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Crossing boundaries: complex systems, transdisciplinarity and applied impact agendas

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This paper highlights the challenges of distilling generalizable principles and guidelines for sustainable co-management arrangements and demonstrating the practical impact of the underlying research. We explore the complexities of multi-country, socio-ecological research and address the challenges of moving beyond pure research to engage with the science-policy-practice interfaces. Growing demand for such applied research by official funding agencies is linked to the requirements of policy relevance and 'research impact'. Successful applied research requires ongoing user engagement throughout a project, which is often hard to achieve, especially when diverse stakeholders have sharply different power, knowledge and interests. The arguments are exemplified by our personal experience on such a complex project. Clear impact agendas could be useful for strengthening efforts to achieve transdisciplinarity but research applications should not be penalised on account of inherent potential uncertainties and risks.

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Introduction

Integrative multidisciplinary research to address complex real-world problems requires large teams, comprising members from disciplines with different traditions. Interdisciplinary science is increasingly important in relation to natural resource governance. Engaging integratively across distinct disciplinary 'languages' — both within and between the natural and social sciences — presents formidable challenges.

Indeed, successful collaborations across the often still rather impervious intellectual, epistemological and methodological boundaries between natural and social scientific disciplines remain relatively limited, especially when they involve partnerships between teams in several countries spanning very different geopolitical and socio-economic-environmental contexts [1,2••,3].

The same applies to substantive engagement with policy makers and other stakeholders or 'research users' to maximise the prospects of research findings and recommendations based on them being implemented. The challenges of participatory processes and meaningful practitioner involvement have recently received increasing criticial attention in the literature [4••,5••,6•,7•,8•,9•]. These papers reflect and further stimulate current debates over how to develop solutions for complex 'real world problems' at the environmental–societal interface. Such debate is timely, given the increasing use by funding agencies and foundations of what is often called the 'impact agenda', an instrumental objective of demonstrating the immediate 'policy relevance' of the funders and the research they finance.

This commentary focuses on three aspects of partnerships that are crucial for achieving impact from multidisciplinary research:

1. The challenge of integrated socio-ecological research
2. The challenging relationships between complex science, the science-policy-practice interface and the complex research requirements for co-management
3. The prediction of research impacts in the light of the increasingly prominent so-called impact agenda.

A final section then reflects on these issues in the light of our own experience on a major international collaborative and comparative project on sustainable utilisation of tropical Asian water bodies. The FISHSTRAT project funded by the European Commission's INCO-DC programme involved natural and social scientists from five European and three tropical Asian countries who undertook a comparative study of fisheries sustainability in five reservoirs and lakes [10]. Our findings are of broader import, contributing to the definition of guidelines for interdisciplinary research between ecology and socio-economics, and for policy arena engagement in the context of aquatic resource governance [10,4••].

The challenge of integrated socio-ecological research

The central challenge in interdisciplinary projects is to develop a coherent research framework and approach that is compatible with the diverse research methodologies of the respective disciplines and adds value through their integration. Although negotiating problem-specific or discipline-specific research protocols is important for ensuring that different (sub-)teams work to a standardised methodology in the different field locations, it is very difficult to step beyond the 'comfort zone' of individual disciplines and national research frameworks and to define and implement a common interdisciplinary approach [10].

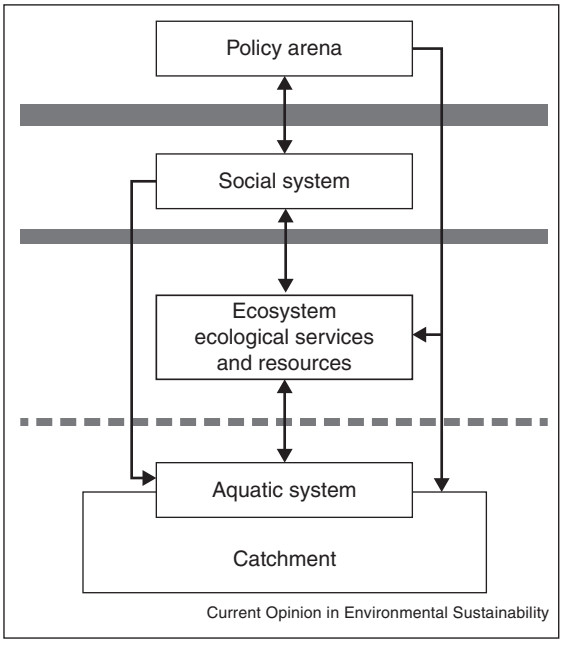
This challenge exists even among narrowly focused natural sciences. Similarly, there are profound differences within social sciences, for instance between quantitative approaches such as econometrics and qualitative methods such as textual analysis or ethnography, which fall within broadly positivist and humanist or cultural traditions respectively. Hence a mutually acceptable concept like a catchment or watershed approach should provide an appropriate and unifying geographical frame [11]. Optimally this should be complemented by a conceptual systemic approach that is capable of integrating different epistemologies to help understand human–environment interactions or socio-ecological systems [12–16].

As implied by the term socio-ecology [17,18], the challenge is to analyse how the ecological and social systems are integrated. The bridges between them comprise socio-cultural values and institutions, and the rules according to which people utilise the resource base and the extent to which conservation and sustainability are embedded as explicit operating objectives [17–21]. The socio-economic challenge is to incorporate evidence for the functional basis for ecological services, and for top-down human impacts (as shown by a semi-permeable filter in Figure 1), and to develop functional response relationships and analyse cause–effect chains within the eco-socio-economic framework. Conversely, we propose that the 'homework' for ecology is to perceive the social forces and traditions governing the resource use and human impacts, and to integrate the social structure and development into their functional response models. In our experience, this has to be achieved by the careful formulation of the bridging research questions and hypotheses in the initial project design phase.

The challenge of the science-policy transfer and the compound research requirements for co-management

Ultimately the challenge is not so much to evolve science-based management but to create a management-oriented integrative scientific approach that provides relevant findings and recommendations in appropriate formats.

Figure 1



Integrated sustainable water resource management framework. The figure represents schematically a multilevel model of an enclosed water body and its aquatic system within its catchment context and the associated socio-ecological system of resources and ecosystem services, as well as the interface between these and the policy arena. One complication is that socio-natural boundaries seldom coincide with politico-administrative boundaries, thus creating a series of transboundary statistical and administrative problems. The arrows represent respective bottom-up and top-down drivers and the shaded bars represent barriers of variable porosity between the levels that reflect degrees of openness or resistance to transdisciplinarity and policy engagement respectively. The key drivers for the catchment/aquatic system intersection are the hydrological and nutrient cycles and the uncertain dynamics introduced by environmental/climate change, as well as the dynamic socio-economic system. These define the trophic state and the aquatic ecosystem energetics. The ecological system services include clean water and fisheries and sometimes irrigation, hydropower production and recreation and environmental conservation. The social system constitutes the riparian population and those elsewhere in the catchment, their economic activities and resource use, as well as resource flows out of and into the catchment.

Due attention therefore needs to be paid to the permeability of the boundary between research and the policy arena, where decisions are rarely based on detailed scientific findings, which are either ignored or cherry picked for politically palatable elements [21–24]. There is no guarantee in this respect but available evidence and our own experience suggests that prospects for uptake of evidence-based recommendations are increased through direct engagement with decision makers as stakeholders alongside the researchers, other interested parties and the intended project beneficiaries throughout the project life and not just in a final dissemination workshop and through the distribution of reports and publications.

Crucial among the challenges is to retain the interest and participation of non-academic stakeholders who commonly hold conflictual positions and exercise differential power in the resource governance arrangements. Retaining their engagement commonly depends on demonstrating how doing so will be in their own interests (in whatever terms) to a greater extent than maintenance of the status quo [1,4••,5••,6•,7•,8•,9•,23–29].

A transition to greater sustainability will require improved awareness of common as well as conflicting interests and seek to institute and enforce a uniform and acceptable regulatory regime, ideally on a co-management basis. By definition, this will need to address the unequal power relations between stakeholders.

The essence of successful co-management is to ensure that all stakeholders in natural resource management and socio-ecological systems work collaboratively to promote the sustainability of the resources concerned. Many challenges arise, not least because legacies of conflict or mistrust often exist, and are linked to power differentials and socio-economic and/or political cleavages. Larger, more complex systems also add to the difficulties, not least because of larger numbers of stakeholder groups, greater biophysical and socio-ecological diversity and more complex 'external' linkages ([30] pp. 495–6).

Decision-making under adaptive co-management should be informed by ecological parameters in deciding on sustainable limits and mixes of activities and in formulating regulations and joint enforcement regimes to implement them. Adaptive co-management also requires the building of bridges and confidence among stakeholders. This necessitates socio-culturally appropriate and generally agreeable rules and procedures for the conduct of negotiations and which compensate for existing power imbalances ([30–32], pp. 494–7). Systematic stakeholder analysis can therefore be an invaluable tool as an integral element of such initiatives, taking account of institutional structures, stakeholder interests and how they advance them; power relations and political influence.

Thus we advocate an integrative paradigm that includes genuine stakeholder participation from the planning stage and applied participatory research involving relevant stakeholders.

The predictability of research impacts

Many research councils and other funding agencies are now explicitly promoting efforts to demonstrate policy relevance and research 'impact' through joint research programmes designed to enhance transdisciplinarity [33]. These efforts seek not only to mobilise adequate resourcing and to encourage research that crosses traditional research council remits but, crucially, also to address applied real-world problems in pursuit of the government's priorities. By its very nature research addressing complex natural or socio-ecological systems, often has uncertain outcomes. When attempting also to engage in policy and practice, the challenge is magnified yet further. Hence achieving in practice the instrumental claims of policy relevance now commonly required by government funders in grant applications is often impracticable [23,24].

Debate is raging within academia and in the press over two related issues in this regard. The first of these is the ability to predict what a research proposal's 'pathway to impact' might be at the time of submission. The second is whether the post-facto impact of research outputs can be measured and quantified in the rather linear manner now required, for instance, for the 2014 Research Excellence Framework (REF) in which British universities are competing for quality-related research funding over the following five years [34]. By contrast, the Dutch model has been developed along more participatory lines and avoids the crystal ball-gazing and wishful thinking of requiring applicants to predict specific impacts of planned research often many years into the future. Instead, it focuses on ensuring realistic dissemination plans so that outputs and results reach appropriate audiences for future uptake [35]. Whilst the European Commission (EC) is also committed to maximising the impact of its funded research, this is currently measured in broad terms as benefits to science and technology, and economy [36] rather than in such narrow, instrumental and sometimes spuriously quantifiable terms. To date there has been no such requirement in the USA although individual universities already seem more receptive to applied research able to demonstrate practical value.

The EC's broad approach is the most likely to enable researchers to demonstrate the applied relevance of their work and to be able to predict progress along the 'pathway to impact' of their research with some degree of confidence. However, outcomes are uncertain and dependent not just on the rigour of the research but — especially in complex systems-oriented research — on dynamic stakeholder interactions and local socio-political processes that often interact with broader regional or national dynamics far beyond the researchers' control and which are extremely difficult to predict.

Under current narrowly prescriptive research funding regimes, such research applications risk being penalised if the uncertainties and risks surrounding the achievement of potential outcomes and impacts are declared honestly. The problem therefore lies principally with the funders' requirements and expectations rather than the nature of the research. Moreover, politically motivated budgetary pressures on research funding for social sciences, as in the USA, may see disproportionate cuts just when their indispensible role in complex sustainability science is being widely recognized [37].

Concluding reflections based on the FISHSTRAT project

The FISHSTRAT project adopted a holistic, systems approach to each water body within its catchment, examining control of its biota to determine its productivity and the level and sustainability of its current human utilisation through capture fisheries and aquaculture, in the context of other uses and pressures on the water body. The focus of the programme was to understand the differential impacts of capture fishing and aquaculture and derive appropriate co-management policy recommendations.

Two examples will suffice. First, the added value of interdisciplinary research is exemplified by our experience in Sri Lankan reservoirs, where only a minority of fish species (mainly exotic tilapia and carp) are currently exploited. These are the larger fish. Yet over half of the total fish biomass and more than 80% of their productivity comprises small-sized minor cyprinid species that are not harvested [10], despite the larger species being harvested at or marginally above maximum sustainable yield [30,38].

The minor cyprinids have traditionally not been utilised because inland fisheries were started by migrant fishermen with cultural and experiential preferences for larger-sized species, including exotic tilapia. Successful exploitation of all available resources thus requires not just understanding of the resource base but also defining appropriate fishing regulations and addressing issues of local cultural acceptability [38]. Collaborative engagement with the fisher communities would be needed to seek acceptable ways of overcoming the inhibitions in capture and use of small fish species. If successful, fishing gear will need to be carefully selected and regulated in order to avoid simultaneous capture of immature specimens of the larger species that are essential to the productivity of the existing fishery.

An alternative possible management response, of encouraging aquaculture, probably principally of tilapia, would need careful introduction and expansion in order to avoid depressing capture fisheries through the toxic effects of excess feed and excreta in these shallow reservoirs. Both scenarios will require participatory co-management between littoral communities, the respective fishermen's associations, and fisheries authorities based on a sound ecological understanding of the resource base [31,30,39].

A contrasting governance challenge is illustrated by Lake Taal, a large and deep natural lake in the Philippines, where the overall MSY of capture fisheries and aquaculture is threatened. Some individual species are being harvested heavily but the principal concern is excess aquaculture cage density and stocking rates in and around the key fish sanctuary. This leads to eutrophication and seasonal 'fish kills'. Existing conservation regulations on cage and stocking densities are widely ignored. One reason is that the ownership of fish cages is highly skewed towards a relatively small number of large and wealthy owners who are well connected and hence influential. In this situation of highly unequal power relations, their ability to promote or defend their interests tends to outweigh that of the more numerous small producers. The outcomes are therefore also predictably asymmetrical: fish kills affect the livelihoods of the small owners and poorer capture fishers disproportionately because wealthier producers have larger and more geographically dispersed stocks and can better withstand losses [40].

The scale of both capture fisheries and aquaculture is far larger than in Sri Lanka and the littoral zone is shared by multiple municipalities, while fishers' associations do not exist for the entire lake and the aquaculturists are well organized. Enforcement of particular regulations also falls to different agencies and government bodies. In other words, there is fragmented control in a highly politicized and densely populated context of highly asymmetrical power relations. Mass fish kills in Lake Taal do focus minds and may provide the sense of urgency required to take action that addresses the root of the problem rather than just immediate symptoms [28].

In summary, the three aspects addressed in this paper are strongly interlinked. Our experience suggests that in order to overcome the epistemological and methodological barriers between the social and natural sciences, the integrated research questions, hypotheses and methodologies have to be jointly defined before the start of the programme, as do engagements with non-academic partners and stakeholders across the science-policy interface [4••]. Ultimately prospects for achieving the objectives of such projects are maximised when integrative governance-oriented science can 'speak to' policymakers and other stakeholders throughout a project's life rather than just during final dissemination activities.

The 'impact agendas' of funding bodies could be helpful in stimulating applied research by careful evaluation that transdisciplinarity is achieved by a robust framework of bridging research questions (resulting in joint publications) and that the interactions of the science-policy interface throughout the programmes are based on solid plans. In these form impact agendas could become an important stimulus. Many of the current approaches, however, are driven substantially by financial imperatives to ration resources in recessionary times. They therefore need urgent revision in order to avoid discouraging or disadvantaging, complex-system science [2••,4••,5••] that integrates scientific rigour with policy/practice that is increasingly necessary in today's world.

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- • of special interest
- •• of outstanding interest

1. Wickson F, Carew AL, Russell AW: **Transdisciplinary research: characteristics, quandaries and quality**. *Futures* 2006, **38**:1046-1059.

2. •• Jahn T, Bergmann M, Keil F: **Transdisciplinarity: between mainstreaming and marginalization**. *Ecol Econ* 2012, **79**:1-10.
This important article traces the long history of transdisciplinary research efforts and argues that the difficulties in achieving it serve to create a situation where the commitment to it has often become rhetorical and superficial in an almost politically correct manner that often marginalizes those who attempt to undertake substantive transdisciplinary research and policy interventions.

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4. •• Brandt P, Ernst A, Gralla F, Luederitz C, Lang DJ, Newig J, Reinert F, Abson DJ, Von Wehrden H: **A review of transdisciplinary research in sustainability science**. *Ecol Econ* 2013, **92**:1-15.
Based on the analysis of numerous studies in the literature, the authors identify a set of key challenges, especially the formulation of a coherent framing and the integration of methods and research in order to attain transdisciplinarity and improve transferability across the science-society interface; the linkage between practitioners and scientists; and the challenge of generating impacts.

5. •• Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P, Swilling M, Thomas CJ: **Transdisciplinary research in sustainability science: practice, principles, and challenges**. *Sustain Sci* 2012, **7(S1)**:25-43.
This paper seeks to enhance understanding of the requirements for challenges of transdisciplinary sustainability science, understood as participatory, community-based engagement with non-academic stakeholders. It begins with an ideal-type model and distils ideas and principles on the basis of experience in diverse settings across several continents.

6. • Reyer C, Bachinger J, Bloch R, Hattermann FF, Ibisch PL, Kreft S, Lasch P, Lucht W, Nowicki C, Spathelf P, Stock M, Welp M: **Climate change adaptation and sustainable regional development: a case study for the Federal State of Brandenburg, Germany**. *Reg Environ Change* 2012, **12**:523-542.
This paper outlines adaptation measures for climate change with respect to sustainable regional development recognizing the requirement for a systemic perspective in order to approach resilient social-ecological systems and ways to organize participatory processes.

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