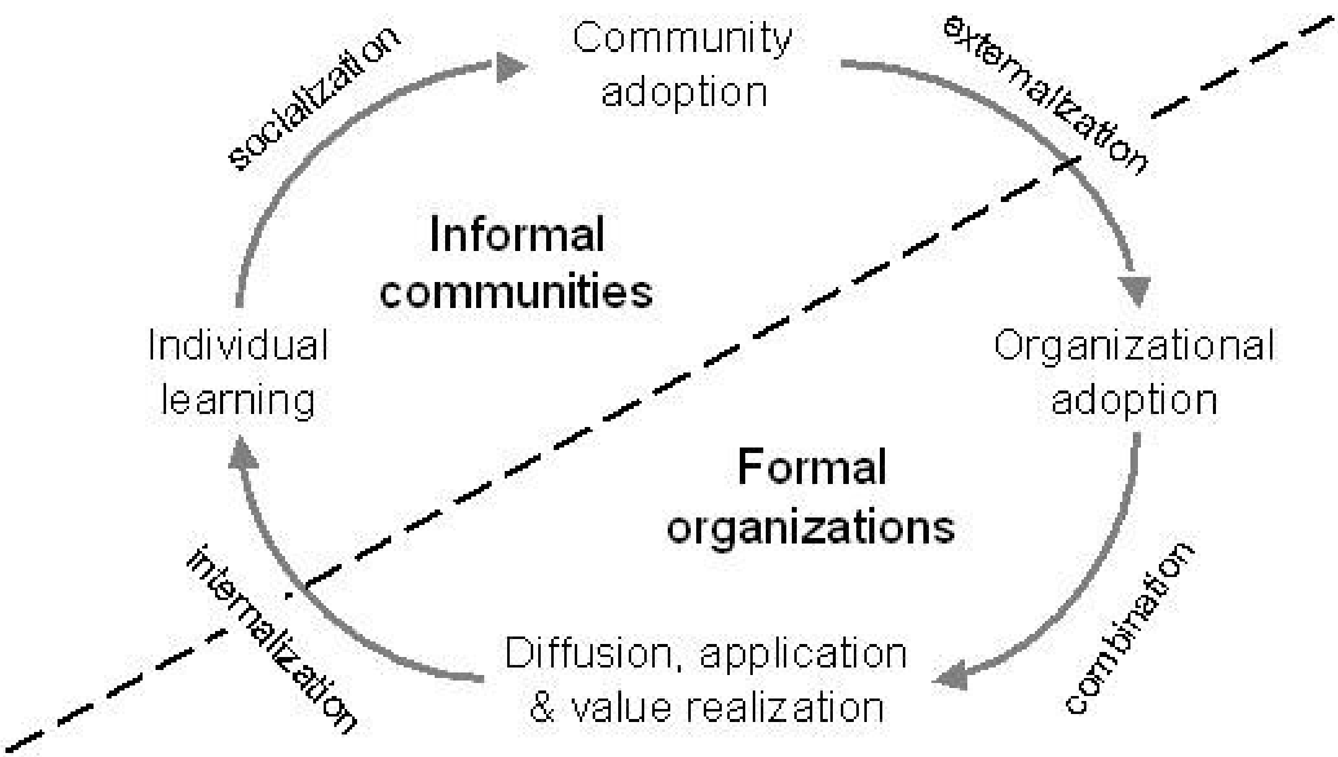
Tacit knowledge is highly personal and difficult to formalize, often making it problematic to share with others. Such knowledge is deeply rooted in an individual's action and experience, as well as in their ideals, values, or emotions. By expressing our "knowledge" in words, numbers, formulae, product specifications, or principles, we do make a component explicit. However, the explicit component represents content, and as human knowledge is so deeply contextual, we always know more than we can verbalize, and we can verbalize more than we can write down. The loss of context when writing down, or "codifying," tacit knowledge means that explicit knowledge (or information) can only partially represent what we know (Snowden 2002).

Nonaka and Takeuchi (1995) suggest that four conversions of knowledge between tacit and explicit forms represent the fundamental building blocks of the knowledge creation process, namely socialization, externalization, combination, and internalization (Fig. 1). These conversions embody key steps to the amplification of individual knowledge to organizational capability, and ultimately to integrate knowledge in application processes (Miller and Morris 1999).

- *Socialization—tacit knowledge sharing.* Tacit knowledge is rooted in individual experiences, ideals, values, and emotions (Nonaka et al. 2001). Self-organizing communities facilitate the sharing of individual knowledge by focusing people ("socialization") on a common issue. Knowledge sharing in these communities is almost entirely based on trust that is developed through face-to-face interactions (Wenger et al. 2002).

- *Externalization—converting tacit into explicit.* Tacit knowledge that has been shared through socialization could be captured in explicit forms ("externalization") such as concepts, diagrams, or specifications. For example, tacit knowledge about the needs of resource

Fig. 1. Knowledge amplification from individual knowledge to institutional capability, based on Nonaka and Takeuchi's (1995) four modes of knowledge conversion.



managers can be made explicit by documenting the design specification of a resource-monitoring program. Members of a learning community can readily transfer knowledge in this codified form to their organizations where it may be met with wider adoption or with rejection.

- *Combination—combining explicit forms.* Not all forms of translated explicit knowledge are necessarily directly applicable to resource management. A number of explicit knowledge components may still have to be linked together ("combination") to form a practical knowledge application (e.g., in the form of a decision-support model).

- *Internalization—converting observations into new tacit knowledge.* The process of embodying explicit knowledge into tacit knowledge ("internalization"), is closely related to the process of "learning by doing." Operational application of combined explicit knowledge presents a laboratory for learning. New knowledge is internalized through experimentation and reflection, and it broadens, deepens, and reframes the individual's tacit knowledge base. This tacit knowledge is in turn shared with others through socialization, setting off a new cycle in the enforcing spiral of knowledge creation and amplification.

By recognizing only the explicit character of knowledge, we underestimate the true effort required to transfer knowledge. Information or explicit knowledge can be passed on to others relatively easily; the transfer of associated tacit dimensions requires intimate human interaction. People need to spend time together, develop mutual trust, learn more about each other's contexts and jointly facilitate conversions of knowledge between tacit and explicit forms. Without this comprehensive knowledge transfer, an adopter’s ability to understand, replicate, or exploit new knowledge is severely constrained (Zahra and George 2002).

Knowledge Diversity and the Need for Bi-directional Knowledge flows

Research represents the most formal and systematic mode of knowledge creation, but this in no way gives science a monopoly in resource management. Highly relevant knowledge is also created in the policy, management, societal, and traditional (also referred to as indigenous) knowledge domains. Each of these domains generates its own knowledge supply and demand. Knowledge is constituted very differently in each domain because they differ widely in the degree to which knowledge is codified (made explicit) and the emphasis placed on application (Fig. 2). The traditional perspective of basic vs. applied research, although relevant, is far too simplistic to capture these differences, and a broader model is required (Fig. 2):

- *Fundamental or basic research, also termed classic or Mode 1 research* (Gibbons et al. 1994) refers to scientific investigations that primarily serve the advancement of understanding rather than the solving of specific problems. Knowledge in this domain is highly systematized and organized along disciplinary lines. Quality control is dominated by intensive codification and peer review.

- *Applied or Mode 2 research* is trans-disciplinary, heterogeneous, and directed at solving practical problems. Knowledge creation is driven by its perceived usefulness and is highly contextual, but not necessarily any less original. Successful application requires a “development and design” phase in which the knowledge is specifically packaged to address the needs of potential adopters.

- *Policy formulation and strategy development* have their own brand of knowledge, which includes statements of intent, operating principles, frameworks, guidelines, plans, and desired outcomes at various levels of centralization and/or decentralization. These knowledge domains demand much synthesis of inputs from other domains and must meet high adoption and diffusion needs. Knowledge must be well codified (made explicit) if implementation is to be successful.

- *Operational management* represents a combined explicit–tacit knowledge domain dealing with infrastructure and organizational capability. Explicit knowledge comes in the form of guidelines and manuals, and tacit knowledge is based on experiential learning and verbal sharing of good practice as well as failures.

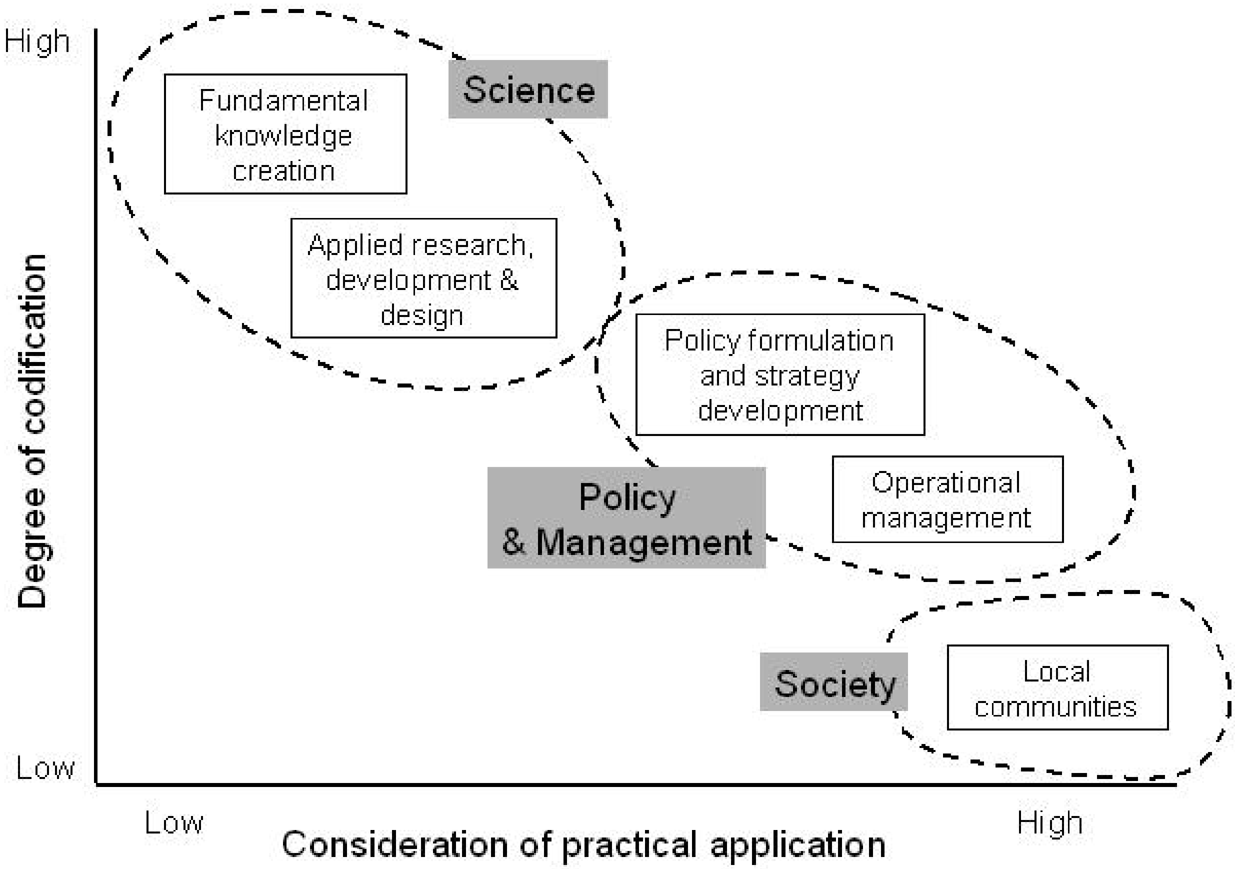
- *Local communities* “own” local, indigenous, or traditional knowledge (see Gilchrist et al. 2005) that has evolved through generations of hands-on learning while meeting day-to-day challenges. It is transferred over time in folklore, societal norms, management systems, and social memory (Berkes and Folke 1998).

Successful knowledge generation and its application in ecosystem management depend on a free flow of knowledge between these five domains. It is, therefore, very surprising to find how few natural resource management agencies have explicit processes to initiate and manage these knowledge flows. Management of knowledge across the spectrum of domains is usually left implicit without recognition of the major barriers that can prevent its flow (Gunderson et al. 1995). The mere difference in the way that knowledge is produced, validated, and stored in the different domains represents one such barrier.

A further barrier to the free flow of knowledge is rooted in the worldview or frame of reference of each individual. This is molded by factors such as past experiences of individuals; knowledge acquired through fulfilling social roles, which may be specific to race, class, gender, culture, or ethnic affiliation; the era in which an individual grew up (age related); geographic or environmental influences; or a particular disciplinary or theoretical schooling (NRC 2000, Reagans and Zuckerman 2001, Adams et al. 2003).

The barriers presented by knowledge diversity are not only a factor between science and management or between the knowledge nodes shown in Fig. 2, but also between individuals within any particular node. The worldview of an individual provides the

Fig. 2. Various domains involved in managing ecological resources differ in their degree of knowledge codification, or explicitness, and emphasis on practical application.



context within which information is processed. Two individuals with divergent worldviews will, by drawing on their past experience and current understanding, cognitively frame very different conclusions from the same information (Adams et al. 2003).

Proper consideration of the plurality of views that are likely to prevail in any interaction between ecosystem researchers and managers is essential to effective dialogue. This emphasizes the need for bi-directional as opposed to unidirectional flows of knowledge—if the existing knowledge, understanding or worldview of individuals is not engaged during the sharing of knowledge, they may fail to grasp new concepts and information that are presented (Becker 2005). This theme of empathetically engaging multiple perspectives relates to the field of appreciative inquiry (Cooperrider et al. 2003) and also to the much broader topic of public participation. However, it is not the purpose of this paper to address knowledge flows in this broad context,and the remainder of the paper will focus on the knowledge interfacing and sharing between the domains of science and management.

KNOWLEDGE INTERFACING AND SHARING

A lack of mutual engagement in two-way communication and its concomitant strategy-of-hope represent the major shortcoming of the push–pull strategies. In particular, it leaves scientists and managers focusing on pushing and pulling information without an appreciation of the complex nature of tacit knowledge, and of the effort required to achieve bi-directional knowledge flows between diverse worldviews. In this section, we conceptualize the knowledge interface as the overlap, based on the degree of common understanding, between two distinct knowledge entities or systems. The knowledge interface provides a conceptual space for the two systems to meet, communicate, share knowledge,and collectively create new knowledge. We explain how the knowledge interface between science and management provides a critical link between individual knowledge and an improved capability of the larger science–management community regarding the understanding and management of ecosystems.

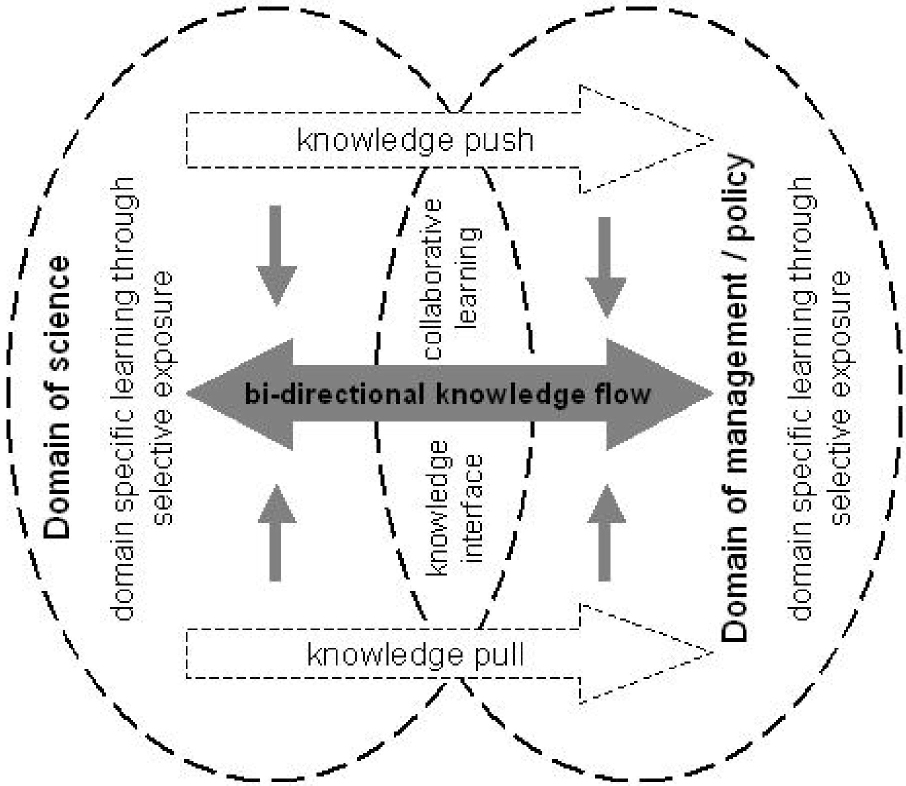
Shared Understanding

Knowledge diversity is a strength in any system, providing robustness when responding to new challenges (Cohen and Levinthal 1990, Westley 1995). Exchanging information or explicit knowledge between diverse units is relatively easy, but stimulating the transfer of context-laden tacit knowledge requires a much higher intensity and quality of interaction, and it takes much more time! The irony is that the greater the differences in knowledge possessed by two units, the more potential exists for knowledge to be exchanged. At the same time, a larger knowledge differential also implies a greater obstacle to achieving successful knowledge transfer. In essence, some overlap in understanding must exist for knowledge to flow between two domains. Fragmented and unrelated knowledge entities are of little or no use to the bigger purpose (NRC 2000), and knowledge between entities can only be complementary if it is different, yet at the same time related (Zahra and George 2002). Science and management represent two different communities of practice that are complementary only to the degree that their knowledge or understanding is able to interface (Fig. 3).

Recognition of a knowledge interface not only provides a node for dialogue, but also facilitates the co-evolution of values, priorities, intent, and action that provide robustness to decision making. When scientists and ecosystem managers engage each other at the knowledge interface, they become a unified learning system in which new and shared experiences lead to “joint fact finding” and the creation of new knowledge. In a functional interface, the parties move beyond the traditional roles of knowledge provider and knowledge consumer, to that of partners who negotiate what is feasible, desirable, and acceptable. A first step toward achieving this functionality may be to make the knowledge structures of relevant disciplines explicit, including disciplinary histories, spatial and temporal scales of knowledge, precision, accuracy of predictions, and availability of data (Benda et al. 2002).

A common obstacle to effective knowledge interfacing is the natural tendency for learning to take place within groups of knowledge homogeneity. As existing knowledge influences both the ability to put new knowledge into memory and to recall and use such knowledge, learning is most efficient when the object being studied relates to what is already known (Cohen and Levinthal 1990). Quite naturally, people adopt learning patterns that favor subject matter that relates to previously accumulated knowledge. The downside is that the more a person’s worldview is shaped by learning within a defined field, the harder it becomes to associate with realities that emerge from other fields. Miller and Morris (1999) refer to this tendency as “trained incapacity”—the conundrum in which the more we know about something, the harder it is to learn to do it differently. Rogers (1995) refers to the same phenomenon as the path of selective exposure; Lyndon (1989) talks of proactive inhibition, whereby an individual protects knowledge already acquired by disregarding conflicting or unrelated information; Becker (2005) suggests that more recently acquired knowledge may be easier to relinquish (in order to accommodate new information and behaviors) than experience and knowledge that was acquired and reinforced over a long period of time, and that may have become deeply entrenched beliefs. Such deeply entrenched knowledge can also act as a barrier to the acquisition and adoption of new knowledge.

Fig. 3. The knowledge interface facilitates collaborative learning, shared understanding of key concepts, and co-evolution toward common purpose, intent, and action.



The challenge is to overcome this resistance to "trying on" new and different perspectives and assumptions by moving people out of their path of selective exposure (Rogers 1995) into teams where new content and context are generated within an interface. Learning together, through sharing content as well as contexts, fosters much needed shared understanding of the concepts, principles, and approaches relevant to the respective domains (Fig. 3). This is especially hard for scientists who may be rewarded for staying in their chosen field, but it is also difficult for managers and policy makers who cannot afford to be seen not to know.

The introduction of new water legislation in South Africa provided an "interface" or common purpose that science and management engaged with equal vigor. The common purpose was motivated by a slogan, "some for all forever," that embraced the principles of a finite resource, and the need for equitable access and for sustainable development (de Coning and Sherwill 2004). Ecologists, social scientists, politicians, and managers could all align their expertise with this purpose. Similarly, the process for determining and implementing an "ecological water reserve" (akin to environmental flow requirements) for aquatic ecosystems provided a common playing field for researchers, planners, and managers. This process was feasible only because all the parties participated as partners in the adaptive development and implementation proess, an engagement that led to invaluable learning and shared understanding (see Postel and Richter 2003).

Communities of Practice

Formal organizations and informal learning communities are both prerequisites for effective inter-domain knowledge sharing and adoption, and incorporation of such knowledge into institutional policies and processes. However, it is the informal "communities of practice" (CP) that most easily facilitate interfacing between science and management. Recent development of a theoretical discourse around how these communities function (e.g., Wenger 1998, Wenger et al. 2002) has improved our ability to harness the value of CP as knowledge resources.

In formal organizations, individuals try to act as "rationally" as possible within the organization's mandate, and so they tend to retain control, maximize winning, and avoid error or losing. Clinging to one's safe worldview (Raelin 2001) is a good strategy under these circumstances. Informal communities of practice, on the other hand, are "groups of people who share a passion for something that they know how to do and who interact regularly in order to learn how to do it better" (Wenger 2005). The currency in these communities is knowledge, and not the rules of a specific mandate; membership is based on participation rather than official status. Communities of practice constitute webs of inclusive relationships in which people feel valued when they share their knowledge and are not bound by organizational affiliations (Fig 4).

To be successful, communities must generate enough excitement, relevance, and value to attract and engage members. The self-organizing nature of these communities is the key to extracting their full potential. Some individuals, especially scientists, find the concept and practice of freely sharing their knowledge, especially with managers, an uncomfortable cultural shift. Wenger (2005) lists three fundamental characteristics of CP:

- *Domain.* A CP is about something. Its identity is defined not only by a task, as it would be for a project team, but by an "area" of knowledge that needs to be explored and developed. Domain provides a common focus that gives the community its identity, and defines the key issues that members need to address.

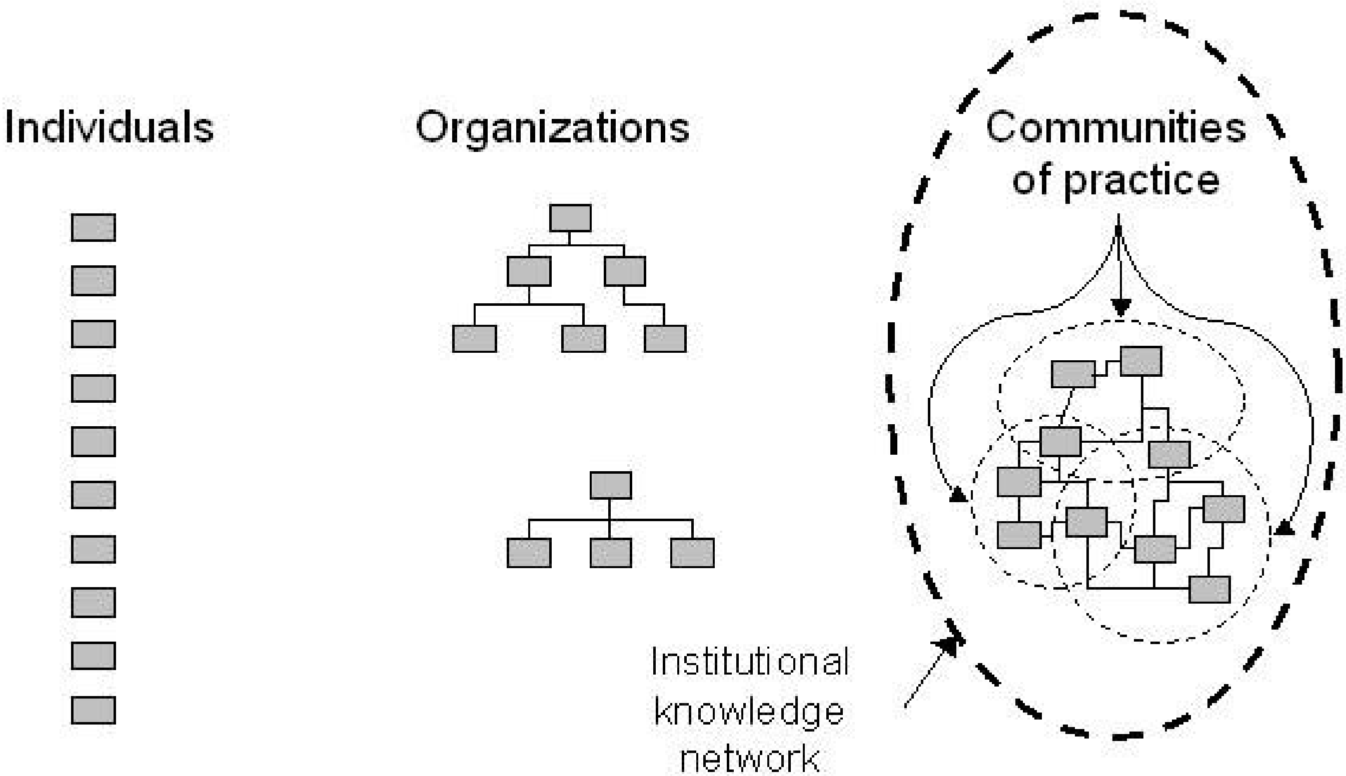
- *Community.* A CP is not merely a website; it involves people who interact and who develop relationships that enable them to address problems and share knowledge. Community refers to the group of people for whom the domain is relevant, and the quality of the relationships among members. These relationships enable collective learning.

- *Practice.* A CP is not merely a community of interest. It brings together practitioners who are involved in doing something. Over time, they accumulate practical knowledge in their domain. They also have a special connection with each other because they share real experiences. They understand each other's stories and insights. This allows them to learn from each other and build on each other's expertise. Practice refers to the body of knowledge, methods, tools, stories, cases, and documents that members share and develop together.

A small "core group" (10% to 15% of the whole community) actively participate, providing strong leadership, and giving the CP intrinsic legitimacy. This group largely determines the agenda and activities of the community. An "active group" (another 15% to 20% of the community) also participates actively, but without the intensity or singleness of purpose of the core group. A "peripheral group," which makes up the largest portion of the community, prefers to observe rather than to make direct contributions. These peripheral activities, however, form an essential dimension of CPs, and the participants often use the acquired knowledge to influence their home organizations (Wenger et al. 2002)

For centuries, successful collaborations between scientists were embedded in an invisible college or network of informal communities, whose size and density seem to be increasing over time (Barabási 2005). There are also examples of effective communities of practice in natural resource

Fig. 4. Alternative configurations of people as basic knowledge units have implications for the degree of connectedness (lines) and associated sharing of knowledge. Overlapping communities within a bigger institutional knowledge network effectively connect people from government agencies, universities, science councils, conservation bodies, and the like.



management, especially it seems in management of aquatic systems. Programs on Chesapeake Bay (Costanza and Greer 1998) and in the Everglades (Davis and Ogden 1994) in the USA, the Murray River (Mackay and Eastburn 1990) in Australia, and the KNP (du Toit et al. 2003) in South Africa all focus on specific ecosystems. In South Africa, a vibrant CP has emerged around the development and implementation of a national River Health Programme (Roux 2004) and new water and environmental legislation (Postel and Richter 2003). However, in general, there is a long way still to go before these sorts of programs cease to be exceptional examples and become the R&D norm in resource management.

R&D Programs

As learning-oriented collaborations, CP run a risk of foundering due to a lack of resources (see Westley 1995), although in practice, R&D programs can facilitate the formation and maintenance of CP. The design challenge for R&D programs is to avoid the pitfall of being either research driven or user driven. Successful programs will engage both ends of the spectrum in a dialogue from which emerges a negotiated view of what is both feasible and desirable. Too many programs of research aimed at supporting natural resource management are either operating under the “strategy of hope,” or are too focused on formal structures and communication to be really effective.

Well-designed natural resource R&D programs will place much more emphasis on creating an environment conducive to promoting a self-organizing CP that fills an important role in fostering bi-directional flow in the knowledge interface. Such programs should be defined primarily by knowledge needs, integration processes, and adoption outcomes, and not by task, or geography, or individual projects. Program steering committees commonly put their efforts into initiating a range of individual projects to cover their information needs, and in so doing become focused on short-term time frames and fragmented outputs. It is important to put much more explicit emphasis on integrating knowledge needs and flows, on longer program time frames, and on integrated program outcomes.

We make the important distinction between outputs and outcomes. Far too often, the end result of research programs is a series of reports, documents, or publications that present, in explicit form only, the knowledge gained. These are outputs. Outcomes need to be expressed as knowledge adoption that has captured the transfer of tacit knowledge, and so can be measured as demonstrable changes in practice within the adopter agency. This requires programs to go the proverbial extra mile, to step beyond the strategy of hope, and to ensure that the knowledge gained is actually used and not merely presented as being potentially useful. Most program participants will need to step beyond their disciplinary comfort zones; informal CP that are free of officialdom and institutional norms provide a safe environment for such bold moves.

Building a science–management alliance requires bringing together a combination of creativity and pragmatism, based on the respective experiences and tacit knowledge of researchers and managers, to build a better future. The road to such a strategic alliance often starts with a single interaction; commonly based on a contractual appointment of a scientist to undertake some work for a management or funding agency. A research report is exchanged for financial compensation, and if both parties are satisfied, follow-up interactions are likely.

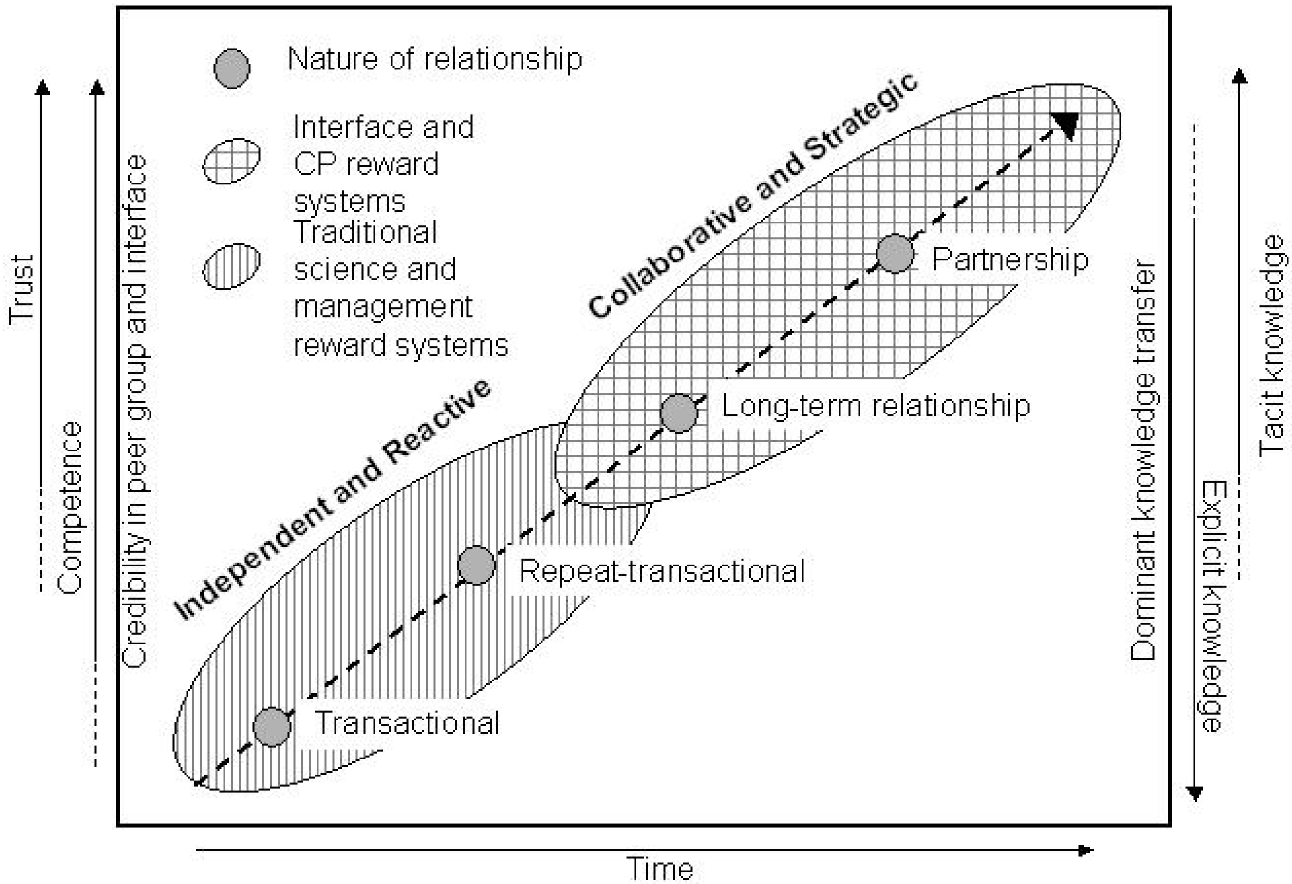
In conventional transactional relationships, managers reduce their risk by drawing up a defined contract for the commissioned work. Scientists reduce their risk by qualifying their findings and recommendations to the point where they may be of little help to the manager. Such transactional relationships are primarily based on competence credibility and require little if any safety credibility (Fig. 5).

Contractual agreements do not represent a true partnership or alliance between science and management, nor do they provide the time and space for uncovering latent needs, defining strategic direction, or jointly developing a better future. A true partnership implies 5- to 10-year (or longer) planning cycles, shared ownership, and risk (research results belong as much to the researcher as to the manager), as well as high levels of trust. Unlike shorter-term relationships or highly contractual arrangements, the strategic alliance provides the temporal and intellectual space for individuals to learn from each other and to understand each other’s culture.

The core group or leader(s) form a very significant enabler of an R&D program. To lead or facilitate the convergence of the two knowledge domains requires transdisciplinary skills, and few people have any formal training in this area. Although there are the exceptions of interdisciplinary graduate programs, e.g., in integrated water resource management (Kirshen et al. 2004), unidisciplinary education is widely predominant at institutions of higher education (Max-Neef 2005). True transdisciplinarity involves actions that span empirical levels (existing knowledge in disciplines such as mathematics, geology, ecology); to pragmatic levels (what we are capable of doing: architecture, engineering, forestry, etc.); to normative levels (planning, design, politics, law); and finishing at value levels (values, ethics, philosophy (Max-Neef 2005)).

Identifying and empowering the core group of interface leaders is key to developing a functional interface between science and management in individual programs. These leaders have one foot in each of two worlds, and often find themselves marginalized from their original peer group. Managers who take on such a role are often accused of spending too much time on people and issues beyond their organization’s mandate, and colleagues feel they are not contributing enough to solving “real” management problems. Scientists on the other hand face the risk of losing competence credibility among their peer group because their publication rate falls off. Career paths that encourage “migration” back and forth between the knowledge interface and the home peer group may be a solution to this dilemma.

Fig. 5. The formation of a strategic alliance between science and management requires time for the development of trust (safety credibility), and would benefit from a reward system that acknowledges the need for tangible outputs such as papers, reports, and policies, as well as intangible outcomes such as new relationships, changed perceptions, and improved behaviors.



CONCLUSION

Wilson (1998) talks about "consilience" as "literally a jumping together of knowledge by the linking of facts and fact-based theory across disciplines to create a common groundwork of explanation." He suggests that all knowledge, from disciplines as diverse as biology, anthropology, physics, economics, and the arts, is intrinsically unified. Consilience is the key to return to the intrinsic unity of knowledge from its current fragmentation. Wilson illustrates the appeal of consilience through the domains of environmental policy, ethics, social science, and biology. "We already intuitively think of these four domains as closely connected, so that rational inquiry in one informs reasoning in the other three. Yet undeniably each stands apart in the contemporary academic mind. Each has its own practitioners, language, modes of analysis, and standards of validation. The result is confusion ..."

The long and entrenched legacy of separating the growth of scientific knowledge from its application has clearly been detrimental to the management of natural resources. Some have suggested that the separation has protected science from becoming biased, or losing independence and objectivity (Aumen and Havens 1997), but we would strongly contend that it has been entirely unnecessary. The fragmentation of science and its separation from application are simply artifacts of scholarship (Wilson 1998). To effectively respond to the challenge of managing complex social–ecological systems, scientists cannot afford to remain detached experts (Ludwig 2001) who deliver knowledge to managers, but must assume the roles of collaborative learners and knowledge generators (Folke et al. 2005) in a science–management partnership.

Much of the notion that science will lose its objectivity and independence in the face of application comes from concern that user agencies will "dictate" the nature and outcome of research, and that this will therefore not be "cutting edge." This is not a problem of either science or application, but of the honesty and objectivity of the parties involved, just as it would be in any other venture of knowledge generation and transfer, be it in agriculture, engineering, or business. It is time for a change in mindset, especially when we are dealing with common property natural resources in social–ecological systems. The new mindset should simply see science as being in service of society, rather than purely of scholarship, and that good scientists will ask novel questions of, and seek objective approaches to, any unsolved problem. Similarly, potential adopters will know that if the solution to a problem does not exist it will require some novelty to find it, and if the approach is not scientifically objective, the solution will not stand up to either societal or scientific scrutiny.

Science is commonly depicted at the "upstream" end of a one-way process by which useful discoveries and inventions eventually "flow" to an application home (Ziman 2000). Although this may be the dominant direction of knowledge flow during the development of new technological capability, its successful adoption and implementation is highly dependent on the bi-directional flow of knowledge between science and management. The challenge articulated in this paper is that of developing a sound relationship between a nation's (and a planet's) capacity to create and supply appropriate knowledge, and its capacity to absorb, translate, and exploit such knowledge. More and better scientific solutions will only be of academic interest unless there is a receptive management cadre that possesses the capability to both absorb and implement the new solutions. Similarly, the best policies and management strategies will be in vain without a constant stream of tested and verified concepts, tools, and methods to facilitate their implementation.

We contend that adherence solely to the explicit dimension of knowledge can diminish the inherent value embodied in the concept of knowledge transfer. Instead of mere knowledge transfer, we propose that "co-production" of knowledge through collaborative learning between "experts" and "users" is a more suitable approach to building a knowledge system for the sustainable management of ecosystems. This can be achieved through knowledge interfacing and sharing, which require a shift from a view of knowledge as a "thing" that can be transferred, to one of a "process of relating" that involves careful negotiation of meaning among partners. This latter view requires the establishment of a trusting relationship between ecosystem researchers and managers that can enable them to share and compare the various interpretations of their messages, as well as the success of the outcomes that they jointly achieve.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol11/iss1/art4/responses/

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