RETHINKING HOW WE DO ENVIRONMENTAL SCIENCE

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This paper examines 17 reviews of various philosophical, conceptual and methodological issues and experiences with environmental interdisciplinary work. These were presented and read in the 6th International Conference on Environmental Future, on Interdisciplinary Progress in Environmental Science and Management, held in Newcastle University, UK, July 18-22, 2011. The 17 reviews are examined for indications of the current progress and direction of the development of interdisciplinary approaches to environmental research and governance. The implications of interdisciplinarity to sustainability (or how environmental interdisciplinarity contributes to improving the geospheric, biospheric and ethnospheric well-being in our planet) are drawn from the reviews.

KEYWORDS: environmental science, interdisciplinary, epistemology of interdisciplinarity, methodology of interdisciplinarity, experiences on interdisciplinarity, sustainability

INTRODUCTION

THE SCOPE OF human appreciation of "environmental problems" can range from being very local and immediate—like waking up one day and realizing that there are no more robins singing outside our window (Carson, 1962) to very global and remote—like worrying over melting glaciers in places we have not been to and on how it signals changing conditions on earth (Intergovernmental Panel on Climate Change, 2007).

In turn, public demand for environmental knowledge cuts across a range of disciplinal domains. It can be confined to one discipline such as chemistry (e.g., how heavy metals contaminate table wines; Naughton & Petróczi, 2008) or extend to many disciplines (such as demography, marine biology, forestry, hydrology, political science, agronomy, geography, economics, anthropology and sociology) to understand and do something about marine pollution, fishery collapse, or deforestation (Fisher & Chen, 2011; Ommer, 2011; Lele & Kurien, 2011). It can extend to even wider domains like piecing together scientific and traditional knowledge on how life and geochemical processes occur across different cultural, economic and political systems, to much better understand and respond to present threats to biodiversity and human survival on earth (Millennium Assessment, 2005).

Public demand for comprehensive environmental knowledge has inspired scientists (and practitioners of other knowledge-generating traditions[1]) to reconsider and rethink how we produce and put together environmental knowledge to produce wider aggregates of useful and correct views of contemporary environmental events (Trompf, 2011).

The task is not simple. Questions abound, such as how far can we go into piecing environmental knowledge together without losing the verifiability and truth value of its composites? How can a bit of environmental knowledge be mixed with other bits without eroding their individual and collective credibility? Does scale of knowledge integration matter?

This paper examines 17 reviews on interdisciplinarity that touch on different aspects of the epistemological basis and methodological possibilities of interdisciplinary environmental

[1] This paper recognizes that there are many knowledge-generating practices other than science. Many references have been made on "local" or "traditional" knowledge that do not necessarily practice or include the methods of science. This paper focuses on science.

science. Some of the reviews discuss lessons learned from experiences in doing it. Some talks of how interdisciplinarity links with sustainability (or to how earth systems [our geosphere] are able to continue supporting life systems [biosphere] and human well-being and ways of life [ethnosphere]). The object of the paper is to draw some indications, not to summarize them, of the stage and progress of current rethinking of environmental science as a disciplinary, multidisciplinary and interdisciplinary enterprise. The references in these reviews to the *epistemology*, *methodology*, and *experiences* with interdisciplinary studies and other environmental works are grouped into these three topics.[2]

EPISTEMOLOGICAL BASIS OF INTERDISCIPLINARITY

Western theories of knowledge link modern sciences to Classical Greek roots. The link runs along how knowledge is to be understood (or on what it is) and how it is obtained. Two theories stand out: Platonic Idealism and Aristotelian Empiricism. Initially, they were viewed as being opposed over the nature of knowledge and on how knowledge is obtained. But as Western philosophy moved on forward, the two were eventually combined into a single view of science as a process that obtains knowledge from both "ideas" (Platonic) and "verifiable experiences" (Aristotelian).

Science has since proved a powerful influence on the economy and culture of many nations and societies, particularly in the West, which had used it as an engine for intellectual and material progress. It has been regarded as among the major factors for the West's "rise" to global dominance (McNeil, 1963). Its stress on "objectivity" (which allows for acquiring knowledge independent of what might be preferred by otherwise intimidating institutions such as the State or the Church), and its ability to produce useful technologies, inevitably set science as an epistemological icon in contemporary society, in most parts of the world.

[2] For the purpose of this paper, "epistemology of interdisciplinarity" refers to theories and notions of knowledge (and on how knowledge is gained or lost) used to provide a basis for validating (or invalidating) interdisciplinarity. "Methodology of interdisciplinarity" refers to how interdisciplinarity is (or can be accepted to be) validly done. "Experiences on interdisciplinarity" refers to how interdisciplinarity has been attempted and the lessons learned from the attempt.

The Western Tradition of Classifying Knowledge Into Disciplines

To Trompf (2011), the "burgeoning acquisition of information on the workings, scope and diversities of the cosmos" marks Europe's intellectual legacy that has been mainly rooted on science. And Frodeman (2011) noted that the rapid accumulation of western knowledge is associated with the science and research traditions of European academia.

But "burgeoning" knowledge requires that they be organized into sensible categories. This gave rise to disciplines and the early departmentalization of knowledge production and knowledge delivery in many western schools. Trompf (2011) pointed out that the rapid acquisition and accumulation of knowledge in Europe had "put serious pressure on 19th century European intellectuals to classify branches of human knowledge." That's apparently what happened.

Frodeman (2011) described the "deep roots" of classifying knowledge in European academia "going back to Antiquity." This, he said, "brought coherence to [European] academic programs through the centuries." He cited the Kantian, Humboldtian and Cartesian traditions of European education and how they had led to classifying knowledge along related lines and areas of interests (that is, by "discipline"). For his part, Trompf (2011) saw Europe's practice to organize knowledge along "more 'rational,' 'scientific' and 'secular' principles of order" as being "a mark of European modernity." He saw the value of ordering "subject-areas and disciplines intelligently, or assess them for apparent degrees of certitude."

Disciplinal specialization, however, suffers from a serious deficiency: it has limited immediate reach and relevance when taken in relation to wider and broader interlocking concerns of peoples and societies. Its stress on internal validity and on factual details appears mismatched with how many more people today would rather prefer knowledge that has high external validity and direct relevance to a broad range of their concerns. Frodeman (2011) and Trompf (2011) cited limits of specialization. Frodeman (2011) said that modern information technology, neoliberal education, and the demand for accountability challenge disciplines to widen their analytical range. He agreed but on another tack. He saw

the "tensions between positivistic and holistic styles" in science pointing to a need "to discover some synthesizing principle by which all the distinctive methods of approaching the world might be viewed in interrelationship."

The Need for Integrating Disciplines

There seems to be two compelling reasons for achieving interdisciplinarity in environmental science. The first is the complexity of human-nature dynamics that require many perspectives to better understand them. Pretty (2011), Ostrom and Cox (2011), Tacconi (2011), Fisher and Chen (2011), Ommer (2011) and Christie (2011) discussed large socio-ecological and socio-cultural systems as settings of interlocking resource and social issues. They are large units of analyses that are beyond the usual boundaries of disciplines. Pretty (2011) described how "emergent human cultures have shaped and in turn been shaped by local ecosystems" and elaborated on how the vulnerability of these systems involves disruptions of livelihoods, governance institutions, resources, and cultural traditions. Understanding these requires many disciplines. He cited research mixing physical and social sciences to address conservation and resilience in these systems. This is echoed by Ostrom and Cox (2011) who stressed that effective resource and environmental governance requires "knowledge and perspectives from scientific disciplines that are frequently isolated from each other." Tacconi (2011) and Acevedo (2011) cited the need for "synergies" of disciplines to better understand resource and environmental governance and food security issues. Acevedo (2011) gave examples of interdisciplinary research work in agriculture and environment and how they lead to increasing food productivity. Fisher and Chen (2011), Ommer (2011), and Christie (2011) discussed people-resource issues across continental coasts and oceans and how they are best understood with information derived from an integration of science disciplines and non-science knowledge systems. Hecht (2011) refered to the "multiplicities of political ecologies, policies, politics, science and technologies" that need to be understood in unity in order to better understand forest conversions and dropping deforestation rates in Brazil.

The second reason for interdisciplinarity is that sciences have been expanding in reach and range of knowledge domains.

Spangenberg (2011) cited how sustainability science, as a discipline, involves "integrated assessments and interdisciplinarity" and is composed of many basic disciplines. It "can be subdivided into the more traditional, disciplinary based science for sustainability." It represents, he said, "a new step in the evolution of science." Beder (2011) described how environmental and ecological economics have progressed towards environmental interdisciplinarity and offer perspectives on complex ecological and social problems that improve our "understanding of the real world."

Integrating discipline-generated knowledge and fusing knowledge systems can be pivotal to effectively addressing present-day environmental concerns.[3] This was pointed out by Ostrom and Cox (2011), Ommer (2011), Christie (2011), Pretty (2011), Spangenberg (2011), Fisher and Chen (2011), Tacconi (2011), Beder (2011), and Acevedo (2011). Some of the concerns have global dimensions including biodiversity loss, climate change, food security, and environmental conflict and justice. They need to be told in interdisciplinary stories and perspectives because they are often seen by people and policy makers as single unities rather than as being a composite of different events.

Barriers to Integration

Although many might desire integration, three barriers stand in the way of its adoption. First, academics, in general, prefer to work within clear disciplinal boundaries. This is for perhaps two reasons: accountability and productivity. Trompf (2011) discussed how there had been an intensification of public demand for knowledge workers to be accountable over what they do. If this is to be, it would seem better that workers confine themselves within clearly set boundaries of disciplinal responsibility. Beder (2011) described how environmental economics kept to within its disciplinal boundaries even if it expanded its reach and applications. This suggests, at least perhaps to Beder, that expanding a discipline could be an option, instead of integration.

The second barrier lies in the difficulty of translating integrated

[3] Frodeman refered to "interdisciplinary approaches to education and research" which he defined as "the integration of different disciplinary approaches and discipline-based methodologies." A similar notion of "interdisciplinary research" was used by Acevedo. It is in this sense that disciplinal and knowledge "integration" is understood and used in this paper.

knowledge into effective environmental actions. People tend to view environmental problems in more local scales. They act local. And so, even if integration might improve our understanding of ecological events, Beder (2011) noted that it still has to "overcome political and social barriers to translating that understanding into widespread implementation of effective environmental measures." One social inhibitor of integration can be the "false dualism" mentioned by Pretty (2011). It is the tendency to place superior value to particular sources of knowledge (e.g., science over local knowledge). This thwarts integration. Another is the "disciplinary biases" noted by Fisher and Chen (2011).

The third barrier is the inherent difficulty of integration. What would be its basis and its "synthesizing principle" which Trompf (2011) claimed is essential for integrating "distinctive methods of approaching the world"? Or what would be the "purpose of research" that Spangenberg (2011) said is a feature of interdisciplinarity in the case of sustainability science? How might it be done? What methodological challenges are to be overcome? These questions need to be resolved (with wide acceptance) before interdisciplinary integration in environmental science could gain ground.

Bases for Interdisciplinary Integration

Reyers, Roux, & O'Farrell (2011) discussed how "disciplinary divides" may be bridged. They distinguished "multidisciplinarity" and "interdisciplinarity" based on earlier works by Jantsch (1972), Max-Neef (2005) and Lengwiler (2006). The two concepts stem from a notion of a "continuum of disciplines" that starts with "disciplinarity" (or "about the monodiscipline and represents specialization in isolation"). It extends to "multidisciplinarity" which "represents more than one discipline being studied or applied without actually integrating the disciplines", or "cooperation [among certain disciplines] with low degree of exchange between the disciplines"). The continuum ends with "interdisciplinarity" which involves "cross-disciplinary cooperation feeding back into disciplinary knowledge."

To Reyers et al. (2011), interdisciplinarity is couched in a four-level "knowledge hierarchy." In this hierarchy, "all levels of the hierarchy are coordinated on the basis of an over-all purpose."

- The first level is the "empirical." It encompasses "the basic life, earth, social and human sciences which use logic as their organizing language and usually claim objectivity" (see Jantsch, 1972). Here, "multidisciplinary cooperation between several empirical disciplines" can occur, creating what are referred to as "interdisciplines."

- The second level is the "pragmatic". It "uses the language of cybernetics, the science of regulation and control, as its organizing language" (see Jantsch, 1972). This level encompasses the "applied or sectoral interdisciplines like forestry, engineering and architecture which are informed by the underlying empirical disciplines, while at the same time providing them with direction and coordination" (see Max-Neef, 2005). At this level, "vertical cooperation and coordination required by pragmatic interdisciplines demands close collaboration between empirical- and pragmatic-levels practitioners equivalent to an interdisciplinary research program of universities, research institutions and sectoral agencies jointly generating knowledge and understanding."

- The third level is the "normative." This level "uses planning as its organizing language and deals with the design of social systems including policy, planning and law." At this level, "humans shape their own and the earth's future" (see Jantsch, 1972).

- The fourth level is the "purposive" (or "the level of meaning"). It "introduces values into the interdisciplinary structuring of the normative disciplines below." The "organizing language at this level should be anthropology at its most profound" which, in Jantsch (1972), refers to "the science of creating an anthropomorphic world where humans can survive changing environments."

Reyers et al. (2011), suggested that interdisciplinarity occurs when knowledge freely flows between "interdisciplines" within and across tiers of the knowledge hierarchy. If correct, this offers one epistemological basis for interdisciplinary integration in environmental science.

But there are other possible bases for integration. One is the

inherent nature of environmental problems that often pertain to how humans live and survive in certain settings. This was pointed out in a number of the reviews. But for Pretty (2011), it offers a basis for research approaches that "connect knowledge with action" intended to "produce optimal outcomes for both nature and culture."

Another is the close complementation of certain disciplines that lend to their more easily linking their research. Beder (2011) cited how ecological economics which "incorporate the research of economists, ecologists, philosophers and social scientists" create a basis for interdisciplinarity.

Trompf (2011) has refered to how "planetary survivalism in the present time has pushed environmental science center-stage as a pivotal activity encouraging interdisciplinary collaboration." This suggests that having a common environmental concern can be a basis for integration.

Some other bases for integration may emerge in the future. Frodeman (2011) said that certain pressures on discipline-focused knowledge will eventually lead to "the integration of disciplinary approaches and discipline-based methodologies." Disciplinary responses to the pressures can result to the development of new theories that justify integration.

Acevedo (2011) refered to different levels of production that requires interdisciplinary approaches and which can push for developing new interdisciplinary theories and methodologies.

METHODOLOGICAL POSSIBILITIES FOR INTERDISCIPLINARITY

Several of the reviews discussed methodological issues of interdisciplinarity. They comment on processes and procedures for conducting interdisciplinary research.

Methodological Assumptions on Interdisciplinarity

The interplay of social and ecological dynamics associated with environmental concerns requires methodologies that facilitate understanding them in ways that cut across traditionally-delineated disciplines. This was pointed out or was alluded to in several of the reviews:

- In the case of marine contaminants, Fisher and Chen (2011) said that understanding them "requires the identification of environmental variables that influence ecological and human effects, the ability to predict spatial and temporal occurrences, and development of integrative interdisciplinary and mechanistic models for predicting their occurrences and severity."

- Christie (2011) laid out reasons why "disciplinary theories and methods to support interdisciplinary and integrated ocean and coastal management policies and implementation should conform to a perspective that ocean management is a societal activity with diverse goals ideally informed by interdisciplinary information."

- Ommer (2011) pointed out that understanding fishery collapse in Canada will require delving into "complex interdependent social and environmental issues" that requires "interdisciplinary applied work."

- Lele and Kurien (2011) described tropical forest research as "a quintessential interdisciplinary research problem straddling the social-natural divide."

- Tacconi (2011) discussed how forest change studies need to involve "research integrating economic, political, social, and environmental aspects" because they "cannot be satisfactorily addressed by single disciplines." This is also pointed out by Acevedo (2011) in the case of food security and global change studies.

- Ostrom & Cox (2011) discussed a "panacea problem" which refers to the "tendency to adopt oversimplified institutional prescriptions like government or private ownership to 'solve' environmental and conservation problems." They review works being done "to move beyond this panacea" and using "multiple levels of analysis in a diagnostic framework, applied with a diversity of scientific perspectives and methodologies."

- Agrawal & Benson (2011) said that "different strategies to govern resource commons produce effects that can be assessed

along different dimensions, in terms of the (a) ecological and social sustainability of the resource system, (b) contributions to the livelihoods of those who rely on these resources, or (c) equity in the allocation of benefits." These strategies, they pointed out, require "systematic understanding" to explain how they play out under different governance situations.

There is a wide recognition in the reviews that methodology is a critical element in interdisciplinary environmental work, mainly because of the complexity of nature-culture dynamics involved in creating environmental situations. It is this complexity that makes it reasonable to assume that interdisciplinary methods (and methodologies) facilitate systematically coordinated research processes that accommodate and are hospitable to diverse disciplinal methods.

Doing and Facilitating Interdisciplinarity

As a concern in interdisciplinary work, methodology encompasses the aspects of properly doing it in a way that is valid and correct, and giving robust theoretical legitimacy to its procedures. Several of the reviews point to four factors that are crucial to doing interdisciplinary work: [1] its theoretical bases; [2] its techniques; [3] its organization; and [4] its support systems.

Theory. The theoretical basis of interdisciplinary methods gives them validity and legitimacy, just as in all research work. But interdisciplinary methodology is presently a complex issue among researchers. Lele & Kurien (2011) cited "differences in implicit values, theories and epistemologies across disciplines" that are often a challenge to interdisciplinary forest research. This difficulty is also alluded to by Agrawal and Benson (2011) who lamented the lack of a theory linking equity and benefits in resource commons that otherwise facilitate interdisciplinary assessments of resource governance outcomes.

But while the value of theory is recognized, only three of the reviews actually suggest some possible theoretical underpinnings for interdisciplinary methods. These are Reyers et al. (2011) who suggested that "interdisciplines" and hierarchies of knowledge can be a basis for integrating knowledge; Ostrom and Cox (2011) who described multi-tiered analysis as a valid tool for systematically obtaining knowledge from different sources; and Berkes (2011)

who explained how participatory learning processes can be a method to acquire valid information.

Technique. Doing interdisciplinary work requires creative ways to facilitate collaboration among different researchers and sources of information. Several of the reviews describe (or suggest) certain techniques to do this.

- Ostrom and Cox (2011) proposed adopting a diagnostic method founded on a framework of "socio-ecological systems" (SES). Citing Anderies, Janssen, & Ostrom (2004), they, too, saw SES as 'social systems in which some of the interdependent relationships among humans are mediated through interactions with biophysical and non-human biological units.' SES thus provides an analytical framework to diagnose how "several primary classes of entities" influence each others' behaviors when "embedded in a social, economic, and political setting and in related ecosystems" (McGinnis, 2010). Multi-tiered diagnostics requires a systematic identification of entities that determine and affect environmental outcomes occurring within and across different levels of a socio-ecological system.

- Berkes (2011) described an approach featuring "learning by doing" that stresses "user participation and feedback learning." He points to "deliberation, visioning, building social capital, trust and institutions, capacity building through networks and partnerships, and action-reflection-action loops for social learning" as a valid way to bring about multi-level interdisciplinarity in resource governance.

- Spangenberg's (2011) reference to reflexivity and applicability as features of the "science of sustainability" alluded to a technique along similar principles elaborated by Ostrom and Cox (2011) and Berkes (2011).

- Tacconi (2011) suggested an interdisciplinary technique involving the usual hypothesis testing in science. He refered to how "empirical research needs to include testing hypotheses arising from theoretical developments, assessment of policy uptakes, and new exploratory research." The procedure for doing this is the same as those in most science disciplines but the hypotheses to be tested are formulated from different

aggregations of knowledge using "mixed methods" of research. Such hypotheses may be generated presumably from fusing knowledge in the manner described by Reyers et al. (2011) and Pretty (2011), or from experiences on SES and learning loops described by Ostrom and Cox (2011) and Berkes (2011). Experiences on inter-cultural resource governance like what Filer (2011) described in the case of Papua New Guinea, or on coastal resource management and global networks of marine protected areas like those discussed by Ommer (2011) and Christie (2011), can also form the bases for formulating these "aggregated" hypotheses.

- Acevedo (2011) suggested modeling as a tool and technique to encourage interdisciplinary research.

Organization. Technique is one thing, but organization is another. The way researchers and knowledge workers are made to work together is crucial in interdisciplinary work. Ommer (2011) cited sensitivities, values, ego, willingness to work with others, and interpersonal skills as being keys to the success of a large coastal study involving researchers from many disciplines. How the researchers are organized and who among them is made to work with another, facilitate or impede success. Fisher and Chen (2011) noted that an "appropriate organizational structure" facilitates multivariate analyses of marine contamination.

There are perhaps two aspects about organization that play important roles in interdisciplinary success: purpose and people.

- Beder (2011) emphasized purpose. He suggested that researchers be organized around a common concern. He talked of researchers tackling different aspects of broad theoretical and policy issues in environmental and ecological economics being fruitful only if they work around a common theme.

- Christie (2011) stressed people and who are involved in the work. He refered to "self reflexive and multidisciplinary research teams" and how this is a factor in the success of interdisciplinary coastal conservation work.

Support systems. Fisher and Chen (2011) talked of the role and value in interdisciplinary work of "core facilities that can be

used to support different collaborating teams." They can facilitate or erode collaboration. This implies, too, that funding is critical. An interdisciplinary team is often large and interdisciplinary work is an intricate cogwheel of tasks and schedules. Facilities and funds are heavy constraints on them.

Other reviews have cited the roles of networks, institutions and clarity of goals. They facilitate interdisciplinarity by widening the circle and extent of intellectual, organizational and funding support for it (Acevedo, 2011; Beder, 2011; Berkes, 2011; Christie, 2011; Lele & Kurien, 2011; Ommer, 2011; Ostrom & Cox, 2011; Pretty, 2011; Spangenberg, 2011).

EXPERIENCES WITH INTERDISCIPLINARY WORK AND LESSONS LEARNED

Several reviews describe experiences with environmental interdisciplinary work and the manner they addressed the epistemological and methodological issues of interdisciplinarity. They point to two lessons learned from these experiences: [1] there are key factors to its success; and [2] it is difficult to do.

Experiences

A number of the reviews allude to both epistemological and methodological issues as core concerns in interdisciplinary work. But the experiences they describe are about overcoming the barriers to integration and less on how they built up a theoretical basis for it. The legitimacy of the interdisciplinary work, it seems, is lodged on the assumption that having more people with different expertise and points of view coming together to look at complex environmental issues, is logically valid and appropriate.

Two ways are described on how barriers were overcome. One is by how people work together, and the other is about the tools being used to do the work.

People. Ommer (2011) gave an example of this. She described scientists and knowledge workers with otherwise different disciplinal backgrounds appealing to a shared purpose, a high sense of professionalism, and good interpersonal skills, to successfully undertake a complex research project. Interdisciplinary work was facilitated by good teamwork, not much by adhering to a shared

epistemological point of view or methodological preferences. Other reviews point to a similar approach: different experts looking at marine conservation issues (Christie, 2011); researchers from many disciplines looking at forests and forest changes (Agrawal & Benson, 2011; Hecht, 2011; Lele & Kurien, 2011; Tacconi, 2011); and natural and social scientists collaborating to understand different aspects of global changes and food security (Acevedo, 2011). This is a "quilting" of methods, as it were, and is deemed a correct (and presumably valid) research approach. Scientists and experts with diverse methodological orientations and toolkits are made to come together to bring into a common environmental concern their different perspectives on it. Each expert and researcher uses a method that they find appropriate. There is no stress on researchers needing to first agree on a common theory of knowledge or a common methodological orientation. Beder (2011) described interdisciplinarity in environmental and ecological economics and how they have advanced even if their practitioners diverge on their epistemological roots and methodological orientations.

Tools. Ostrom and Cox (2011) and Berkes (2011) described the use of certain analytical tools and learning processes to facilitate interdisciplinarity. They allow for different disciplinal methods to come together to "fuse" learning. Diversity of disciplinal methods is assumed and is welcomed, but rather than taken as an impediment to interdisciplinarity, the different methods are taken as sources of knowledge that can be processed using a "synthesizing" analytical procedure. The procedure, if done right, could produce more comprehensive information on a research topic. It is not pointed out that researchers and participants in these processes shall need to agree first on an epistemological or methodological theory of interdisciplinarity before these tools and processes can be used.

The experiences on interdisciplinarity described in the reviews so far are more about how it was done in ways that seem logical and reasonable enough. There is no mention of experiences in constructing epistemological and methodological theories to validate interdisciplinarity, or which generated these theories.

Lessons Learned

The reviews identify four factors behind successful interdisciplinary exercises, and four reasons why they are difficult

to do.

Factors of interdisciplinary success. Fisher and Chen (2011) found that successful interdisciplinary work was linked to three factors: scientists were working around common "analytical cores or public 'outreach' cores"; scientists were organized into interdisciplinary groups; and funding was specifically committed to support collaborative endeavors. Other reviewers found "pressures" to disciplines as another factor.

- **Common Core.** Ommer (2011) said that when scientists from different disciplines are made to work together, it would be crucial that they have a "shared vision or concern." A shared vision can be a game changer because it "captures the synergies that are the huge reward in research of this kind and holds researchers together." He added common method, language, training and organization and a factor that, like funding, has something to do with incentives for scientists to work together. This is the matter of "equitable ways to publish results."

  The factor of a "common core" is alluded to in the other reviews. Acevedo (2011) refered to "common goals" of interdisciplinary teams and Spangenberg (2011) pointed out that a common "purpose of research" and "reflexivity and applicability" are features of interdisciplinarity. Ostrom and Cox (2011) cited the importance of a common research aim "that facilitates the accumulation of empirical data on both social and biophysical variables at multiple levels of aggregation." Christie (2011) agreed with this point that shared "worldviews" among those involved in interdisciplinary ocean studies is a key factor to "improve our ability to interpret scientific conclusions." In the case of Papua New Guinea, Filer (2011) saw interdisciplinarity as being facilitated by a common place of concern.

- **Organization.** The factor of organization is pointed out in three reviews as being not only about how scientists work together but also about who are involved in the work. They stress the value of having a wide compass of knowledge workers engaged in interdisciplinary research. Pretty (2011) cited the need to involve different sources and practitioners of traditional knowledge. Berkes' (2011) stress

on "common learning" is shared by Lele & Kurien (2011) who refered to "engagement in a common sphere" and "shared learning and building of common frameworks" involving different stakeholders to a common resource, as essential to interdisciplinary forest research.

- **Funding.** Interestingly, other than Fisher and Chen (2011), none of the other reviews specifically mentions funding as a critical factor to interdisciplinary environmental work. But virtually all the reviews imply that funding is critical. Interdisciplinary work involves many people doing many things and attending to many areas of concern (Beder, 2011; Berkes, 2011; Christie, 2011; Lele & Kurien, 2011; Ommer, 2011; Ostrom & Cox 2011). Funding is therefore a critical concern. What is particularly important is that funding is committed to interdisciplinary work, said Fisher & Chen (2011). This is a point that might be grounded on the fact that most funding agencies desire to have clear returns to their investments and disciplinal outputs tend to be more precisely describable than the more nebulous outcomes of collaborative research. Funding can easily swing toward supporting disciplinal research.

  Funding implies incentives. Consequently, it can be surmised that in the same basket with funding, incentives (salaries, job security, standing among peers, and professional advancement through publications) are among the factors of successful interdisciplinary work.

- **Pressures.** Three reviews cite pressures on disciplines as a key factor in interdisciplinary success. Lele & Kurien (2011) pointed out that "the pressure for more rigour and more integration… from outside of academia" can lead to more interdisciplinary work. "Quality and rigour," they said, "should not be defined purely internally, in terms of logical connections between theory, hypothesis and evidence. They should also be defined externally as rigour in identifying the most pressing problems, as rigour in defining them in socially relevant and normatively transparent ways, and rigour in examining one's own representation of the 'other'." The pressure for this kind of rigor encourages interdisciplinary collaborations.

  Tacconi (2011) implied the same pressures on researchers in forest policies. They face pressures to provide a comprehensive

basis for different policy options, which require that they go beyond the natural sciences and incorporate into their analyses knowledge products and perspectives from political and other social sciences. This is because "the inclusion of governance factors in the analysis and development of policies aimed at reducing deforestation and promoting a transition to reforestation are fundamental to the success of those policies."

Hecht (2011) pointed to "new institutional framings, ideologies, political decentralization, globalization and an expanded arena for new social movements and civil society" as external contexts of forest transitions. To achieve rigor in transitions research, these contexts need to be integrated in the analyses of forest cover change. It is a pressure that cannot be ignored in forest cover change studies in Brazil.

Difficulties of Interdisciplinary Work

But the reviews indicate that interdisciplinary research work is not easy. Four reasons are pointed out: [1] it takes time to get it going; [2] it takes many to do it, and do it together; [3] it requires many tools to do it; and [4] then there is politics.

Takes time. Ostrom & Cox (2011) find that "enabling scholars from multiple disciplines to share a common framework for diagnosing the sources of diverse environmental problems will take time and effort within a dedicated research programme." Berkes (2011) found the same difficulty in adaptive co-management. It takes time to get it to get it going.

Involves many. Interdisciplinary research requires many scientists and knowledge workers coming from different knowledge perspectives to work together well (Ommer, 2011). To do this, they need to have a wide appreciation of their different knowledge tacks, sources, and epistemological orientations (Agrawal & Benson 2011). Pretty (2011) cited the difficulty of linking disciplines and knowledge systems because it requires from their practitioners "a concomitant effort to appreciate, protect, and support cultural diversity."

Involves many tools. Agrawal & Benson (2011) and Acevedo (2011) said that interdisciplinary research requires complex analytical tools. These tools can constrain and inhibit interdisciplinary collaboration. They include both quantitative and qualitative tools which means that interdisciplinary researchers

should be able to use (or be at least familiar and comfortable with) both tools.

Politics. Perhaps a significantly intractable dampener of interdisciplinary undertakings is the effects of politics on collaborative research. Beder (2011) said that "knowledge alone, no matter how refined and comprehensive, is insufficient to overcome the power of vested interests." Powerful groups may choose to adopt a policy over another on the basis of what suits their interests. They would tend to be selective on which research they will support (and which ones they will kill).

A similar point is elaborated by Filer (2011) who noted that interdisciplinary debates have had a long and rich history in Papua New Guinea. Yet they have no direct and significant influence on current environmental policy in the country because "indigenous society-environment relationships" are presently the ones dictating policy, more than science.

Trompf (2011) said that "environmental scientists always need to take stock of the socio-political contexts in which interdisciplinary action takes place." It can do or undo an otherwise useful research work.

IMPLICATIONS TO SUSTAINABILITY

Trompf (2011) said this about specialization and interdisciplinarity:

> The trouble is so much specialization impresses itself on researchers that they will naturally be suspicious of interdisciplinarians, who seem to have bitten off more than their fair share. Even though interdisciplinarity is sorely needed to solve complex problems, and by now a small academic industry is devoted to it (Weingart & Stehr, 2000), a likely future holds that solutions will have to come with collaborations of specialists; and even such collaborators, wherever they are, will have to operate between the competing pressures of academy, politics, industry and independent activists (Cromwell & Levine, 2007).

To Trompf (2011), the obvious links between environmental interdisciplinarity and sustainability center on the complexity

of biospheric and ethnospheric interactions that keep life going on earth. Understanding them requires analytical approaches that cut across disciplinal boundaries, and which overcome the competing pressures that he cited. A number of the reviews refer to the complexity he cited, as this occurs across different ecological settings:

- In the case of agriculture, Acevedo (2011) cited the extensive dynamics between biodiversity, agricultural productivity and ecosystem services. He said that interdisciplinary models can lead to designing effective strategies for sustainable food production. He refered to an "eco-agricultural approach" to shaping strategies that improve productivity that are "wildlife-friendly" and promotes biodiversity conservation alongside raising food outputs. He claimed that "biodiversity at the landscape level is key to sustain both agricultural production and the provision of ecosystem services" (see Brussaard et al., 2010). Because they are closely linked, it is necessary that "agricultural and natural areas are jointly managed to produce ecosystem services" (see also Scherr & McNeely, 2008).

- Forestry features very close links between nature and culture. Lele and Kurien (2011), Tacconi (2011), and Hecht (2011) described the biological and social complexity of forest ecosystems so that multi-, cross-, and interdisciplinary approaches would better facilitate understanding myriad human and natural events that affect their sustainability.

- In the case of oceans and coasts, Fisher and Chen (2011) described the fate and severity of marine contaminants being driven by both natural and social influences. Interdisciplinary approaches facilitate more accurate and comprehensive determination of their movements and shape responses to the threats they pose to the sustainability of ocean ecosystems and services. This is echoed by Ommer (2011) and Christie (2011) who explained that because of the complex human-nature dynamics occurring in marine ecosystems, research on them is best done using interdisciplinary approaches.

The reviews that look at large and complex socio-ecological systems (Agrawal & Benson, 2011; Beder, 2011; Berkes, 2011;

Ostrom & Cox, 2011; Pretty, 2011; Reyers et al., 2011; Spangenberg, 2011) point to sustainability being hinged on fully appreciating intricate nature-culture dynamics. They give these reasons:

- Values, philosophy and ethics shared by a community dictate the manner and extent that they use environmental assets like land (Reyers et al.. 2011); these need to be understood as related influences on sustaining the assets.

- In order "to build a new research programme on the sustainability of complex SES," said Ostrom and Cox (2011), "dialogue between scientists of different disciplines, as well as between scientists and practitioners, under the auspices of an applied science of sustainability" would be necessary.

- Sustainability, Spangenberg (2011) suggested, is couched in intricate human-nature interactions. Interdisciplinary appreciation of these interactions is crucial to laying "a robust basis" for sustainability.

- Cultures are complex systems encompassing beliefs, meanings and world views; livelihoods, practices and resource management systems; knowledge bases and language; and institutions, norms and regulations (Pretty, 2011). These connect communities to their environments. The "cultural continuity" of a community and the sustainability of its resource base are linked to how they are properly understood.

- Society and resource systems are constantly in flux. And the flux can cut across different tiers of ecological and social structures. Thus, to Berkes (2011), decentralization, learning-as-participation, adapting, and capacity-building would be crucial to sustaining resources and resource governance systems. These cannot occur without a multifaceted appreciation of these fluxes.

- For Beder (2011), environmental policy which addresses sustainability issues has broad and intricate economic contexts. Achieving sustainability will require the interweaving of many disciplines from both the natural and social sciences. A failure in interdisciplinarity can lead to shortcomings of

policy that, in turn, erode sustainability.

- Policies generate multiple outcomes (Agrawal & Benson, 2011). Interdisciplinary approaches can lead to better ways of combining them and so, presumably, to also ensuring sustainability.

What the reviews seem to be saying is that complexity begs interdisciplinarity. Trompf (2011) cited the fields of economics and ecology that have had long histories of interdisciplinarity. Their success in producing considerable interdisciplinary knowledge (which to Trompf is the "universitas" of knowledge), has contributed to influencing human behaviors that in turn had affected the sustainability of environmental systems (see also Polunin & Burnett, 1993).

CONCLUSION: EMERGING CHALLENGES AND OPPORTUNITIES FOR INTERDISCIPLINARITY IN ENVIRONMENTAL SCIENCE

There is general recognition that there is value to interdisciplinarity. The reviews show why and how it facilitates comprehensive and intricate (and so, perhaps, more correct) appreciation of complex human-nature interactions. But there remain three serious challenges to interdisciplinarity:

- First is *epistemological*. Its theoretical foundations still need further work. There are conceptual constructs of knowledge that might justify and validate interdisciplinarity (Frodeman, 2011; Ostrom & Cox, 2011; Reyers et al., 2011; Trompf, 2011), but they seem not much in terms of giving interdisciplinarity firmer intellectual and conceptual moorings or bases for developing a distinctive philosophy and epistemology of interdisciplinarity. There also remains the question of these constructs gaining wide acceptance across disciplines and practitioners of different knowledge systems.

- Second is *methodological*. Interdisciplinary methods and methodologies are still scant. The reviews show that interdisciplinarity is being done more by gathering disciplines

together and providing researchers that otherwise have different toolkits and methodological orientations, with a basis for them to collaborate on a common problem. There appears to be not much being done on actually constructing a body of theories and procedures that facilitate the acquisition of interdisciplinary knowledge that has clearly assured internal and external validities, and which allow for replicability. Frodeman (2011) put it this way: "The age of disciplinary knowledge may be ending, but we do not yet know the true shape of interdisciplinarity."

- Third is *institutional*. There is lingering hesitance among discipline-trained researchers to be involved with it. The value of interdisciplinarity might be widely accepted, but it will be difficult and will take much effort and time to convince researchers to subjugate their disciplinal traditions to a new one in which disciplines play less starring roles. And, too, the providers of support facilities and funds might be less attracted to the involved processes and engagement of large numbers of people and the long gestation periods that often characterize interdisciplinary work.

In spite of the challenges, however, there are opportunities for promoting and strengthening environmental interdisciplinarity. The reviews suggest three:

- There is rising awareness of it and willingness to do it among scientists and knowledge workers within and outside science. It is considered relevant and appropriate for understanding and responding to complex environmental dilemmas that presently threaten human survival and sustainability. The reviews indicate a rising recognition by science scholars and practitioners that these dilemmas require interdisciplinarity.

- There is an intensifying public demand for it. People, policy-makers, priests, politicians and power brokers are hungering for knowledge products that can give them a broader sense of environmental threats to life and property, and which can give them a better handle of closely intertwined issues affecting life systems. A number of the reviews cite the close links between interdisciplinary research and public policy. They note how

these are getting more extensive and intense.

- Scholars and science practitioners are recognizing the limits of disciplines. Discipline-oriented research is being recognized as having a limited reach when set against the breadth of contemporary environmental dilemmas. The reviews hint of a rising suspicion (if not already a realization) of a "Kuhnian anomaly" (Kuhn, 1962) in the relevance of traditionally-bounded disciplines to address present-day environmental concerns. It would seem that, in a word, a growing number of adherents of disciplinal sciences might now be reconsidering Robert Frost's line, "Good fences make good neighbors."

In brief, the 17 reviews indicate that [1] interdisciplinarity is something we are better off doing in the face of the multi-dimensional, multi-locational, multi-scalar and multi-level complexity of our current environmental dilemmas and prospects for sustainable well-being; [2] it can be done (and in fact is being done); but, [3] we have yet to build up a wider consensus within and outside the science and knowledge-building communities, including the public, on theories and methods that justify, validate, and give credibility to interdisciplinarity.

We know we need it, and although we are doing it and are quite clear about why we do it, we are still really unsure of what it is and how to do it.

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