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Framework for participative reflection on the accomplishment of transdisciplinary research programs

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ABSTRACT

In response to the increasingly complex social–ecological issues facing society, there is a growing trend to conduct environmental research in large collaborative programs. This approach is described as transdisciplinary research as it transcends formal disciplinary boundaries, explicitly acknowledges that many different perspectives are relevant to the resolution of complex problems, and actively involves the users of research. This poses challenges for the evaluation of "impact" as any evaluation process must take into consideration the different expectations, values, culture, language and reward structures of the main participating groups, the funders, researchers and end users. How can these participating groups learn about the progress of a transdisciplinary research program in a way that is purposeful and structured, continues through the life of the program, and includes explicit feedback mechanisms that facilitate adaptation during the course of the program? This paper presents a framework for co-reflecting on the accomplishment of transdisciplinary research programs. The framework incorporates the perspectives of funders, researchers and users, and recognizes that while they place different emphasis on measures of achievement such as efficiency, rigor and relevance, ultimate accomplishment in terms of translating knowledge into practice requires that the needs and expectations of all three groups are adequately addressed. What emerges from the framework is the importance of early investment in processes, behaviors and relationships that foster social learning and the co-production of the knowledge and understanding that are required to ensure relevance; while maintaining emphasis in the traditional areas of formally testing evidence and mentoring young researchers to ensure rigor and build confidence and capacity in transdisciplinary approaches.

1. Introduction

In a world of competing proposals to tackle complex problems with limited research funds, there is growing pressure to demonstrate the contribution of research to society. The public funding of research is increasingly viewed much like any other business investment (Ziman, 1996; Etzkowitz, 2003), requiring tight accountability against a range of performance criteria. Accordingly, the quantitative evaluation of research has emerged as a central practice for determining individual performance of researchers, the quality and effectiveness of research programs and the

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scientific standing of whole organizations (Gibbons and Georghiou, 1987).

While research in many fields lends itself to traditional cost:benefit or return on investment analysis, (Bozeman and Melkers, 1993; Kerssens-van Drongelen and Bilderbeek, 1999; Salter and Martin, 2001; Ruegg and Feller, 2003), this is difficult in the arena of natural resource management due to long time lags between intervention and response, large spatial scales, multiple interacting drivers of change and resources held and managed as common property. The non-linear interdependencies that occur at multiple scales and the unknown thresholds of system change that are typical of most natural resource management issues lead to an inevitable level of ''irreducible uncertainty'' (Walker and Salt, 2006), which makes evaluation particularly challenging.

Natural resources such as water and biodiversity are essentially embedded in social systems, which are typified by a range of stakeholders with very different values, expectations and time horizons (Pahl-Wostl and Hare, 2004). In addressing the management of multi-stakeholder social–ecological systems, we are faced with problems or issues that cannot be confined to a single spatial scale or timeframe. Causes and effects tend to be connected across spatial and temporal scales in often non-linear relationships. Examples include the effects of: land use and nutrient dynamics in a catchment on the tropic status of a water body (Carpenter et al., 1999); population density of elephants on the structure of savanna vegetation (Scholes and Mennell, 2008); and deforestation and irrigation regimes on the salinity and level of a groundwater table (Walker and Salt, 2006). Such non-discreet issues are not amenable to simple solutions brought about by disciplinary research projects. Researchers may have to seek answers and integrate concepts from across natural and social science disciplines. Furthermore, to successfully address diverse stakeholder values, an acceptable solution may not be in the form of ''the right answer'' but rather in the form of a negotiated outcome. Research accomplishment in the broad social–ecological context may be more important than whether or not a particular project or program successfully achieved its objectives.

Accordingly, scientists are expanding their research approaches to social–ecological issues in order to increase their effectiveness in society as a whole (Lubchenco, 1998; Nowotny et al., 2001; Gallopin et al., 2001). To this end, a number of relatively new and somewhat overlapping research paradigms are emerging. These paradigms essentially ask something new of science in terms of its relationship with society. Notable examples are post-normal science, sustainability science, interdisciplinary studies and transdisciplinary studies.

In broad terms, post-normal science seeks to address issues in society associated with substantial uncertainty and high decision stakes, and to do so in close collaboration with non-scientist stakeholders (Funtowicz and Ravetz, 1993; Rogers, 2008; Francis and Goodman, 2010). Sustainability science aims to bridge divides between disciplines and between producers and users of knowledge, with a focus on human–environment relationships and the advancement of sustainable development at multiple scales (Clark and Dickson, 2003; Komiyama and Takeuchi, 2006; Burns and Weaver, 2008). Interdisciplinary studies are concerned with addressing topics or problems that are too broad and complex to be dealt with by a single discipline and in the process draw on, integrate and synthesize insights from different disciplines to produce a more comprehensive understanding or conceptual advancement (Newell, 2001; Klein, 2004; Repko, 2008). Transdisciplinary studies incorporate interdisciplinary integration and add additional research dimensions by (a) addressing problems that are user inspired and context driven; (b) embracing complexity; and (c) acknowledging and incorporating multi-stakeholder perspectives and values (Nicolescu, 2002; Lawrence and Despres, 2004; Max-Neef, 2005; Hirsch Hadorn et al., 2008). The mentioned approaches are meant to be complementary to, and not replace, disciplinary research. Although significant overlap of purpose exists between these emerging research paradigms, for this paper we use the term, and build on the concept of, transdisciplinary research.

A key characteristic of transdisciplinary research is that the domains of science, management, planning, policy and practice are interactively involved in issue framing, knowledge production and knowledge application. To achieve co-evolution of understanding, alignment of purpose and harmonized action across these domains, substantial cooperation and management effort is required at the core of the research project (Hollaender et al., 2008). If we are to seriously embrace transdisciplinary research, and in particular want to foster an effective inter-domain research partnership, how do we effectively embed domain-inclusive learning and adaptation as part of current transdisciplinary practice?

While the ultimate achievement of transdisciplinary research might be changed practice based on well tested evidence whose value to society exceeds the cost of enquiry, this cannot be assessed for several years after a particular research program has come and gone. Conventional project evaluations seem to fall short of what is required for transdisciplinary research, in part because of the latter's multi-domain nature, the imperative of (and uncertainties around) implementing new knowledge and relatively long and uncertain time scales for realizing ''impact''.

In this paper we draw from our experience in diverse projects related to evaluating the impact of research. Whilst acknowledging that conventional impact evaluations have their place, we recognize a need to facilitate inter-domain learning and adaptation towards more effective practice of transdisciplinary research. To this end we propose participative reflection as a complementary activity to evaluation. We present a framework for reflecting on the broader accomplishment of transdisciplinary studies from the perspective of researchers, funders and the users of the research. The framework should be used to facilitate co-reflection during the course of a transdisciplinary research project/program in order to help shape the processes, behaviors and relationships required for achieving the ultimate goal. We discuss how our framework and an associated process of co-reflection could promote social learning and broad accountability across researcher, funder and end user domains.

2. From impact evaluation to co-reflection

The authors of this paper are scientists who have had research contracts with a variety of funding agencies and have a

collective experience spanning the fields of sustainable agriculture, nature conservation and water resource management, as well as contextual settings from two continents. Most of these contracts operated over 2–4 years, involved a few scientists in closely related disciplines and addressed focused problems. More recently we have been involved in a number of inter- and transdisciplinary research initiatives. We have also been asked by funding agencies to ''evaluate the impact'' of collections of projects that make up a specific research portfolio or program. The latter includes the impact evaluations of: a program to underpin the adaptive management of water allocations between conservation and other users (Breen et al., 2000); a program to address multi-objective land use change at catchment scale by bringing together scientists and land managers (Earl and Cresswell, 2005); a program to bring together agriculturalists and ecologists to explore novel approaches to food production (Stirzaker and Lefroy, 2002); and a program for monitoring and assessing the health of river systems as a basis for informed decision-making (Roux et al., 2008).

Program evaluations are usually commissioned to fulfill a policy requirement of the funding agency and to enable the agency to report to its stakeholders on the ''impact'' that was generated by investing in the research. Evaluations typically seek to measure progress against set objectives with growing emphasis on quantitative standardization. In our experience, research evaluations are typically commissioned at the end of a research program. While post-program evaluations provide a sense of closure, they usually do not provide for reflection on the accomplishment of the initiative in the context of society's aspirations. Also, they happen too late for the associated learning to influence the direction of the program being evaluated. While we have found the knowledge that emerges from a research evaluation to be rich and useful, it remains largely locked up in the evaluation team and evaluation report, and therefore mostly in the grey literature. The report is ticked off, the program is closed and both funders and researchers move on to their next projects with no time or funding left to respond to the lessons learned from the successes and failures of the previous project. Researchers and funders typically do not have a ''reflect and revise'' period in which they assess their collective progress towards a defined social purpose or aspirational goal and then modify their research approaches and methods where necessary.

Whereas research evaluations are normally taken to mean ''estimate the nature, quality, ability, extent, or significance of'', reflection is viewed as ''a calm, lengthy, intent consideration''. Evaluation implies an element of judgment against set objectives while reflection is an integral part and distinct enabler of adaptive learning taking account of a broader social–ecological context (Biggs et al., in press). Although it is often assumed that evaluation would lead on to reflection, in our experience this is rarely the case; especially if one considers that, in transdisciplinary research, ongoing reflection and adaptation should ideally cover the aspirations of three groups as follows:

- Research funders responsible for priority setting and the selection of research teams that can deliver against those priorities.
- Research providers responsible for understanding the current state of knowledge in all the relevant disciplines and having the skills to produce and contextualize new knowledge.
- Research users who use the knowledge to make informed decisions, including policy makers, operational resource managers who make decisions about resource use, and others who make use of, and have direct access to, or have power and influence over natural resources.

While successful collaboration in transdisciplinary partnerships can lead to these three groups seeing themselves primarily as co-investors in new knowledge rather than as funder, provider and user, they each place slightly different emphasis on what constitutes success or value. Research funders tend to place greater emphasis on efficiency as measured by the return on investment of public funds. Research providers on the other hand have to place significant emphasis on the rigor of the research as their reputation and professional advancement is determined to a great extent by the quality of research output as assessed by their peers. Research users meanwhile tend to place great emphasis on relevance for obvious reasons. The ultimate measure of achievement in transdisciplinary research is not only that all three conditions are satisfied, but that they also reflect on the accomplishment of their combined efforts against the expectations of society. While this may never be achieved in reality, it remains an aspirational goal and noble vision to strive for.

In view of such an aspirational goal, the indicators in Table 1 represent a 'wish list' of the desirable characteristics of transdisciplinary research. They have been selected because they featured in one or more of the programs evaluated by the authors, and were considered to have contributed to their success. These indicators have been clustered based on which group (funder, researcher, and user) would be primarily accountable for their realization. Some of the indicators in Table 1 contribute directly to the scientific rigor and practical relevance of research outputs while others direct attention to the emergent influences that are more relevant to the expectations society has for research. Collectively, the indicators provide an aspirational target to remind us of the breadth of activities we are involved in and to keep us on track through the difficult periods. Reflecting on these indicators will alerts us to the fact that we will have to juggle multiple and seemingly conflicting responsibilities.

The framework presented in Table 1 could potentially be used for evaluations of research projects. However, we propose the framework primarily as a tool to be used for facilitating co-reflection and associated adaptive learning. There is an important distinction between these applications. An evaluation would sometimes be carried out by ''mid-term'' but more commonly after completion of a research project/program and primarily evaluates the performance of the researchers. Co-reflection acknowledges a combined intent and for our purpose seeks to promote shared understanding, aligned purpose and harmonized action across funder–provider–user domains. We suggest that for this intent to be made explicit it is necessary that a dedicated co-reflection workshop should take place at the commencement of a program and thereafter at least annually to enable 'learning by doing'.

Table 1 – A framework to guide co-reflection on progress in transdisciplinary research programs that incorporates the accountabilities of funders, researchers and end users. The indicators presented are not intended as a comprehensive set but rather as examples to serve as a departure point from where the framework could be modified or expanded based on the context of a specific research initiative.

Functional domain	Accountability indicators
Funders of research	– *Strategic planning and leadership:* A clear case has been articulated for the research program that aligns with national priorities in the context of complex social–ecological systems. Program leadership has been established, aspirational and dynamic program goals developed, and a suite of research projects identified – *Continuity and scientific competency*: Program funding and consistent leadership has been established that is conducive to long-term research including the advancement of facilities, inter-project learning and mentoring of students. – *Discourse:* Events have been programmed and funded to develop and sustain discourse to strengthen relationships between research providers, research users and the wider community to inform and contextualize the research – *Flexibility*: Research projects and teams have freedom to explore modes and structures of practice within appropriate limits of scientific and financial accountability – *Adaptive learning*: Feedback from project and program evaluations is being used to improve processes, relationships and behaviors
Providers of research	– *Professionalism*: Project milestones are being delivered on time and all relevant parties are engaged in a professional manner – *Knowledge sharing*: Researchers are sharing their findings and insights with peers, researchers from other disciplines and parties that represent other knowledge forms – *Relevance*: New knowledge is developed with the explicit recognition of its intended application in the context of complex social–ecological systems, as measured by the degree of interaction with research users and their involvement as co-authors of publications – *Capacity building*: Students and early career researchers are mentored, as measured by the number of research higher-degree students and post doctoral fellows involved – *Research excellence*: Research findings are published in high impact, international, peer-reviewed journals
End users of research	– *Capacity for adoption*: End user partners ensure they have in-house capacity to engage in the research process and to absorb and utilize relevant new knowledge – *Adaptive decision-making and policy revision*: End users have the processes and flexibility to incorporate new research findings into their decision-making, strategic planning and policy where relevant – *Continuity*: End users maintain commitment and engagement to the research program over the whole course of a transdisciplinary research program – *Co-location*: End users are prepared to host post-graduate students and research staff to enable them to conduct their research in real-world contexts – *Organizational research capacity*: Research users support the capacity and availability of their staff to engage with the external research community

In the next two sections, we discuss the proposed co-reflection in the context of achieving social learning and broad (inter-domain) accountability.

3. Social learning

For the program partners to progress along the contextual continuum from research only to research within a social–ecological implementation context means we must progress along the continuum from single-, multi- and interdisciplinary research to working in transdisciplinary teams. Disciplinary research represents specialization in isolation. Multidisciplinarity is about extracting congruent parts from several disciplines useful to addressing a social–ecological issue. Interdisciplinary research goes a step further by integrating the contributions from a number of underlying disciplines to construct a new common model or discipline (Ramadier, 2004). Transdisciplinary research moves outside the conventional realm of science to form bridges between different knowledge spheres, not only between scientific disciplines, but also spanning science, management, planning, policy and societal values (Max-Neef, 2005; Hirsch Hadorn et al., 2008). It is obvious that such a journey will take time to build trust and understanding and will encounter setbacks.

By articulating the features of effective transdisciplinary research, we are in effect warning prospective researcher partners of the extra effort required in team building, communication and mentoring that is required compared to more traditional or disciplinary research approaches. This has parallels with Tuckman's (1965) description of the typical pattern of team formation (forming, storming, norming and performing) with the added complication of bridging disciplinary, language and professional boundaries in the forming and storming stages. Where participants are fore warned of the need to plan for these stages and adequately resource them, we suggest they will be better prepared and more likely to succeed.

Essential ingredients for learning and adaptation within a transdisciplinary research process include face-to-face practice time (Senge, 1990) and leaders with the appropriate experience and skills to act as facilitators (Clark and Stankey, 2006). Transdisciplinary leaders must understand and straddle different contexts and facilitate a healthy tension between knowledge diversity and shared under-

standing. These leaders must be skilled at facilitating multi-party learning while enabling cohesion within a heterogeneous group through identification with a shared goal (Hollaender et al., 2008). Once a proper understanding (not necessarily agreement) of one another's contexts and perspectives, basic trust and a common language exist, parties are ready to (a) transform knowledge produced at a disciplinary level to have meaning at a pragmatic or normative level and (b) co-produce new knowledge that transcends disciplines and contributes to broader societal goals.

In transdisciplinary research, the initial issue identification and structuring phase is very resource and time demanding. Because it engages social–ecological complexity it has to build on several knowledge bases and even different knowledge forms (Hirsch Hadorn et al., 2008) that reflect the individual accountabilities in the research and implementation continuum. This is a time during which reflection on the research process itself is most useful to establishing synergies amongst the diverse participants from science, management, government and user groups.

Strong parallels exist between the ''transdisciplinary learning'' described above and the established concept of social learning. The latter has emerged as a mechanism for facilitating shared understanding and collective action among diverse but interdependent parties (e.g. Blackmore, 2007; Mostert et al., 2008; Van Bommel et al., 2009). It is a process of participative and iterative reflection through the sharing of experiences and ideas with others (Keen et al., 2005), leading to co-creation of new understanding and adaptation (Pahl-Wostl and Hare, 2004). Principles and lessons from the relatively large body of literature on social learning could clearly provide useful guidance to any prospective facilitator of the co-reflection that we propose. To mention one example: because groups from different disciplinary backgrounds or knowledge communities are likely to use different and even divergent interpretive frames when making sense of the same information, explicit attention to multiple ways of framing an issue or concept is an important part of a social learning process (Dewulf et al., 2007) and should be catered for during participative reflection.

4. Broad accountability

If researchers, funders and end users commit to a process of co-reflection and transdisciplinary learning, accountability is broadened beyond the contractual agreement that accompanies most research projects and programs. Co-reflecting on the indicators in Table 1 will serve as a catalyst for funders, providers and users of research to debate and ultimately better understand each other's accountabilities, reward structures and operational procedures – all within the context of their collective progress towards a defined social purpose or aspirational goal. In this section we discuss some of these accountabilities and highlight the broadening of the accountability base with the progression from disciplinary to transdisciplinary research (summarized in Table 2).

Research funders are expected to articulate a clear case to government and industry for specific research programs that align with national priorities and to demonstrate relevance to the broader community and industry. They have to create the space for contextualization, inter-project learning and adaptations based on feedbacks from research projects. Funders furthermore play a critical bridging role between providers and users of research and have to keep abreast with the relevant contexts of these diverse worlds. They ultimately have to balance upwards management of accountability to stakeholder priorities over increasingly shorter time frames, with downwards management of a creative knowledge-production process that thrives on flexibility over longer time frames.

The accountability of the researcher is centered around their expert knowledge, which must be demonstrated through peer-reviewed publications in high impact journals. Accordingly, the use of bibliometrics based on the number of papers published, the impact factor of the journal in which they appeared and the number of times they are cited, dominates the evaluation of researchers. These readily accessible measures are the accepted indicators of research quality, but do have limitations inherent to their calculation (Seglen, 1997; Lawrence, 2003, 2007; Dong et al., 2005). An over-emphasis on quantitative measures of research impact (the so-called audit culture) may stifle quality or novelty, and impair diversity of styles that contribute to overall innovation (Sparkes, 2007). More importantly, bibliometrics are likely to completely miss or even select against the most important attribute of the scientist, which is their creativity (Lawrence, 2006).

Established scientists need to mentor early career scientists and support the culture into which they are growing. The effort and time taken to inspire students may leave a much bigger legacy than research papers they produce themselves. Cultivating transdisciplinary skills involves developing disciplinary depth for complex problem solving and also facilitating exposure to multiple disciplines, the ability to synthesize knowledge from several disciplines and generate an integrative framework, and the art of influence across multiple knowledge spheres (Klein, 2008). A subgroup of scientists, with the required predisposition and skills, needs to participate in public debate as part of priority setting and problem framing; understand the knowledge domains of other players and their value systems; ensure that their research is demand driven and aligned with a social purpose; develop greater context-sensitivity and link abstract and case-specific knowledge; and engage in social learning with people in the ''real world'' while actively seeking to inform decision-making and policy.

The end users of research must also be accountable within a transdisciplinary program. These end users may include national, provincial, state and local level government units and agencies, such as policy units, conservation agencies and catchment management agencies. End users may also include resource user communities such as commercial farmers and local communities that depend on direct access to natural resources. The emphasis given to program evaluation has not encouraged reflection on the roles and accountabilities of research users as part of the research contract. Yet, as key members of a research partnership, developing measurement indicators and benchmarks for end users of research is likely

Table 2 – Cumulative levels of accountability for funders, providers and users of research.

	Nature of accountability		
	Research funders	Research providers	Research users
Disciplinary research – relatively well defined and small contextual problems that can be dealt with by single research projects; provider–supplier contract; produce research report for money	– Identify and articulate strategic research needs – Solicit proposals and award projects – Manage research teams	– Design and execute projects that are aligned with needs – Complete pre-defined research project on brief, on budget and on time – Protect IP for competitive advantage	– Contribute to the development of research priorities – Review research proposals
Multi- and interdisciplinary research – larger contextual scale requiring input from several disciplines; science-funder contract; produce peer-reviewed papers, student degrees, reports, fact sheets and other interpretive material	– Enable capacity building within research – Facilitate conceptual integration across disciplines of science – Facilitate learning interdependence between research projects	– Advance disciplinary knowledge (engage peer-review process) – Mentor next generation of researchers – Integrate knowledge – Share knowledge across disciplines and generations for competitive advantage	– Contribute to identification of priority issues – Contribute to the definition of research questions – Take part in project or program evaluation – Participate in the development and authorship of research outputs – Host research staff and students
Transdisciplinary research – large contextual scale; science–society contract; produce shared rationality about current realities and desired futures	– Identify and enable transdisciplinary leadership – Facilitate conceptual and social integration across levels of the transdisciplinary hierarchy (research, planning, management, policy)	– Engage with research users – Contextualize new knowledge around implementation realities – Participate (including to freely share knowledge) in open learning network for competitive relevance	– Participate in the knowledge creation process – Implement new knowledge within their organizations and generate feedbacks

to consolidate their role of providing context and ensuring relevance which benefits all parties.

In transdisciplinary research, science is expected to speak to society. However, one-way communication will not realize the ideals of transdisciplinarity. Society has to speak back to science and play an equal role in maintaining a two-way conversation that helps to reframe research needs such that they remain relevant. This role highlights a number of responsibilities, such as making time available and acquiring an appropriate level of relevant scientific knowledge, just as researchers have to acquire an understanding of relevant societal contexts to ensure a meaningful conversation. From a meaningful conversation, engagement needs to advance to the co-creation of knowledge. Shared knowledge is an emergent property of these conversations.

An important accountability of end user representatives that participate in a transdisciplinary research process is to take relevant new knowledge and understanding back to their agencies or communities. As opinion leaders, they are in a position to facilitate diffusion and adoption of the new knowledge, mobilize resources for prototype application, and participate in monitoring to provide feedback to the overall research program. Adoption may also include management actions and policy informed by new knowledge.

5. Discussion and conclusion

The organization of scientific research into disciplines has certainly contributed to its systematic knowledge-production ability. Transdisciplinary research is however necessary when addressing ''wicked'' problems where fact and value are mixed, issues are embedded in specific social and ecological contexts, and there are no obviously right answers. Transdisciplinarity essentially makes a shift in emphasis from research as the producer of information, to research as an active contributor to a social process of resolving issues through participation and social learning (Hirsch Hadorn et al., 2006). During such a process, disciplinary knowledge is transformed into social understanding, which in turn could help to bridge the science-implementation gap (Pohl, 2008; Reyers et al., 2010).

Disciplinary research provides essential building blocks for transdisciplinary research and not all researchers necessarily have to step out of their disciplinary research modes. Individuals that commit to a transition in their mode of research practice may have to sacrifice certain outcomes in order to gain others, for example in some instances researchers may have to trade off paper counts for relevance (see Tress et al., 2005). As with most change events, this is likely to be met with at least some resistance. Our own experiences have alerted us to further realities that accompany the transition from disciplinary to transdisciplinary research. Pertinent lessons learned are that:

- Building transdisciplinary teams is difficult. Gaining consensus across funder, researcher and user domains, and turning this into researchable questions, takes a lot of time and emotional energy.
- A transdisciplinary team is essentially a complex adaptive system in itself. Its overall identity and function is determined by the existence and interactions of the constituent members with their respective backgrounds and world views. A certain level of unpredictability and surprise regarding the formation of relationships and the development of shared understanding is inevitable. Emerging patterns have to be managed on an ongoing basis.
- It is important to find facilitators skilled in the social process of running meetings where people have contested ideas of reality and clashes of culture. The field of social learning may have lessons and principles to offer facilitators and practitioners of transdisciplinary studies.
- Transdisciplinary learning is not necessarily ''efficient'', considering a set of stakeholders with diverse expectations which are clouded (if not misguided) by different world views, which in turn are based on different knowledge forms. Some participants may have to slow down their own learning while others catch up.
- When dealing with large-scale social–ecological contexts, multiple interdependencies, where the outputs of one project become the inputs of another, must be managed with care. Development of an integrative framework at the outset may help this process. Autonomy within discrete teams is good so long as frequent exchanges are fostered to give teams a chance to learn from each other.
- Transdisciplinary research requires a long-term commitment. Without a 5- to 10-year time frame the considerable upfront costs are unlikely to pay off.

The conceptualization of research as a service ''purchased'' by funders or users of research has confounded acknowledgement of these parties being severally and jointly accountable for attaining the social intentions for research. Perhaps the most important message of this paper is that, for transdisciplinary research to accomplish its aims, research funders, providers and users must accept joint accountability and form an effective knowledge partnership. To do so these parties have to dedicate time for learning about each other's contexts and accountabilities, including their respective motivations and reward systems (Gibbons et al., 2008). By actively debating differences and commonalities, the base of shared understanding can be expanded, overlaps in purpose negotiated, and capacity for coordinated action increased (Kim, 1993).

The practice of transdisciplinary research is relatively new and represents, in terms of the evolving relationship between science and society at large, the early stages of a social experiment. However, we can only call it an experiment if we actively build in and learn from feedbacks. This has prompted us to design a framework for co-reflection (Table 1) in order to (a) help structure an ongoing process of social learning, (b) provide feedbacks for informed adaptations, and (c) promote broad accountability in our transdisciplinary endeavors. This framework is based on experience stemming from research evaluations. However, it is untested in the co-reflection mode suggested here. We present the framework with the hope that other workers will modify and apply it to various contextual settings to test its usefulness. Ideally, case-specific tailoring of indicators and negotiation of a measurement benchmark for each indicator should be carried out jointly by research funders, providers and users – all as part of a joint learning journey.

The broad accountability framework is in line with our belief that a higher degree of commitment from research partners is needed, to define the social purpose of a specific body of research and bring about institutional arrangements that would foster the required dialogue and adoption of new and relevant knowledge. In the same way that we ask something more from ourselves as researchers, we are asking something more from funding agencies and from end users of knowledge. We propose that a process of social learning, structured around a broad accountability framework, will contribute to the cultivation of a reciprocal relationship between key research partners to embed research into society.

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