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Boundary Work and the Complexity of Natural Resources Management

Peter P. Mollinga*

ABSTRACT

This paper discusses how research on natural resources management systems can address the complexity of such systems. Three different types of complexity are identified: ontological, societal, and analytical. Significant ideas for "dealing with complexity" are extracted from U.S., Swiss, and U.K. literature on inter- and transdisciplinary research. Based on this, the "boundary work" framework is presented to systematically think through complexity challenges. The framework suggests that inter- and transdisciplinary research on natural research management requires three types of work: (i) the development of suitable *boundary concepts* that allow thinking of the multidimensionality of NRM issues; (ii) the configuration of adequate *boundary objects* as devices and methods that allow acting in situations of incomplete knowledge, nonlinearity, and divergent interests; and (iii) the shaping of conducive *boundary settings* in which these concepts, devices, and methods can be fruitfully developed and effectively put to work. The ideas presented are illustrated with an example of a research program on sustainable land and water management in Uzbekistan. The concluding section highlights three issues important for increasing the effectiveness of inter- and transdisciplinary research on natural resources management.

Dep. of Political and Cultural Change, ZEF (Center for Development Research), Walter Flex Str. 3, 53113 Bonn, Germany. Received 6 Oct. 2009. *Corresponding author (pmollinga@uni-bonn.de).

Abbreviations: FTI, follow the innovation; NRM, natural resources management.

Resilience is one of the concepts aiming to capture the system-level properties of natural resources (management) systems. Resilience, like sustainability, vulnerability, adaptive capacity, robustness, transformability, and other concepts, seeks to define a quality of natural resources (management) systems that simultaneously captures their stability or endurance, as well as their capacity to respond to change and adapt. This paper does not address substantive questions regarding the definition and operationalization of such concepts, but takes as its starting point the observation that concepts like resilience attempt to capture properties of natural resources (management) systems *as complex systems*. The paper takes its direction by asking what, generally speaking, "dealing with complexity" involves, and how this might affect research practice.

The paper first identifies three types of complexity in relation to research on natural resources management (NRM). This is followed by a brief and selective literature review on how inter- and transdisciplinary research has dealt with complexity. Some useful insights from different perspectives developed in different regions and scientific traditions are listed. The paper subsequently presents the notion of "boundary work" as a framework for systematically addressing the challenges related to complexity. The framework has three components: boundary concepts, boundary objects, and boundary settings. The paper continues by illustrating some of

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the elements of the framework with the example of an ongoing research program on sustainable land and water management in Uzbekistan. The concluding section summarizes the main argument and highlights three issues important for enhancing the effectiveness of inter- and transdisciplinary research on NRM.

MEANINGS OF COMPLEXITY

Few would want to disagree with the statement that contemporary NRM is a complex phenomenon and poses complex problems. Some would even argue that these problems are "trans-scientific," that is, can be formulated in scientific terms, but cannot be solved by science.[1] The discussion below will suggest that NRM problems can never be solved by science alone, when solving means finding workable ways of dealing with a problem in the real world. The reasons for this can be understood by unraveling the notion of complexity.

Natural resources management systems are complex systems because they consist of heterogeneous components with a diversity of relations connecting these components. The components are physical, technical, and human; the relationships are physical and ecological, infrastructural, social, economic, and political—with emergent properties at different scale levels. Moreover, complex natural resources management systems behave in a nonlinear and unpredictable manner. This is the first meaning of complexity, which can be called *ontological complexity*.

The second type of complexity can be called *societal complexity*. Natural resources management systems are populated, managed, and governed by different groups of people for whom the system has different purposes, benefits, and meanings. As a result, these groups have different interests in NRM. Because these interests are often conflicting, NRM is inherently contested. It is in this contested arena that planning and decision making on NRM takes place.

Analytical complexity is the third form of complexity. Natural resources management systems are also complex in the sense of complicated, difficult to understand. Generally, knowledge about the behavior of NRM systems is partial—incomplete data sets are available, and not all the mechanisms operating in the systems, and their interactions, are known. In addition, science has advanced through a division of labor that has focused on individual parts and relations—disciplinary science. Disciplinary organization is very powerful in some respects, but constitutes the problem of how to achieve comprehensive understanding. To incorporate in one analysis the hybrid sets of parts and relations that compose NRM systems, as well the plurality of meanings that may exist regarding an object or process, is a great intellectual challenge.

[1] *Trans-science* is a term coined by the nuclear physicist Alvin M. Weinberg (Weinberg, 1972). Huber (1998, p. 27) describes it as "the study of problems too large, diffuse, rare, or long-term to be resolved by scientific means."

Ontological and analytical complexity constitute the need for developing *interdisciplinary* approaches to research. Societal complexity constitutes the logic of a *transdisciplinary* approach to research. In a simple definition, transdisciplinary research is interdisciplinary research with interest groups (so-called "stakeholders") involved in all phases of the research.[2] Pohl and Hirsch Hadorn (2007, 2008) suggest that transdisciplinary research becomes necessary:

1. When there is a socially relevant problem field,
2. Where those involved have a major stake in the issue,
3. Where there is societal interest in improving the situation, and
4. When the issue is under dispute.

There are very few contemporary NRM issues related to, for example, land, water, forest, and biodiversity that do not fulfill these criteria.

Notwithstanding the strength of this argumentative logic, science and society practically operate in a manner that makes interdisciplinary and transdisciplinary research difficult to do and sustain. Society has created many boundaries that hinder the implementation of integrated approaches. These boundaries include intellectual boundaries in the form of disciplines, the heavily guarded academic territories inhabited by academic tribes (cf. Becher and Trowler, 2001). The boundaries also include the gap between research and policy. These two domains often find it difficult to communicate and like to caricature each other. Other boundaries are those between experts and laypersons, including the appreciation of local knowledge, and the organizational boundaries between different agencies involved in a problem, say, between different government departments. There are political, ideological, and cultural boundaries involving different worldviews or paradigms in relation to the problem at hand. And so forth.

APPROACHES TO THE INTERDISCIPLINARY STUDY OF NATURAL RESOURCES MANAGEMENT

The increasing prominence of NRM problems in public action and government policy in recent decades has generated a variety of attempts to deal with the "boundary crossing" challenges associated with NRM research.[3]

Sustainability Science (United States): The Research–Policy Interface

In the United States, interdisciplinary research on NRM under the "sustainability science" banner has made significant contributions to the analysis of the

[2] A Web page discussing definitions of *interdisciplinarity*, *transdisciplinarity*, and related terms is http://learningforsustainability.net/research/interdisciplinary.php (verified 26 Dec. 2009).

[3] The discussion below of U.S., Swiss, and U.K. contributions does not mean to suggest that the issue is only addressed in an industrialized country context. An important contribution from India is Lele and Norgaard (2005). A systematic review of the globally emerging literature on inter- and transdisciplinary research on NRM is still to be written.

research–policy interface. It has produced at least two very useful insights.

The first is an answer to the question, "What characteristics should scientific knowledge have to be taken seriously in decision making by decision makers?" A standard response to that question is to say that good, credible science is the primary requirement (as in the notion of "evidence-based policy"). Sustainability science researchers have convincingly shown that apart from credibility, the qualities of salience and legitimacy are at least as important for scientific knowledge to be taken seriously (Cash et al., 2003). *Salience* refers to the relevance of information for stakeholders and decision makers. Information needs to be timely, accurate, and specific for it to be salient for real-world applications, that is, speak to the concerns of knowledge users. *Legitimacy* refers to the fairness of the information-gathering process. For a process to be legitimate, it needs to consider appropriate values, interests, concerns, and specific circumstances from the perspective of different users. Most people trust knowledge that is coproduced by themselves more than knowledge produced by outsiders.

The second insight produced by sustainability science is the first part of the title of this paper: boundary work. The basic insight is that crossing the research–policy boundary does not happen automatically, but needs work. Systems and processes at the interface of research and policy should seriously invest in communication, translation, and/or mediation, and thus balance credibility, salience, and legitimacy. *Communication* has to be active, iterative, and inclusive. *Translation* is necessary because mutual understanding is often hindered by jargon, language, experiences, and presumptions about what is a convincing argument. *Mediation* is necessary because there are tradeoffs between credibility, salience, and legitimacy, which may lead to conflicts among partners/stakeholders. All of this needs conscious design of structures and procedures through which these processes can happen effectively—professional boundary management is part of effective inter- and transdisciplinary research.

Transdisciplinarity (Switzerland): Design Principles

The Swiss Academy of Arts and Sciences in 2003 established a Transdisciplinarity Centre. The Centre has produced an impressive number of evaluative studies on the practice of interdisciplinary and transdisciplinary research on NRM, particularly in the European context (Pohl and Hirsch Hadorn, 2007, 2008). These studies provide the logic summarized above of when to opt for transdisciplinary research.

The second contribution is the articulation of a set of "design principles" for transdisciplinary research based on the evaluation of inter- and transdisciplinary research practice. To shape the transdisciplinary research process and to keep it within practicable boundaries, Pohl and Hirsch Hadorn (2007) formulate and discuss four principles.

1. Reduce complexity by specifying the need for knowledge and identifying those involved.
2. Achieve effectiveness through contextualization.
3. Achieve integration through open encounters.
4. Develop reflexivity through recursiveness.

For implementation of these principles, five tools are presented in detail (Pohl and Hirsch Hadorn, 2007). I highlight one interesting aspect: the observation that transdisciplinary research needs three qualitatively different types of knowledge:

1. *Systems knowledge* (knowledge about the genesis and possible development of a problem and about life–world interpretations of a problem);
2. *Target knowledge* (knowledge to determine and explain the need for change, desired goals, and better practices);
3. *Transformation knowledge* (knowledge about technical, social, cultural, legal, and other possible means of acting to transform existing practices and introduce desired ones).

Pohl and Hirsch Hadorn convincingly show that these types of knowledge influence each other in a given project, and provide tools to articulate these linkages. Nevertheless, in practice a division of labor also tends to exist in this respect, with systems knowledge being the domain where academic NRM researchers feel most at home, target knowledge often left to decision makers and research funders of different kinds, and transformation knowledge delegated to special categories of communication and "interface" experts (cf. Moll and Zander, 2006), if addressed at all. Explicit integration of these three types of knowledge often remains elusive.

Rural Research (United Kingdom): Development and Participatory Modeling

In the United Kingdom, a large inter- and transdisciplinary research program called RELU (Rural Economy and Land Use Programme, http://www.relu.ac.uk/ [verified 26 Dec. 2009]) is being implemented. The program is cofunded by three different research councils and the Scottish and British governments. This program has two characteristics relevant for the present discussion. The first is that it problematizes the notion of "development" more systematically than the first two schools. The first two are examples of what Klein has called "instrumental interdisciplinarity," while the U.K. research is closer to what she calls "critical interdisciplinarity" (Klein, 1996). The more critical flavor of the U.K. research may have to do with the relatively large influence of approaches used in developing countries contexts. A second contribution is some very strong examples of participatory modeling approaches. In participatory modeling, interest groups are closely involved in "defining the problem" at the outset of the research. As the Swiss school also emphasizes, joint problem definition, and negotiation of the different understandings of what is whose problem, is the most crucial factor for successful inter- and transdisciplinary research.

BOUNDARY WORK: CONCEPTS, OBJECTS, AND SETTINGS

Despite the fact that the practice of inter- and transdisciplinary research is attracting increasing attention, doing it remains a major challenge. A large part of the discussion on interdisciplinarity focuses on problems, constraints, challenges, and frustrations. Therefore, it is important to understand what exactly the nature of these problems is.

Boundary crossing is a central metaphor in the study of inter- and transdisciplinarity (Klein, 1996). It is more than a metaphor, however. The social study of science literature has extensively analyzed "boundaries," and developed a vocabulary for the issues of boundary guarding and boundary crossing in science and in science–society relations (Gieryn, 1983; Halffman, 2003). The notion of boundary work suggests, as noted above, that integration as a form of boundary crossing does not happen automatically but requires concerted effort. The framework for operationalizing boundary work proposed here suggests that effective inter- and transdisciplinary analysis and action requires three types of work:

1. The development of suitable *boundary concepts* that allow thinking, that is, conceptual communication, about the multidimensionality of NRM issues.
2. The configuration of adequate *boundary objects* as devices and methods that allow acting in situations of incomplete knowledge, nonlinearity, and divergent interests.
3. The shaping of conducive *boundary settings* in which these concepts, devices, and methods can be fruitfully developed and effectively put to work.

Boundary Concepts: Knowledge for Understanding

Boundary concepts are words that function as concepts in different disciplines or perspectives, refer to the same object, phenomenon, process, or quality of these, but carry (sometimes very) different meanings in those different disciplines or perspectives. In other words, they are different abstractions from the same "thing."

The concept of "water control" as used in irrigation studies is a good example of a boundary concept. "Water control" is used in different disciplinary domains, referring to the same object (irrigation water management), but looks at this from very different perspectives and with very different interests. Three dimensions of water control can be distinguished: technical, organizational, and socioeconomic/political water control (Table 1). The point is that the three different dimensions of water control are not independent, but define each other. Changes in one dimension trigger or require changes in the other two. Interdisciplinary analysis is about understanding the interrelation of these different dimensions.

Sometimes multidimensionality is captured by designing a new concept. This has happened with the concept of "ecosystem services." This concept has officially been accepted on a global scale through the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005). The globally shared typology distinguishes between supporting, provisioning, regulating, and cultural ecosystem services. This concept allows ecologists, economists, sociologists, and other disciplines to have a common language on the usefulness of ecosystems to human society. The history of this concept started in the early 1970s, as the notion of "functions" (De Groot, 1987, 1992; De Groot et al., 2002). It took about 25 yr to consolidate the ecosystem services concept (and elaborate it as an analytical framework). This suggests that the development of boundary concepts that can capture the hybrid, multidimensional nature of NRM systems can be a slow and long-term process, with these concepts having the character of "loose concepts" (Löwy, 1992) while being in the making.

Boundary concepts also play an important role in policy making and in other social processes. The concepts of "sustainable development" and "integrated water resources management" are typical examples, uniting different policy constituencies in a single alliance. According to Robbins (2004) the academic field of political ecology has gelled around the concept of "marginalization," as differentially understood by the disciplines that have informed the formation of this field.

Resilience, while having its origins in the discipline of ecology, is now a concept used across disciplines, with the different dimensions of the resilience of socio-ecological systems under close scrutiny. From a concept it is evolving into a theory (Walker et al., 2006). The resilience concept also works as a "social organizer," as is clear in the existence of the Resilience Alliance (http://www.resalliance.org/1.php [verified 26 Dec. 2009]), and its application in policy ("resilience-based management").

Boundary Objects: Knowledge for Doing

The use of scientific knowledge for decision making creates a big dilemma. Decision makers would never be able to take a decision when they would have to wait until comprehensive analysis of a problem situation would be available based on fully developed theoretical understanding of that particular problem. Such knowledge is probably not possible, but more importantly, the structure and behavior of NRM systems is location specific and historical. Natural resources management systems are variable in both space and time, and their development is inherently

Table 1. Three dimensions of water control.†

Dimension	Association/Meaning	Disciplines	Example references
Technical control	Guiding–manipulating–mastering of physical processes	(Civil) engineering, soil mechanics, hydraulics, hydrology, agronomy, meteorology, agro-ecology	Plusquellec et al. (1994, p. 35)
Organizational control	Commanding–managing of people's behavior	Management science, extension science, public administration, organization sociology	Hunt (1990, p. 144); Huppert (1989, p. 35); Lowdermilk (1990, p. 155)
Socioeconomic and political control	Domination of people('s labor) Regulation of social processes	Political economy, economics, rural sociology, political science, social and cultural anthropology, gender studies, agrarian history, law	Stone (1984, p. 202); Boyce (1987, p. 198–199, 229, 233); Enge and Whiteford (1989, p. 5–7)

†Source: Adapted from Table 2.1 in Mollinga (2003, p. 38).

unpredictable, given their nonlinear and open system characteristics. That NRM systems are open systems means that the human actors who are part of them can (un)learn and decide to change structural properties of the system.

The other side of the dilemma is that, increasingly, demands are made on scientific research to come up with useful and usable knowledge for solving the complex societal problems of our time. Decision makers' time horizons are short. Science has to find shortcuts to contribute useful and usable knowledge to decision-making processes in situations structurally characterized by incomplete, and sometimes unreliable, data, uncertainty, nonlinearity, and unpredictability.

Science has taken up this challenge in a variety of ways. In practice, three different routes or strategies for inter- and transdisciplinary knowledge integration can be identified: the *analytical* route of conceptual and theoretical modeling, the *assessment* route of pragmatic frameworks for mapping and assessment, and the *participatory* route of communication and negotiation for social learning and transformation (for detailed discussion, see Mollinga [2008]).

The Analytical Route: Models as Mediators

The analytical route is the route that attempts holistic or comprehensive modeling of the behavior of complex systems. The basic idea is that when these models represent reality's behavior adequately enough, they then lend themselves for use as decision support systems.

The analytical approach has attracted a huge amount of (disciplinary as well as interdisciplinary) academic research attention. This research tries to find out how to do best the modeling of the behavior of different kinds of natural resources (management) systems. Examples are the application of chaos theory to physical and biological systems, and the development of agent-based modeling of social and hybrid systems. The idea is to get a model "running" that represents reality well enough to ask it "if–then" questions. The understanding of system behavior that the model embodies, is instrumentalized as a decision support system. Scenario development, simulation modeling, and the development of model-based decision tools for specific issues, are typical examples.

The track record of such science-driven decision support tools is, however, rather weak. Very few make it to active use, at least in less developed countries, but probably in industrialized countries also (cf. Stephens and Middleton [2002] on the poor uptake of agricultural decision support systems). Many modeling and decision support system development efforts are science driven, not user driven. Such efforts tend to focus on "good science," credibility, while overlooking the salience and legitimacy aspects. Overlooking the legitimacy aspect amounts to a lack of focus on the process of modeling, and a failure to understand that a lot more goes into models than theory and data. Many scientists prefer to think of models as neutral tools that allow objective identification of scenarios, options, opportunities, and constraints. This is a naive position. Modeling is essentially a mediation process. Models assemble different types of knowledge, including (policy) objectives and other normative claims (Boumans, 1999). When models are developed to be used at the research–policy interface, they operate as strategic resources in politically contested decision-making processes, sometimes with different parties mobilizing different models to support their positions (King and Kraemer, 1993).

With the promise of comprehensive modeling remaining unfulfilled, additional routes have been traveled.

The Assessment Route: Frameworks as Learning and Decision Tools

The most common strategy to achieve integration in the field of NRM is probably the development of "frameworks," notably assessment frameworks. A "framework" is a conceptual construct with limited theoretical (explanatory) ambition as such. It is mainly oriented toward bringing together different pieces of knowledge together in a "workable" manner. Frameworks are "models," but they do not have the objective to adequately represent the behavior of a particular NRM system. Frameworks are simplified, generic conceptual models serving practical purposes. They are made for learning and decision making rather than for explanation.

Figure 1 gives an example of a framework for an integrated analysis of drainage. It portrays drainage as part of both a broader natural resources system and of society.

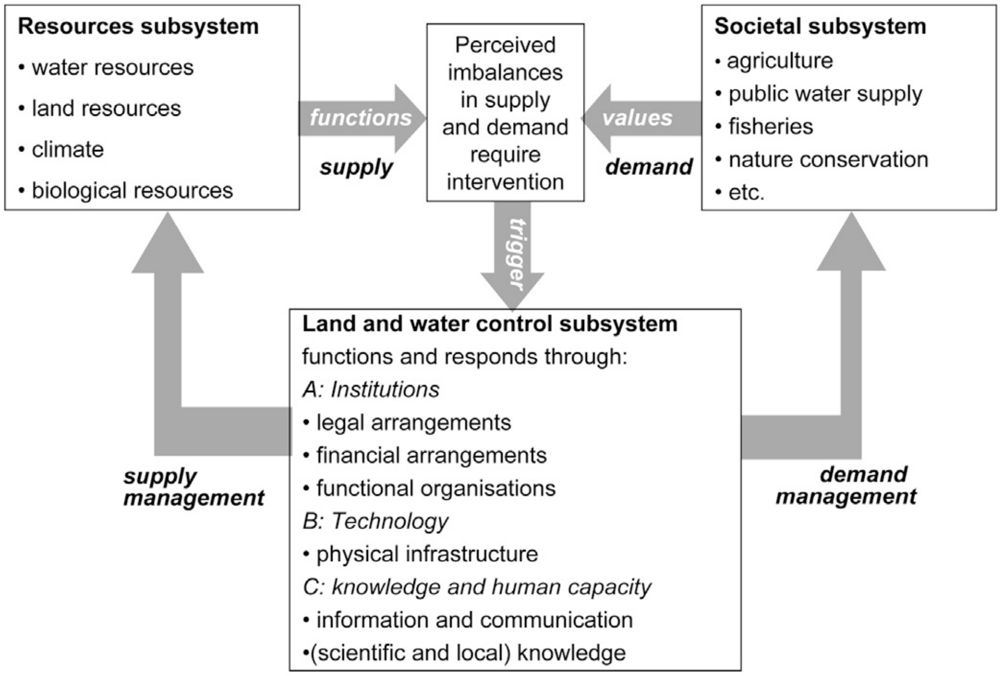

Figure 1. Relations between the resources subsystem, the societal subsystem, and the land and water control subsystem. Source: Abdeldayem et al., 2004 (based on Slootweg et al., 2001).

The framework is a practical tool for designing and implementing "integrated" drainage interventions.

This framework is not meant to be a new scientific theory or model of socio-ecological dynamics. It is meant to be a practical tool for enabling interaction and decision making across different disciplines and concerns. It is full of black boxes: functions (or ecosystem services), values, system, supply, demand, etc. It is exactly the simplicity that makes a framework like this attractive to and usable for decision makers.

"Frameworks" are typical examples of boundary objects, as they build practical connections between the worlds of science and that of policy and between different knowledge domains, thus becoming devices for learning and decision making. For environmental impact assessment, many boundary objects have been developed in the form of protocols/procedures and matrices that allow a plurality of data and concerns to be considered and compared in a single framework. The strong interest of decision makers in "indicators" can also be understood in this context: underlying them are, ideally, frameworks consisting of a limited number of variables while maintaining adequacy for decision making.[4]

The Participatory Route: Processes and People to Negotiate Boundaries

Lacking in most approaches of the analytical and framework routes is explicit and detailed attention to the processes of social learning and political mediation/negotiation as part of knowledge system development for sustainable NRM (Pahl-Wostl, 2002; Dutton and Krämer, 1985). The third route to address uncertainty, unpredictability, and complexity emphasizes exactly this dimension: the social process through and in which knowledge is generated, negotiated, and used as the key factor in designing "adaptive responses."

In the participatory perspective, the process of knowledge generation is *part of* the process of adaptive response through a continuing process of learning, in contrast to the analysis and assessment routes where *externally* developed knowledge developed *before* the decision making is used. In the process of knowledge development, not only different perceptions but also different interests need to be mediated. Negotiating a balance of power in the simultaneous process of resource planning and knowledge development is the core issue.

This perspective strongly resonates with the literature on action research, local knowledge, participatory technology development, and other participatory approaches in (rural) development, and in a broader sense with the literature on innovation and social learning. This has produced a large set of concrete methodologies for participatory work (see e.g., http://www.crdi.ca/en/ev-84706-201-1-DO_TOPIC.html [verified 26 Dec. 2009]).

Boundary Settings: Getting the Institutional Arrangements Right

To flourish, inter- and transdisciplinary research need a conducive environment. This environment can be

[4] The Human Development Index (HDI) is a successful example of this. Indexes and indicators are, however, not always adequate, apart from being inherently biased through simplification and design for specific (groups') purposes. On the Water Poverty Index (WPI), see Molle and Mollinga (2003).

divided in two, interrelated parts, together forming the boundary settings of a research project or program:

1) the *internal* organization and dynamics of the specific research activity;
2) the broader *external* environment of that activity.

The first, "internal" dimension refers to how a research project or program organizes itself—how it creates subunits to implement the research work, nowadays often called *work packages*, which data-sharing procedures it adopts, which intraproject research funds allocation procedures are used, how it organizes communication among partners, how quality control is assured, on what criteria staff working in the project are recruited, what frameworks for internal learning are created, etc. The second, "external" dimension refers to a series of different factors. Given that much NRM research is funded in the context of global, regional, or national policy initiatives for sustainability or policy reform, it is not surprising that the priorities of the funding organizations of such research have a strong impact on the research projects. Some contexts have legal regulations for the conduct of the research, for instance prescriptions for stakeholder involvement and consultation. The institutional arrangements in knowledge organizations such as universities produce certain (dis)incentives for inter- and transdisciplinary research. The question of boundary settings not only appears at the level of specific research projects, but also more generally at the level of the institutional arrangements for research–policy and research–society interaction. This has generated a literature on "boundary organizations" (cf. White et al., 2008).

TRANSDISCIPLINARY LAND AND WATER MANAGEMENT RESEARCH IN UZBEKISTAN[5]

This section reports some of the experience gained in a transdisciplinary research program in the Khorezm province of Uzbekistan, Central Asia.[6] The project seeks to contribute to "economic and ecological restructuring" of irrigated agriculture, infamously focused on cotton (*Gossypium hirsutum* L.), in the direction of enhancing sustainability. Five years into the project, a component was added to strengthen the project's transdisciplinary nature, by working with the knowledge developed together with stakeholders. The research done in the first part of the project had produced specific "plausible promises" for innovation in land and water resources management, of both physical and institutional kinds. An example of the former is conservation agriculture; an example of the latter is ways and means to improve the functioning of Water Users Associations. The approach to innovation was derived from Douthwaite's "follow the technology" perspective (Douthwaite, 2002). The project has labeled its own approach "follow the innovation" (FTI).[7] In terms of "boundary objects" to negotiate the interface between research and practice, the project has thus chosen for a "participatory route": a systematic (step-wise and iterative) method for innovation.

Because the "boundary settings" for innovation were thought to be a major challenge in the Uzbekistan context, these settings are an main target of the FTI component of the project. Interdisciplinary research teams have been created around four "plausible promises" that were identified. The project has created a staff position for guiding and supporting the FTI process. Internally, the support and guidance involves team building and research planning exercises and training on these, for which a specialized consultant/facilitator is employed. Externally, the support and guidance involves developing strategies, methods, and skills to interact with "stakeholders," that is, knowledge users. These are mainly local farmers and Uzbek government officials. The project thus post hoc acquired a transdisciplinary characteristic; it had identified the innovation options without strong involvement of "stakeholders" in problem definition and research design. The salience of the earlier research findings will become apparent during the FTI process.

Some of the experiences gained are the following. The "boundary settings" focus was found to be warranted. Hierarchical contexts are not favorable for interactive learning. The project is dealing with several hierarchies. Externally it confronts a strongly hierarchical and authoritarian government bureaucracy. Internal hierarchies include that between project management and staff, that between supervisors and Ph.D. researchers, and, less easily acknowledged, that between different disciplinary fields. However, these hierarchies cannot be wished away. As a result, the FTI process is much more than a tool to enhance the effectiveness of a specific innovation process. It raises rather fundamental questions about the organization of scientific practice and the attitudes of its practitioners. It tends to question notions of superiority or dominance that may exist, a questioning that may be experienced as threatening. The horizontal work relations that the literature suggests enhance creativity and learning are difficult to achieve. The same is true for building trust with "stakeholders." The legitimacy

[5] This section is based on Hornidge et al. (2009). I thank Anna Hornidge and Mehmood Ul Hassan for their feedback on this section; responsibility for its content remains, of course, the author's.

[6] The full project title is "Economic and Ecological Restructuring of Land and Water Use in the Khorezm Region (Uzbekistan)." The project is implemented by ZEF Center for Development Research, Bonn, Germany, together with Uzbek and other partner organizations. The project duration is 2000 to 2011; main funders are the German Federal Ministry for Education and Research (BMBF) and the German Academic Exchange Service (DAAD). For information on the project, see http://www.zef.de/khorezm.0.html (verified 26 Dec. 2009).

[7] The project has a much broader thematic coverage than the land- and water-related innovations that it has chosen as examples/cases to develop the FTI approach, which is the reference for the discussion here. The research scope includes agroforestry, soil health, value chains in production systems, economics of water, rural gender relations, and several other topics—a wide range of multidisciplinarity.

dimension of transdisciplinary knowledge development thus constitutes a challenge.

A second aspect of the "boundary settings" that was found to be crucial is that the staff and resources needed for the support and guidance of the transdisciplinary process are substantial. They are substantial not primarily in terms of money, but in terms of the quality of expertise required, and the needed duration of that support and guidance. The absence of a similar component in the first half of the project did not help the process in the second half. The experience suggests that explicit boundary work efforts have to start in the project formulation phase, and be seen through systematically throughout the project implementation.

The project puts into interaction three different knowledge systems: that of the Uzbekistan state, including its university and research system, that of local farmers, and that of the project itself (Wall, 2008). Communication problems across these domains are severe. The project has only limitedly tried to mobilize or develop "boundary concepts" to facilitate such communication. These would have to include, given the overall framework of the project, a localized notion of sustainability/sustainable agriculture and the concept of ecosystem services as understood by the different knowledge constituencies. Most research of this kind has focused on the water dimension, by exploring the multidimensionality of "water control" (Veldwisch, 2008) and by analyzing the meanings of "water scarcity" for different categories of water users (L. Oberkircher and B. Ismailova, personal communication, 2009). The major obstacle for a stronger focus on boundary concept development has not been the separation of disciplines as such, but, in line with what Lele and Norgaard (2005) argue, the compatibility problems of the scientific "paradigms" adhered to in the disciplinary fields that make up the project. Differences in understandings of causality and explanation, what constitutes evidence, the value of quantitative and qualitative research methods, and other "paradigmatic" issues have proven to be difficult to discuss and bridge, hence "boundary concept" development has remained limited.

For "integration" the project design has put strong emphasis on developing integrated (e.g., hydro-economic) models for decision support—a "boundary objects"–focused strategy. Mostly following the "analytical route" described above, these models have been largely developed "in house," that is, without close interaction with potential users. How practically adequate the models will prove to be for decision makers practical application will have to show.

CONCLUSIONS

The paper has shown that inter- and transdisciplinary research on NRM require three types of boundary work:

1. Analytical work for understanding: the development of boundary concepts.
2. Instrumental work for action: the design and construction of boundary objects.
3. Organizational work to facilitate the former two: the shaping of boundary settings.

Observation of and participation in interdisciplinary NRM research projects has suggested to this author that the challenge to do all three types of boundary work in the framework of a single project or program, interconnectedly, and not limit research activity to science-driven inquiry, the results of which need "dissemination," is substantial. This has been briefly illustrated with the Uzbekistan case, an experience that may not be atypical. This leads to at least three pertinent questions regarding the improvement of the quality and professionalism of boundary work:

1. What incentives and institutional arrangements are necessary for the enhancement of the often long-term and reflective activity of boundary concept development in a context of policy-driven research emphasizing short-term "deliverables"?
2. How can the "downward accountability" of research projects and programs to knowledge users be enhanced, for better balance with the presently dominant "upward accountability" toward research funders and senior decision makers, and "lateral accountability" to scientific peers?
3. How can research funders and research managers be induced to earmark sufficient funds and human resources for professional boundary management in project and program design?

Actionable answers to these questions can increase the resilience of inter- and transdisciplinary research on natural resources management.

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