Sustainability **2011**, *3*, 1090-1113; doi:10.3390/su3081090

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Review

Defining Terms for Integrated (Multi-Inter-Trans-Disciplinary) Sustainability Research

Paul Stock [1,*] and Rob J.F. Burton [2]

[1] Centre for the Study of Agriculture, Food and Environment and Department of Sociology, University of Otago, PO Box 56, Dunedin 9054, New Zealand

[2] Centre for Rural Research, N-7491 Trondheim, Norway; E-Mail: rob.burton@bygdeforskning.no

* Author to whom correspondence should be addressed; E-Mail: Paul.Stock@otago.ac.nz; Tel.: +64-03-479-9242; Fax: +64-03-479-5266.

Received: 19 May 2011; in revised form: 11 July 2011 / Accepted: 18 July 2011 / Published: 26 July 2011

Abstract: Our contemporary social and ecological problems, including climate change, peak oil and food security, necessitate solutions informed by multiple backgrounds that singular disciplines seem unable to provide, and possibly, are even incapable of providing. The increasing occurrence of multi-, inter- and transdisciplinary (MIT) research projects speak to the recognition of that necessity. But as the literature and our own experiences bear out, just calling a project "beyond disciplinary" or integrated does not necessarily yield the intended outcomes or make progress toward alleviating the hurdles of bridging disciplines. Here we examine the distinctions between three categories (multidisciplinary, interdisciplinary and transdisciplinary) of integrated research and offer reflections on how sustainability researchers can categorize their research to improve common understandings.

Keywords: transdisciplinary; sustainability; multidisciplinary; interdisciplinary; integrated research; research project; methods

1. Introduction

Traditional disciplinary approaches to research have had a considerable and overwhelmingly positive impact on the development of scientific method in the modern world. Disciplines provide scientists with frames of reference, methodological approaches, topics of study, theoretical canons, and

technologies [1]. In addition, they provide shared concepts and language, accreditation to practitioners within their fields (*i.e.*, recognition of competence by others within the shared institution) and, importantly, the epistemological and ontological security that is required to progress science without constantly having to question the nature of science itself. Yet, it is increasingly recognized that, for some of the tasks we expect of scientific enquiry, this is not sufficient. Increasing prominence of issues concerning the linked nature of human and biophysical systems [2,3] coupled with an increasing understanding of system complexity leave traditional scientific disciplines often struggling to understand the problems facing environmental managers. At the same time, politicians are becoming increasingly wary of being "sold simple solutions to complex problems" [4]. As a result, there has been increasing interest over the last decade both within the scientific communities and funding bodies in developing ways of integrating the research outcomes from disciplinary research, thus breaking down the methodological, epistemological and ontological boundaries that prevent shared understandings of complex issues.

In this paper we use the term 'integrated research' as a collective noun to refer to all categories of sustainability research involving integrated multiple disciplines. The term 'crossdisciplinary' is also used in the literature in the same sense [5-7]—however, it has also been used in the past to define a particular type of multidisciplinarity [8]. Further, it suggests boundaries are simply crossed rather than integrated and thus would appear to emphasise weaker forms of integrated research [9]. While other alternatives have been forwarded (in particular, Balsiger [10] suggested the use of the term 'supradisciplinary') 'integrated research' is already in common usage in the literature [11-14] and therefore is likely to be the most widely understood term within research teams.

Nowhere has this push for integrated research mentioned above been more important than in the field of 'sustainability science' (or 'sustainability research' [15]). Jerneck *et al.* [16] note that the very essence of sustainability science lies in its attempts to "... rethink interactions across domains and scales; nature and society, science and democracy, the global and the local, as well as the past, present and possible futures". Luks and Siebenhüner [17] similarly note that sustainability science (which they describe as a "new paradigm of scientific research") has been constituted around the need for resolving real world sustainability issues by combining research on the ecological and social components and involving diverse forms of knowledge. The last decade has seen a proliferation of sustainability studies dealing with issues as varied as climate change, desertification, water resource management, and sustainable agriculture.

'Sustainability' is multiple things at once and navigates interesting territory—it is a goal, an ideal, an umbrella, and a sub-discipline of multiple disciplines. Sustainability is also inherently transdisciplinary. An entire journal focused on sustainability science, (what Lélé and Norgaard [18] would call a scientific community) offers intriguing insights to the practice of sustainability science that is both a problem area and developing sub-discipline to many of the disciplines conducting research on the problem. In essence, a sustainability science elaborates Koc's [19] call to treat sustainability as a discourse. Or as Kajikawa *et al.* [20] argue, "'sustainability' is polyphonic and polysemic, and the content may differ from context to context".

In a follow-up piece, Kajikawa [21] compares studying sustainability through multi-, inter-, and transdisciplinarity, by noting "that sustainability science is not a 'science' by any usual definition—that

is, it is not yet a set of principles by which knowledge of sustainability may be systematically built. Rather, it consists of a plethora of ideas and perspectives, sometimes conflicting, by which one might hope to achieve a viable future for humankind. Although the importance of sustainability is well recognized, the interdisciplinary character of the research hampers us in grasping the entire structure of sustainability science". These definitional issues highlight the inherent epistemological problem of sustainability that hampers transdisciplinary work in sustainability—while studying it, you are also trying to define it.

Despite increasing emphasis on interdisciplinary research, the last ten years have illustrated that integrating research disciplines to deal with complex sustainability related problems is far from unproblematic. For example, Balsiger [10] contends that the whole history of integrated research has been one where typically projects begin with high expectations but end with poor outcomes—or, as Petts *et al.* [1] suggest, "hope tends to triumph over experience". Similarly, Stevens *et al.* [14] argue that, while there has been much recognition of the need for linkages to be developed between the ecological, policy, and social science communities it is easier to 'talk the talk' than 'walk the walk'. Reyers *et al.* [22] note "the multidisciplinary nature of conservation science has long been recognized but seldom achieved". But, successful integration is not merely a 'nice bonus' to the research process; rather the inherent quality of sustainability issues as almost quintessentially interdisciplinary requires or even demands that the outcome of integrated research is positive. Consequently, addressing the issue of how to conduct interdisciplinary research is critical for sustainability research.

Researchers have suggested three fundamental reasons for the failure of integrated research projects. These explanations include the basic lack of interdisciplinary infrastructure (e.g., lack of researchers trained in integrated research [23]; lack of quality journals to publish in [24]; or the lack of a 'college of peers' [25]) to problems with the research approach itself (e.g., the lack of a philosophical stance [26] or epistemological and ontological incompatibilities [1]). While these are important concerns there is perhaps a more fundamental issue that needs to be addressed. Robinson [27] suggests that integrated research has for many years been "bedeviled ... by an ongoing and unresolved discussion about terminology"—an issue that is observed by practically any researcher who cares to investigate researchers' understandings of integrated research terminologies [5,27-30].

"Language and communication have often been cited as barriers to interdisciplinary research" [31,32]. These hindrances provide significant barriers often informed by unannounced assumptions. It is the rare scholar who seeks to read outside the discipline in search of new information and new metaphors that can increase the precision and comparability of their own work. You do not see too many sociologists reading in subatomic physics or vice versa. And that lack of intellectual curiosity hampers personal relationships in projects oriented across disciplines, just as the reverse is true. An assumption of mistrust hampers the sharing of language and knowledge. Others add that friendship (at minimum, a modicum of trust) is a key strategy to overcome language difficulties [33].

These language barriers though also represent the integral jostling inherent in doing research. This boundary work, argues Claire Hinrichs [3,34] can serve to help dissolve boundaries or to ensure they stay erect. A politics of identity emerges from disciplinary differences, but also around the types of researchers involved [35,36]. "Creative interdisciplinarity thereby involves establishing mechanisms and instances through which individual disciplinary knowledges can be appropriately 'translated', in

order to be 'articulated' both within interdisciplinary research teams and beyond, into heterogeneous policy communities" [33]. Others have advocated the use of metaphor to overcome language/jargon differences [37,38].

But these language difficulties and compromises are not mere semantics. They affect project outcomes [22]. Wainwright [39] makes a similar observation related to geography's involvement in climate change research—there is a space where climate scientists advocate social changes without engagement with social science. This mirrors Jansen's [40] description of an implicit sociology—implicit meaning undeclared assumptions about how things are or even should be—related to climate change. This implicit sociology assumes the biophysical world to be facts and immutable to which people simply respond and make decisions accordingly. This provides a major road block/assumption to get over simply to get to a place in the boundary work to find, not just the language of how to talk about it, but what it is that is actually being studied that fails to allow for identification of problems, such that transdisciplinary research is not *project* oriented so much as it is identifying areas that can be studied from different angles, each of which identifies an ideal type or utopia as its own Rosetta Stone to compare reality, or in many cases, a newly derived model. Thus transdisciplinary research quickly and often unacknowledged runs into the is/ought division that often goes unspoken.

A particularly important issue in this regard concerns the variety of types (arguably reflecting different levels of integration) of integrated research that are often confused and incorrectly labeled [5,41,42]. Tress *et al.* [28] suggest this lack of a common understanding is one of the key barriers to integration. There are three possible factors that contribute to this confusion. First, the lack of disciplinary gatekeepers leaves no individual body in charge of defining terms for integrated research—each discipline may adopt its own meaning without fear of question or sanction. Second, the lengthy and complex research procedures are often not reported in interdisciplinary papers (to meet journal publication requirements) and, as a result, the description of the integrated concepts is often so limited that it is difficult to determine what is actually meant by the terms or how they were operationalized [43]. In addition, François [44] suggests "sloppy and inaccurate linguistics and semantics" in journalistic and scientific publications is confusing the notions of inter-, multi-, and transdisciplinarity and notes that this is harmful for an understanding of scientific discourse. Third, the issue may be institutionally driven as neither research councils, academia nor the government appear to clearly understand what is being sought in integrated research and why [1]—leading to an indiscriminant, almost random use of referential terminology.

Regardless of the cause, it is evident that this issue requires further clarification—particularly in the context of sustainability research where effective outcomes are essential. This paper deals with this issue by examining common usage of the three key referential terms 'multidisciplinarity', 'interdisciplinarity,' and 'transdisciplinarity', both within and outside the identifiable 'sustainability' literature. Note that, rather than repeatedly referring to all terms, we refer to 'multi-inter-transdisciplinarity' in the paper as 'MIT disciplinarity', reflecting the fact that the terms represent progressive levels of integration within what may be considered a cohesive 'MIT' framework. We begin by first defining the meanings and objectives of multidisciplinarity, interdisciplinarity, and transdisciplinarity based on their common usage in interdisciplinary studies.

Second, we present a framework outlining the key differences between the three categories. Third, we discuss the importance of clarifying the kind of sustainability research being done.

2. Defining the Key Concepts—Multidisciplinarity, Interdisciplinarity and Transdisciplinarity

In reviewing the literature on integrated research studies one thing becomes immediately apparent: there is an unnecessarily varied nomenclature in use by those reporting the outcomes of integrated studies. Under the umbrella of integrated research an inexhaustive list of terminologies is used to define the concept, including: collaborative, integral, integrated, complementary, combined, participatory, transepistemic, system-oriented, transprofessional, comprehensive, problem oriented, cross-boundary, holistic, multidisciplinary, crossdisciplinary, interdisciplinary, and transdisciplinary [43]. While the basic principle across all these approaches is similar (*i.e.*, focusing on integrated complex problem solving by crossing disciplinary boundaries) there are often subtle, but significant differences between the terms which mean they cannot (or should not) be used interchangeably. In particular the three terms in most common usage—namely multidisciplinary, interdisciplinary, and transdisciplinary—are often considered to constitute a hierarchy in terms of the extent of integration and holism invoked by the term. However, they are also the source of greatest concern.

Without the benefit of disciplinary-style gatekeepers, there are no 'right' or 'wrong' definitions of multi-, inter-, and transdisciplinarity. As a consequence, however, a variety of different meanings have been attributed to the terms, some in concurrence, but others conflicting. Terms are either used interchangeably or the term that implies the greatest integration (transdisciplinarity) is simply taken as a default with little consideration for what it actually means in terms of the level of integration required. Claire Hinrichs' [34] observational, meta-analysis of integrated research in UK agri-food projects employs 'interdisciplinary' because it "seems to prevail in practice" and really the only difference between inter- and trans- is that inclusion of non-academics.

In an attempt to create definitions that can be applied across sustainability research and, consequently, enable researchers to be clear about their level of integration, this section develops definitions of these concepts based on a review of how they are used in the literature. In keeping with its cross-disciplinary nature, the literature reviewed is not solely from the sustainability perspective, but draws from a range of disciplinary perspectives. The process of scanning the literature was conducted using the two largest databases of scientific (social and natural science) literature—namely, Scopus and the Thompson ISI database. The search was conducted using the terms 'integrated research', 'interdisciplinarity,' 'multidisciplinary' and 'transdisciplinarity' that resulted in multiple papers from a wide range of disciplines. Medical journals (where the highest levels of integrated research are conducted) were discarded, with the review instead focusing on literature that examined the environmental, ecological and/or, economic impacts of human land management practices, principally—land use and landscape changes, systems approaches to management, agricultural literature (although this is not common) and ecological/environmental studies.

While the approach followed a similar methodology to that employed by Evely *et al.* [42] there are some key differences. In particular, Evely *et al.* [42] restricted the keyword search for papers to those that mentioned "conservation," thus limiting the outcome to disciplines and studies already engaged with the sustainability debate, rather than disciplines that may in the future contribute to sustainability

debates. In addition, by selecting a body of studies on sustainability, there is a risk that the literature selected has already become introspective in its use of the terms. Given the holistic nature of the debate we considered it important to take a broader perspective. It is important to point out that our efforts here are not intended to be comprehensive. There is such variety within each category of MIT, much less between them that any effort at comprehensiveness in an article like this would fail. Our goals are much more modest. We simply hope to contribute to the growing, but still evolving field(s) of MIT sustainability research.

2.1. Multidisciplinarity

Multidisciplinarity is characterized within the literature as the least integrative from of integrated research—yet, equally, it is arguably the most attainable. Multidisciplinarity features several academic disciplines in a thematically based investigation with multiple goals—essentially, studies "co-exist in a context" [1]. While researchers aim to share knowledge and compare results from the studies there is no attempt to cross boundaries or generate new integrative knowledge [43]. Each member is able to contribute a professional perspective on the issue [45]. Thus the advantage of this approach is that, while the research approaches are disciplinary, the different perspectives on the issue can be gathered into one report for assessment [46]. There is some debate on the extent to which research is coordinated and integrated. While some suggest that multidisciplinary research is coordinated, but not integrated [47]; others contend that there is no coordination, but there is integration at a low level [5]. In general, it is hard to imagine that the research is not, in some way coordinated whilst maintaining even a slight degree of coherence, but it may indeed not be integrated.

Another area of difference in assessments of multidisciplinary research concerns the extent to which the approach is targeted at specific problem solving. While, in general, multidisciplinarity is seen as thematically organized rather than problem oriented [43,48] some contend that the research would normally be focused on a common problem [1,49]. The differences are partly attributable to semantics as it is difficult to imagine a theme that is in some way completely unrelated to a particular problem or series of problems. However, in general it could be surmised that—because of the lack of an iterative research process (*i.e.*, formulating a question in one discipline and passing it to another for problem solving which may then generate new questions for another discipline, *etc.*) multidisciplinary research is not as problem focused as interdisciplinary or transdisciplinary research. The disadvantage of this kind of approach is clear. Whereas with interdisciplinary and transdisciplinary studies researchers are able to resolve discrepancies and explore synergies through an iterative research process between participants, multidisciplinarity simply ensures that the required expert opinions on the issue are provided. In a sense, multidisciplinarity thus provides the assessments required for others to do the problem solving themselves. This limits the extent to which the specific problem can be addressed during the research process and, therefore, the extent to which the process is capable of dealing with the sustainability of real world systems.

Despite this, the term multidisciplinary research is still in common usage. Recent examples of project driven, self-defined multidisciplinary project include a focus on urban greenways [50] and regional sustainability [51]. Uiterkamp and Vlek [52] describe both discipline- and problem-driven multidisciplinary work on sustainability including projects on odor annoyance and climate decision

analysis. They conclude that regardless of the origination of the project (top down *vs.* bottom up), establishing clear mechanisms for coordination remain vital. And Pena *et al.* [50] also target their analysis of urban greenways for policymakers and yet insist on calling their work multidisciplinary despite specific mechanisms for incorporating different kinds of data geared toward specific policy targets—in this instance recommending where greenways could be located to maximize benefits.

Multidisciplinary work is typically project driven or geared toward problem solving, but the kinds of projects that fall into this nominal category often reach for inter- or transdisciplinary heights. Uiterkamp and Vlek [52] go so far as to call successful multidisciplinarity, based on coordination, as interdisciplinarity. With that success-based distinction we move to the literature on interdisciplinarity and sustainability.

2.2. Interdisciplinarity

Interdisciplinarity may be regarded as a step up from multidisciplinarity. Interdisciplinary studies focus on addressing specific 'real world' system problems and, as a result, the research process forces participants (from a variety of unrelated disciplines) to cross boundaries to create new knowledge [29,43]. Essentially the major difference from multidisciplinarity lies in the *level of integration and cooperation* as these projects seek to bridge disciplinary viewpoints [1,45,53] and potentially enable the examination of existing accumulated knowledge from the perspective of a neighboring discipline [54]. Huutoniemi *et al.* [55] provide a relatively comprehensive typology of interdisciplinarity along with specific indicators for research teams to grasp on to. At the same time, Schmidt [56] outlines the importance of a basic literacy in the philosophy of science related to doing such work as well as the kinds of interdisciplinarity. The necessity of bridging disciplinary viewpoints generally (as with transdisciplinarity) stems from the need to address complex "problems that involve an interface of human and natural systems" [48] and, as such, the integration of natural and social scientists is standard practice for interdisciplinary research. This approach involves bringing people and ideas together from different disciplines to jointly frame a problem, agree on a methodological approach, and analyze data [49]. Thus interdisciplinary research requires a much more collaborative approach to problem formulation and methodological development than multidisciplinary research [27].

One interesting feature of the use of the term interdisciplinary is that it is often applied to studies conducted in a multidisciplinary fashion. For example, Guyer *et al.* [57] conducted "interdisciplinary" integrated research where they undertook seven independent studies and then brought the research teams together at the end of the project to discuss the results and draw conclusions. Santelman *et al.* [58] describe their approach as *interdisciplinarity*, however, the authors observe that "this interdisciplinary assessment of the alternative futures integrates the results from disciplinary teams that evaluated the social, economic, and environmental impacts" with the results simply summarized and compared. Hoffman *et al.* [59] conducted what they termed an interdisciplinary analysis by bringing together "unrelated research groups and projects" in a conference setting and then "synthesized" the key elements at the end of the project. Whether it is attributable to a lack of understanding of the requirements of interdisciplinarity or as a result of the interdisciplinary intent weakening during the course of the project is uncertain. However, this portrayal of multidisciplinarity as interdisciplinarity is

relatively common [41] and may simply reflect the difference between the attainable (multidisciplinarity) and the desirable (interdisciplinarity) with the two forms morphing into a hybrid.

Some researchers have attempted to divide interdisciplinary studies into sub-categories based on what are seen as key distinguishing features of the approach. Two examples are particularly relevant. Jakobsen *et al.* [5] observed that, in some disciplinary projects a single discipline may dominate and effectively control the integration of knowledge (e.g., adopting a modelling approach as a unifying framework). The authors term this 'unidirectional interdisciplinarity.' On the other hand, in some cases the interaction and development of the project is guided by the nature of the issue (issue-centric) and this is termed 'goal-oriented' interdisciplinarity. Unidirectional approaches are problematic for both theoretical reasons (e.g., they limit the extent to which the research process can cross disciplinary boundaries by tying it to the methodological, epistemological, and ontological position of a single discipline) and because the greater power provided to one discipline is likely to hinder the creation of trust within the research team (and thus transfer of information, extent of boundary crossing, *etc.*).

There is a more useful division [54]. In this paper the authors differentiate between 'big' and 'small' interdisciplinarity, with big interdisciplinarity typified by links between distant disciplines (e.g., natural and human sciences) and small interdisciplinarity between isolated sub-disciplines (e.g., within natural sciences) where tools and knowledge are exchanged. (Note that this has strong similarities with Max-Neef's [46] "weak" and "strong" transdisciplinarity.) The key to this concept is that it recognizes that not all interdisciplinary research is integrated across disciplines to the same level. In terms of resolving real-world problems, the issue of whether to apply 'big' or 'small' interdisciplinarity should be a function of whether the problem is likely to require big interdisciplinarity or not. There are considerable costs in terms of developing projects that cross the major disciplinary divide between natural sciences and social sciences and thus, if small interdisciplinarity can be applied to solve the problem it is probably preferable from a managerial perspective. On the other hand, most (if not all) interdisciplinary and transdisciplinary research deals with environmental or resource issues where the interaction between the humans and ecosystems is the critical point of the investigation. Small interdisciplinarity is thus likely to be rarely employed.

Clair Hinrich [34] and Jansen [40] focus on the process of working within critical agri-food circles. Other work looks specifically at food quality and biodiversity [33]. Harris *et al.* [60] compare interdisciplinary research projects related to the food system. With an interdisciplinary focus on land use and land cover change in Arctic Russia, Kumpula *et al.* [61] found significant human contribution to the changes—by fruitfully combining GIS, vegetation measurement, and participant observation. Further, they conclude, "The end result is a suite of interpretations, extremely rich in detail and context from both scientists and local stakeholders, which would not have been achievable without each other". Here the emphasis is both on integration and cooperation. Lofti *et al.* [62] focus on the problem of hedgerow disintegration through a combination of GIS data with anthropological observation in an ever-changing agricultural landscape in France. Previously, hedgerows played a significant technical and cultural marker of good farming practice. Their study treats the erosion of hedgerows as a problem to be studied interdisciplinarily.

To examine the related problems of increasing sound pollution and decreasing urban green space, Irvine *et al.* [63] combine environmental psychology, ecology and acoustical analysis to describe both

subjective and objective measures of sound at various places within urban green spaces. Like many MIT projects, when combining multiple disciplinary perspectives, some aspects of one discipline will get appropriated differently than others. To wit, in Irvine *et al.* [63] environmental psychology provides a theoretical framework (nature and green space are good for well-being) and the ecologists and acoustical analysis provide empirical feedback combined with limited psychological measures. To balance the differing scales of measurements, the team limited the number of study areas and scale of those areas that necessarily depressed the number of individuals interviewed. MIT involves a negotiation of our assumptions of how we do research. Some conservationists have recognized the need for good qualitative research to provide appropriate context to human-animal relationships [64]. While not interesting in and of itself, what is emerging from the cross-pollination of natural and social sciences in sustainability is a revalidation of methods. Following successful collaboration in these kinds of projects, those previously skeptical of certain methods of scientific inquiry can not only articulate the benefits of say, qualitative inquiry in an animal conservation context, but also publish to that extent. Transdisciplinarity hopes to move even beyond that by turning collaborative projects into accessible and usable outcomes for policy- and decision-makers.

2.3. Transdisciplinarity

Transdisciplinarity is probably the most desirable and yet difficult to obtain form of integrated research. Some researchers are, in fact, skeptical about whether it can be achieved at all. For example, Pohl [65] observes that the extent of the requirements for transdisciplinary research suggest that it is to some extent "a 'megalomaniac' endeavour." In addition, Tress *et al.* [66] note that, despite the best intentions, "Transdisciplinary landscape research is an exception, even interdisciplinarity is seldom reached." Such studies seek a transcendence of disciplinary perspectives (in some cases "redrawing the disciplinary map" [1]) into a broader framework in "true systemic fashion" that involves practical engagement with "local and regional issues of concern" [45]. In this sense transdisciplinarity is the highest form of integrated project, involving not only multiple disciplines, but also multiple *non-academic participants* (e.g., land managers, user groups, the general public) in a manner that combines interdisciplinarity with participatory approaches [28]. Walter *et al.* [67] suggest that transdisciplinary research is characterized by "a process of collaboration between scientists and non-scientists on a specific real world problem" and combines scientific research with the generation of decision-making capacity for the involved stakeholders or as Schmidt [56] describes it a "problem with the problems". While Mobjörk *et al.* [53] suggest that transdisciplinarity can be divided into "consulting" (stakeholders are consulted but not incorporated in the research process) and "participatory" (stakeholders are incorporated and considered equally valuable) forms, we argue that non-participatory forms of transdisciplinarity are, in fact, interdisciplinary as transdisciplinary approaches are widely defined by their engagement of non-scientists in the research process [43,68]. The variety included in many transdisciplinary frameworks is largely the result of the strong problem solving objectives of the research [48,67] and the need for flexible methodologies in transdisciplinary research is driven by this problem solving approach as "methodologies employed in transdisciplinary research needs to correspond to and reflect the problem and context under investigation". To ensure

that all relevant disciplines are represented within transdisciplinary projects, a pluralistic (rather than unitary) approach to methodology is standard [45].

This focus on the problem, rather than the disciplines excludes the possibility of unidirectional research. As Hadorn *et al.* [15] observe, within a transdisciplinary environment, no single discipline has intellectual precedence. In fact, some researchers go so far as to equate transdisciplinarity with holism, arguing that "It solves disagreements and differences in knowledge and scientific approaches through dialectic thinking, not majority rule, tradition or compromise" [5] or that it is "a different manner of seeing the world, more systematic and more holistic" [46]. As such, Rapport [69] suggests that "the essential element of transdisciplinarity is … 'transcendence'—a creative process whereby a framework for characterizing larger level processes transcends frameworks used to characterize the parts". (For more on creativity and serendipity involved in research that reaches beyond a single discipline [70].) Political ecology is an example of a transdisciplinary sub-discipline that has emerged from the transcendence of a number of disciplines—and has existed under the umbrella of a larger disciplinary body (Geography) since the 1970s [71] though others associate with interdisciplinary work [72].

In promoting a holistic perspective, transdisciplinarity requires considerable effort on the part of engaged researchers to open up their research to alternative ways of thinking, or, as Giri [73] suggests to "overcome one's disciplinary chauvinism" and develop "an openness to perspectives of other disciplines". The adoption of a holistic perspective leads to another key feature of transdisciplinarity—that it has high aims of reconstituting and rearranging the nature of disciplinary knowledge thus creating, through fusion across arbitrary intellectual boundaries, new synthesized disciplines with which to address the real-world problems at hand explicitly through collaboration [2,15,53]. The demands placed on researchers to collaborate and 'overcome chauvinism' means that transdisciplinarity, of all the integrated research forms, has a strong focus on the building of personal relationships and joint understandings [2]. Establishing trust and understanding between researchers within the projects is thus a key objective of building transdisciplinary capacity.

While transdisciplinary studies are invariably implemented with the intention of creating practical outcomes to facilitate change, one issue in the literature is whether the process of extension of the solutions should be incorporated into the research process as part of a process of evaluating possible solutions. In general, disciplines that have solution implementation as part of their standard practices (e.g., management and the various systems approaches that stem from it) incorporate it into transdisciplinarity, and those disciplines where implementing solutions is not a standard part of the disciplinary work do not. In general, as Höchtl *et al.* [74] observe that "The implementation of results is not essential for transdisciplinary projects" as such studies, while always problem oriented, can be either practice or theory based. However, it is not uncommon for studies to contain an implementation component [4,74].

As with interdisciplinarity, researchers have proposed different categories of transdisciplinarity. In particular, Max-Neef [46] identifies two forms of transdisciplinarity "*weak transdisciplinarity*" and "*strong transdisciplinarity*". Weak transdisciplinarity, he contends, is based on following traditional methods and logic. On the other hand, strong transdisciplinarity recognizes simultaneous models of reasoning—rational and relational (non-linear). Lawrence and Després [75] observe that some

transdisciplinary projects follow the model of weak transdisciplinarity in that they adopt positivist approaches as a framework for the investigation. However, the authors argue that we need to revise or dismantle such "epistemological positions that value rational, utilitarian approaches to interpret the layout, use and management of human and natural ecosystems" and adopt strong transdisciplinarity as the standard model of integrated research practice. Unlike Kutílek and Nielsens' [54] notion of "big" and "small" interdisciplinarity, therefore, there is little utility in considering weak and strong forms of transdisciplinarity as its more holistic nature renders 'weak' forms of integration non-transdisciplinary almost by definition.

Finally, it is interesting to note that Aeberhard and Rist [68] observe that transdisciplinarity in terms of the co-production of knowledge of organic agriculture has actually declined since the 1930s when many farmers conducted their own research on the farm and they were supported by extension agents and farmers with stronger connections with the farming community. However, it is unrealistic to expect research to return to the era of the amateur researcher. Both in terms of the technological challenges research presents and the development of theoretical understandings, it is no longer plausible that farmers (or other stakeholders) engage in complex science—for example, managing a large commercial farm and developing a Genetically Modified crop are compatible activities, but the necessary level of expertise requires investment in the development of personal skills and knowledge in entirely different directions. "Transdisciplinarity" is, in fact, thus a development in response to a modern problem—that of the need to address complex problems with equally complex knowledges while, simultaneously, avoiding excluding the contribution of the alternative knowledges of those who are directly embedded in the issue.

As Vandermuelen and van Huylenbroeck [76] argue, "in the case of research on sustainability issues, where problems in economics, ecology and sociology have to be tackled simultaneously, disciplinary research often fails to describe the whole picture". As we have already mentioned, sustainability almost inherently requires transdisciplinary attempts. To that end, specific examples of transdisciplinary sustainability projects have looked at coastal management [77], reef quality [78], and biodiversity conflicts [79]. In other places, transdisciplinarity is invoked as a bridge between research and management strategies. In other places land use change is assessed [80]. Our own work primarily relates to integrated research in sustainable agriculture. Harris [59] conducted a metastudy of transdisciplinary projects focused on sustainable agriculture that identified certain kinds of people involved in the projects while discussing many of the same obstacles [34]. Nuijten [81] examined the specific pragmatics of working out ways to do transdisciplinary research in agriculture. Great work on sustainable agriculture and integrated research comes from New Zealand [82-84]. In other areas, resource management projects involving indigenous communities necessarily involve multiple interpretation, knowledges and methods related to sustainability [85,86]. Perz [87] cautions the simple adoption of theoretical ideas across disciplines (like resilience), though, as they are subject to misinterpretation with potentially negative consequences. This has particular relevance to trying to come to grips with projects under a sustainability umbrella.

Moller *et al.* [83] discusses the pitfalls and successes of the ambitious Agricultural Research Group on Sustainability (ARGOS) project based in New Zealand comparing types of production systems on sheep/beef, dairy and kiwifruit farms. In favor of transdisciplinary research for sustainable management

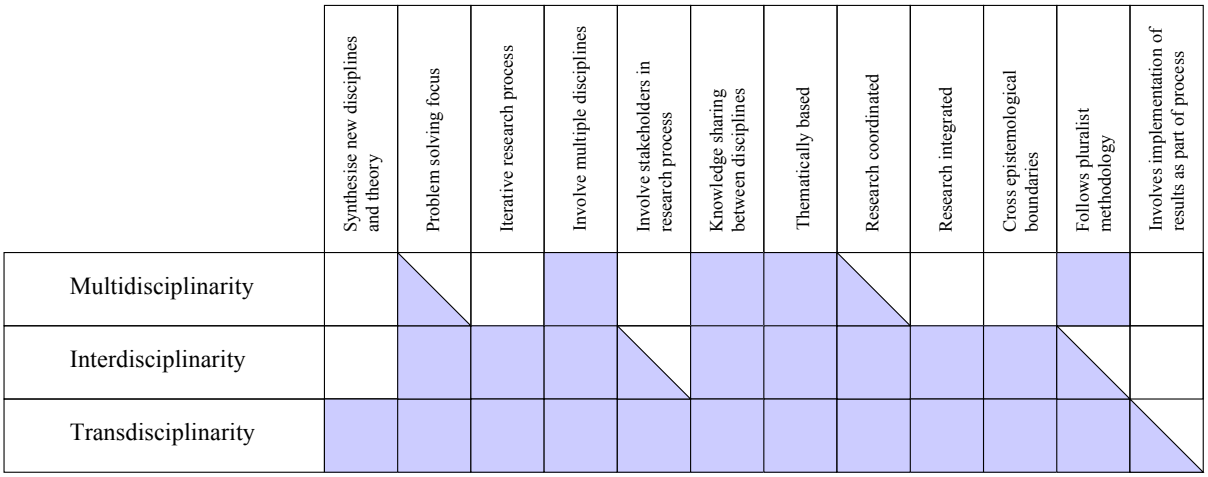
outcomes, they argue "A plurality of approaches is more likely to succeed than just applying one or the other end of the research continuum, especially when achieving genuine transdisciplinarity is problematic, expensive, risky and inevitably competes with disciplinary inquiry for time, funds and available expertise" [83].

Given that sustainability and transdisciplinarity often involve active publics, the incorporation of participatory methods is paramount. How that is accomplished though is varied. For many, it involves the conducting of research that is then translated and given to stakeholders. For others, non-academics are involved from the very beginning and influence project boundaries and methods. Still others adopt hybrid models where previous research projects are then integrated in a participatory manner that tries to delimit academic biases [76]. We cannot offer a preferred method, but simply suggest that sustainability presents a great opportunity to help shape how transdisciplinary research is conducted and will continue to help define what we mean by transdisciplinary research.

3. Indentifying the Differences in Approach

The above sections have outlined and defined the nature of the three main integrated research approaches. Figure 1 summarizes and displays the major differences between the research approaches.

Figure 1. Defining characteristics of integrated research approaches.



Filled boxes represent a consensus that the form of integrated research includes this component, empty boxes suggests a consensus that it does not include this component, and half-full boxes that there is some degree of contention as to whether this component is necessary or not (in general, in this case, either is acceptable).

The defining characteristics are drawn from definitions and categorizations outlined above in the reviewed literature especially those that help create distinctions between two or more of the MIT categories of research. Robinson is particularly notable here [27]. Of note, is that MIT projects can be thematically or problem-oriented. The table also suggests that the approaches share three common trends. They are all invariably thematically based (where the theme could indicate a specific problem), all involve multiple disciplines, and all share knowledge between disciplines on the theme. However, there are features that enable distinctions to be made between the three.

Multidisciplinarity: What divides multidisciplinarity from interdisciplinarity and transdisciplinarity is the lack of iterative research, a failure to cross disciplinary boundaries, the lack of integration in the research process, and a failure to engage non-academic stakeholders as participants in the research. In addition, multidisciplinarity may sometimes focus on the theme under investigation—rather than being problem oriented, and may or may not involve a coordinated program of research.

Interdisciplinarity: Interdisciplinarity is similar to transdisciplinarity. In fact, the only key differences between the two are that transdisciplinary work aims to synthesize new disciplines and theory (whereas this is not an objective for interdisciplinarity) and transdisciplinarity emphasizes holism in its approach (this leads to increased participation from stakeholders and the more likely adoption of pluralist methodologies). The boundaries between interdisciplinary and transdisciplinary projects are thus diffuse and dependent more on a subjective judgment on the level of holism applied than on the presence of clear boundary markers.

Transdisciplinarity: As observed earlier, transdisciplinarity is the holy grail. It maintains a clear emphasis on developing a holistic approach to problem solving involving stakeholders and scientists in a joint project. While this is also often present in interdisciplinary work, with transdisciplinarity it becomes almost a philosophy—extending the research beyond simply problem solving towards synthesizing new bodies of knowledge with which to address complex systems problems.

Despite the above definitions of the three main forms of integrated research, the exact construction of projects is likely to vary with every application. One reason for this is that as there are no formal rules for labeling or constructing projects under any of these frameworks and each is undertaken in response to a particular problem, there is no single prescribed approach to undertaking integrated research [48]. As a consequence, there can be no structured step-by-step or 'best practice' guide to conducting integrated research. (This has not stopped eager research teams from offering their own experiences (or workshops) as examples of 'best practices' though [76,88-90].) In addition, for research employing a transdisciplinary or goal-oriented interdisciplinary approach, the process of designing and conducting the research needs to be an iterative one and, consequently, setting too rigorous a guideline for the integrated project would remove some of the flexibility that is essential for its success. This is a key dilemma within integrated research—*i.e.*, the less rigorous the outline of the research process the more difficult the research will be conduct (and therefore the possibility of a lower quality result emerges) but, if the outline is too flexible, the research process will not be able to deal sufficiently with the complexity of the system and therefore, again, the research quality is likely to decline.

In reality, the boundaries between the three forms of integrated research are, if anything, even more fuzzy than indicated here. With "no clear consensus on what transdisciplinarity is or how it can be evaluated" and, further, no critically robust understanding of what good transdisciplinary research might look like [48] researchers are generally able to define integrated research in their own terms. This creates problems for the development of any cohesive theory of integrated research in the style of disciplinary theories. Many of the features that distinguish transdisciplinarity from interdisciplinarity are highly subjective. For example, the key requirement for transdisciplinary research that it involves transcendence of disciplines [45,69] is made incredibly difficult to evaluate as disciplines themselves are in a state of flux—constantly adopting new ideas from other areas while abandoning others. Another key defining feature—that transdisciplinarity takes a holistic perspective [46] can, essentially,

not be evaluated without knowing the boundaries of holism which are, axiomatically, non-existent. Similarly, with multidisciplinarity and interdisciplinarity the key defining feature—the level of integration and cooperation in the projects [45]—also has no formal boundary with which to evaluate which approach the research is following.

The net result of this lack of consensus is that there is a tendency for published research papers in sustainability to overemphasize the level of integration. For example, in their study of sustainability researchers' assessments of level of integration, Evely *et al.* [42] note that when classifying papers according to Tress's *et al.* [43] classification of MIT disciplinarity, "Authors tended to reclassify papers that were multidisciplinary as non cross-disciplinary, or they retained their definition as multidisciplinary. Most interdisciplinary papers were reclassified as multidisciplinary and transdisciplinary papers were reclassified as interdisciplinary". The authors note this creates problems for integrated research as the inflationary use of the terminology makes it difficult for scientists and research funders to evaluate research papers and build on the developed knowledge [51].

Like sustainability as a topic, the problem of defining the type of integrated research Max-Neef [46] has suggested that transdisciplinary research actually involves two simultaneous research projects—first as a project to resolve the problem at hand and second as a project to develop transdisciplinarity itself. This could equally apply to interdisciplinary research as only multidisciplinary research is able to develop a rigid methodological framework for the research prior to its commencement.

While the integrated research projects are frequently associated with the crossing of boundaries between disciplines with conflicting research paradigms (namely the social and physical sciences) it should be remembered that integrated research can also occur within these paradigms. For example, researchers within the fields of oceanography [91] and hydropedology [54] have conducted interdisciplinary projects within their individual research paradigms. The feature defining the integration of natural and social sciences should again be problem based. If an issue is purely related to the human systems then there is no need to look outside that system for solutions—the answers may be obtainable by conducting integrated research within the paradigm. Similarly with natural sciences, there is no stipulation that integrated research requires the involvement of social sciences if the system under investigation does not involve human elements. With sustainability issues, however, integration between the natural and social sciences is paramount.

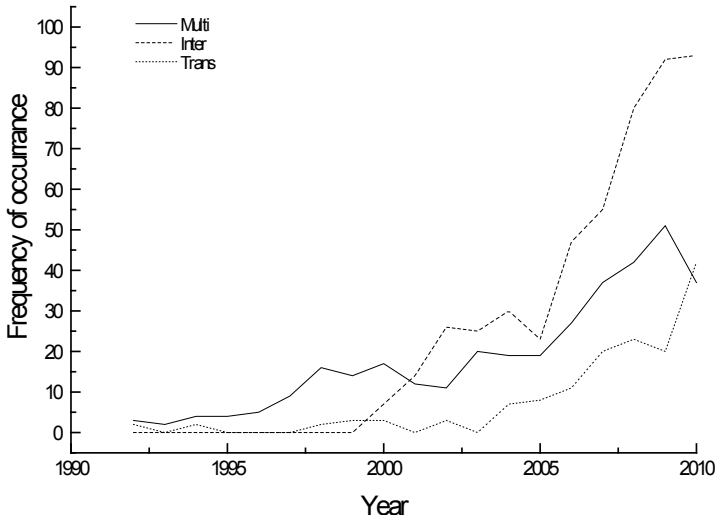
4. The Importance of Clear Definitions of MIT in Sustainability Studies

In conducting this review it became apparent that there is a plethora of research intent on defining terms used within integrated research. Similar efforts, like this one, to clarify the categorizations provide not only starting points for doing related research, but also provide frameworks for empirically investigating MIT research [51,55]. Almost every study into sustainability that employs an integrated approach begins with a discussion on the nature of integrated research yet, as the research also suggests, aspirations are almost invariably inflated. When it is easier to obtain funding by calling yourself 'inter' rather than 'multi' and 'trans' there is clearly an inflationary pressure placed on the terminology. Thus, the term 'interdisciplinary' dominates the literature. Just calling yourself something to gain an inside track on funding does nothing to clarify issues related to gatekeepers and specification

mentioned previously as difficulties in moving toward a beyond disciplines or Mode 2 knowledge production.

As a crude measure, Figure 2 provides an indication of the frequency with which the terms have been used in the sustainability literature over the last decades. The graph suggests that 'interdisciplinarity' is still the most frequently employed term however, the term 'multidisciplinary', while still in wide use, appears to be falling out of fashion while 'transdisciplinarity' is becoming increasingly important, in particular over the last half of the 2000s. As the use of the term 'transdisciplinary' grows, research teams are going to increasingly have to distinguish it from the other forms of integrated research, yet, as we have observed above, the extent of the cross-over between the different forms of integrated research make this task difficult.

Figure 2. Frequency of occurrence of the terms 'multidisciplinar*,' 'interdisciplinar*,' 'transdisciplinar*' along with 'sustainability' in the *Web of Knowledge* database searching under TOPIC.



In the meantime, other questions regarding the framework are emerging. Although studies are generally defined as falling into one category or the other, researchers are beginning to note that it may not be that simple to categorize the integration level developed within the research. Blevis and Stolterman [41] note, for example, that scholars and practitioners can be disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary simultaneously—for example, by working within a transdisciplinary project, but taking interdisciplinary approaches to dealing with specific tasks, and disciplinary approaches when dealing with others. Perhaps this perspective better reflects the reality of integrated sustainability research than the idea that researcher can maintain constant transcendence over the research process—as the regularity of transdisciplinary failure would seem to suggest.

Jerneck *et al.* [16] suggest that integrated sustainability research can be designed as a developmental process, with the research team gradually moving up the MIT hierarchy as the project progresses. Using the Lund University Centre for Integration of Social and Natural Dimensions of Sustainability (LUCID) as an example, the authors outline a staged 10 year process beginning with a first phase of multidisciplinarity (year 1–2), a second interdisciplinary phase (year 3–5), and a third transdisciplinary phase (year 6–10). This would certainly address a number of problems associated with the time-scales

needed to develop trust within the team, develop common terminologies, engage with local communities, and so on, enabling a gradual approach to develop rather than diving into integrated research in its most complex form. However, judging the success of the approach would depend on setting clear definitions of the transition between these stages and, given the extent of cross-over between MIT forms noted above, this is likely to be a difficult task. Further, within the transdisciplinary stage problems are likely to emerge that require lower levels of integration to address specific questions as they emerge [41] which again suggests that the phases of development are unlikely to be as clearly distinguishable as the authors imply.

And certainly we know that not all researchers are as concerned with what are often perceived as minor semantic differentiations between kinds of research. For example, Hopton *et al.* [51] outline their pursuance of less complex regional sustainability metrics for non-scientific and policymaking audiences. While by our definition, this is a transdisciplinary-motivated project, they call themselves multidisciplinary without reflexivity. A counter example can be found in Vandermeulen and van Huylenbroeck [76]. Their conceptualization of the project was integral to its success. By incorporating different projects (interdisciplinary) with a participatory process to integrate the knowledge and reduce bias, they achieved transdisciplinarity. Their definitions actively worked toward a successful project. The real success came not from making the project more complex, but from using clear definitions that distinguish between kinds of projects, simplify the process and therefore make success more readily attainable. By using clear definitions of what they were doing, it made the accomplishment of their goals attainable. We hope that the above clarification can promote similar successes or at least serve as a starting point for new projects.

5. Conclusions

This paper has presented a framework for understanding multi-, inter-, and transdisciplinarity (MIT) in sustainability studies. One of the objectives of writing this piece was to help diffuse inflationary pressures on the terms, to avoid reaching the point where all studies are, as a matter of course, termed 'transdisciplinary' and yet the existing meaning of transdisciplinarity is devalued to the equivalent of inter- or even multidisciplinarity. If this point is reached, there is a danger that funding bodies will become disillusioned with integrated research that promises much in the form of transdisciplinary research, but consistently fails to deliver integrated analysis at this level. This is not a scenario for the distant future. Current criticisms of the over-egging of integrated research levels [1,10,14,22,42,55] suggest that, in many cases, we are already there in terms of the discrepancy between promises and delivery.

Sustainability researchers can play a role in avoiding this scenario. We do not suggest a need for categorical definitions of the components of the MIT framework as, to some extent, this would defeat the collaborative purpose of integrated research, *i.e.*, it could be seen as a framework to be 'imposed' by sustainability researchers on other disciplines—a step towards the problematic unidirectional integration. Nor do we advocate the development of a "common terminology" [11] in general, as researchers need to maintain the utility of their disciplinary perspectives [45]. Instead, we see this paper as a useful source of discussion for those beginning integrated research projects into sustainability

issues—to enable research teams to examine the key issues and collectively determine the level of integration their project requires and represents and to be able to justify their position to funding bodies.

We contend from our analysis that it is important to maintain hierarchical terminology that is capable of expressing the changing extent of integration between scientists, and between scientists and stakeholders. Because the type of integration may vary over the course of the project [16] and different levels of integration may be required to complete different tasks [41], it is important that we can differentiate between the three—and the MIT framework seems to have become the default means of doing so. Disciplinary work conducted within projects should also be acknowledged and differentiated from integrated research as it is disciplinary expertise that provides the structure and legitimacy to the integrated research process [27,55,66,73]. Thus, the temptation to downplay the disciplinary component of the research should be avoided.

As the world's natural resources dwindle and the climate changes, the need for sustainability research will increase—as will the need for both integrated research and clear frameworks for conducting such research. Research on sustainability is vital to our collective interests and will require more and more collaboration across various boundaries. The more clearly we can articulate the bridges between those boundaries, the easier those novel collaborations will be. Our modest hope is that the above discussion can help facilitate that.

Acknowledgements

We acknowledge the New Zealand Foundation for Research Science and Technology for funding the write-up of this paper as part of the Rural Futures project. Thanks specifically to Sue Peoples as part of the Rural Futures project. We would also like to acknowledge insightful comments from the three reviewers and the editors.

References and Notes

1. Petts, J.; Owens, S.; Bulkeley, H. Crossing boundaries: Interdisciplinarity in the context of urban environments. *Geoforum* **2008**, *39*, 593-601.
2. Naveh, Z. Epilogue: Toward a transdisciplinary science of ecological and cultural landscape restoration. *Restor. Ecol.* **2005**, *13*, 228-234.
3. MacMynowski, D.P. Pausing at the brink of interdisciplinarity: Power and knowledge at the meeting of social and biophysical science. *Ecol. Soc.* **2007**, *12*, 20.
4. Jackson, M.C. Creative holism: A critical systems approach to complex problem situations. *Syst. Res. Behav. Sci.* **2006**, *23*, 647-657.
5. Jakobsen, C.H.; Hel, T.; McLaughlin, W.J. Barriers and facilitators to integration among scientists in transdisciplinary landscape analyses: A cross-country comparison. *For. Policy Econ.* **2004**, *6*, 15-31.
6. Cummings, J.N.; Kiesler, S. Collaborative research across disciplinary and organizational boundaries. *Soc. Stud. Sci.* **2005**, *35*, 703-722.
7. Russell, A.W.; Wickson, F.; Carew, A.L. Transdisciplinarity: Context, contradictions and capacity. *Futures* **2007**, *40*, 460-472.

8. Tress, G.; Tress, B.; Fry, G. Clarifying integrative research concepts in landscape ecology. *Landsc. Ecol.* **2004**, *20*, 479-493.
9. Burton, R.; Rønningen, K.; Wedderburn, L. *Conducting Integrated Research: A Critical Literature Review of Interdisciplinary and Transdisciplinary Research*, Report 12/08; Centre for Rural Research: Trondheim, Norway, 2009.
10. Balsiger, P.W. Supradisciplinaryresearch practices: History, objectives and rationale. *Futures* **2004**, *36*, 407-421.
11. Janssen, W.; Goldsworthy, P. Multidisciplinary research for natural resource management: Conceptual and practical implications. *Agric. Syst.* **1996**, *51*, 259-279.
12. Kooistra, M.J.; Kooistra, L.I. Integrated research in archaeology using soil micromorphology and palynology. *Catena* **2003**, *54*, 603-617.
13. James, L.A.; Marcus, W.A. The human role in changing fluvial systems: Retrospect, inventory and prospect. *Geomorphology* **2006**, *79*, 152-171.
14. Stevens, C.J.; Fraser, I.; Mitchley, J.; Thomas, M.B. Making ecological science policy-relevant: Issues of scale and disciplinary integration. *Landsc. Ecol.* **2007**, *22*, 799-809.
15. Hadorn, G.H.; Bradley, D.; Pohl, C.; Rist, S.; Wiesmannd, U. Implications of transdisciplinarity for sustainability research. *Ecol. Econ.* **2006**, *60*, 119-128.
16. Jerneck, A.; Olsson, L.; Ness, B.; Anderberg, S.; Baier, M.; Clark, E.; Hickler, T.; Hornborg, A.; Kronsell, A.; Lövbrand, E.; *et al.* Structuring sustainability science. *Sustainability Sci.* **2011**, *6*, 69-82.
17. Luks, F.; Siebenhüner, B. Transdisciplinarity for social learning? The contribution of the German socio-ecological research initiative to sustainability governance. *Ecol. Econ.* **2007**, *63*, 18-26.
18. Lélé, S.; Norgaard, R.B. Practicing interdisciplinarity. *BioScience* **2005**, *55*, 967-975.
19. Koc, M. Sustainability: A Tool for Food System Reform? In *Imagining Sustainable Food Systems: Theory and Practice*; Blay-Palmer, A., Ed.; Ashgate: Surrey, UK, 2010; pp. 37-48.
20. Kajikawa, Y.; Ohno, J.; Takeda, Y.; Matsushima, K.; Komiyama, H. Creating an academic landscape of sustainability science: An analysis of the citation network. *Sustainability Sci.* **2007**, *2*, 221-231.
21. Kajikawa, Y. Research core and framework of sustainability science. *Sustainability Sci.* **2008**, *3*, 215-239.
22. Reyers, B.; Roux, D.J.; Cowling, R.M.; Ginsburg, A.E.; Nel, J.L.; Farrell, P.O. Conservation planning as a transdisciplinary process. *Conserv. Biol.* **2010**, *24*, 957-965.
23. Massey, C.; Alpass, F.; Flett, R.; Lewis, K.; Morriss, S.; Sligo, F. Crossing fields: The case of a multi-disciplinary research team. *Qualitative Res*. **2006**, *6*, 131-149.
24. Evans, J.; Randalls, S. Geography and paratactical interdisciplinarity: Views from the ESRC–NERC PhD studentship programme. *Geoforum* **2008**, *39*, 581-592.
25. Kueffer, C.; Hadorn, G.H.; Bammer, G.; van Kerkhoff, L.; Pohl, C. Towards a publication culture in transdisciplinary research. *Gaia Ecol. Perspect. Sci. Soc.* **2007**, *16*, 22-26.
26. Madsen, L.M.; Adriansen, H.K. Understanding the use of rural space: The need for multi-methods. *J. Rural Stud.* **2004**, *20*, 485-497.

27. Robinson, J. Being undisciplined: Transgressions and intersections in academia and beyond. *Futures* **2008**, *40*, 70-86.
28. Tress, G.; Tress, B.; Fry, G. Publishing integrative landscape research: Analysis of editorial policies of peer-reviewed journals. *Environ. Sci. Policy* **2006**, *9*, 466-475.
29. Tress, G.; Tress, B.; Fry, G. Analysis of the barriers to integration in landscape research projects. *Land Use Policy* **2007**, *24*, 374-385.
30. Lau, L.; Pasquini, M. 'Jack of all trades'? The negotiation of interdisciplinarity within geography. *Geoforum* **2008**, *39*, 552-560.
31. Donaldson, A.; Ward, N.; Bradley, S. Mess among disciplines: Interdisciplinarity in environmental research. *Environ. Plann. A* **2010**, *42*, 1521-1536.
32. Bracken, L.J.; Oughton, E.A. 'What do you mean?' The importance of language in developing interdisciplinary research. *Trans. Inst. Br. Geographers* **2006**, *31*, 371-382.
33. Buller, H. The lively process of interdisciplinarity. *Area* **2009**, *41*, 395-403.
34. Hinrichs, C.C. Interdisciplinarity and boundary work: Challenges and opportunities for agrifood studies. *Agric. Hum. Values* **2008**, *25*, 209-213.
35. Lingard, L.; Schryer, C.F.; Spafford, M.M.; Campbell, S.L. Negotiating the politics of identity in an interdisciplinary research team. *Qualitative Res.* **2007**, *7*, 501-519.
36. Tilbury, F. 'Piggy in the middle': The liminality of the contract researcher in funded 'collaborative' research. *Sociol. Res. Online* **2007**, *12*.
37. Monteiro, M.; Keating, E. Managing misunderstandings: The role of language in interdisciplinary scientific collaboration. *Sci. Commun.* **2009**, *31*, 6-28.
38. Carolan, M.S. The values and vulnerabilities of metaphors within the environmental sciences. *Soc. Natl. Resour.* **2006**, *19*, 921-930.
39. Wainwright, J. Climate change, capitalism, and the challenge of transdisciplinarity. *Ann. Assoc. Am. Geographers* **2010**, *100*, 983-991.
40. Jansen, K. Implicit sociology, interdisciplinarity and systems theories in agricultural science. *Sociologia Ruralis* **2009**, *49*, 172-188.
41. Blevis, E.; Stolterman, E. Transcending disciplinary boundaries in interaction design. Transcending disciplinary boundaries in interaction design. *Interactions* **2009**, *16*, 48-51.
42. Evely, A.; Fazey, J.; Lambin, X.; Lambert, E.; Allen, S.; Pinard, M. Defining and evaluating the impact of cross-disciplinary conservation research. *Environ. Conserv.* **2010**, *37*, 442-450.
43. Tress, B.; Tress, G.; Fry, G. Researchers experiences, positive and negative, in integrative landscape projects. *Environ. Manage.* **2005a**, *36*, 792-807.
44. François, C. Transdisciplinary unified theory. *Syst. Res. Behav. Sci.* **2006**, *23*, 617-624.
45. Attwater, R.; Booth, S.; Guthrie, A. The role of contestable concepts in transdisciplinary management of water in the landscape. *Syst. Res. Behav. Sci.* **2005**, *22*, 185-192.
46. Max-Neef, M.A. Foundations of transdisciplinarity. *Ecol. Econ.* **2005**, *53*, 5-16.
47. *Environmental Science for Environmental Management*; 2nd ed.; O'Riordan, T., Ed.; Prentice-Hall: Harlow, UK, 2000.
48. Wickson, F.; Carew, A.L.; Russell, A.W. Transdisciplinary research: Characteristics, quandaries and quality. *Futures* **2006**, *38*, 1046-1059.

49. Hammer, M.; Söderqvist, T. Enhancing transdisciplinary dialogue in curricula development. *Ecol. Econ.* **2001**, *38*, 1-5.
50. Pena, S.B.; Abreu, M.M.; Teles, R.; Espírito-Santo, M.D. A methodology for creating greenways through multidisciplinary sustainable landscape planning. *J. Environ. Manage.* **2010**, *91*, 970-983.
51. Hopton, M.E.; Cabezas, H.; Campbell, D.; Eason, T.; Garmestani, A.S.; Heberling, M.T.; Karunanithi, A.T.; Templeton, J.J.; White, D.; Zanowick, M. Development of a multidisciplinary approach to assess regional sustainability. *Int. J. Sustainable Dev. World Ecol.* **2010**, *17*, 48-56.
52. Uiterkamp, A.J.M.S.; Vlek, C. Practice and outcomes of multidisciplinary research for environmental sustainability. *J. Soc. Issues* **2007**, *63*, 175-197.
53. Mobjörk, M. Consulting *versus* participatory transdisciplinarity: A refined classification of transdisciplinary research. *Futures* **2010**, *42*, 866-873.
54. Kutílek, M.; Nielsen, D.R. Interdisciplinarity of hydropedology. *Geoderma* **2007**, *138*, 252-260.
55. Huutoniemi, K.; Klein, J.T.; Bruun, H.; Hukkinen, J. Analyzing interdisciplinarity: Typology and indicators. *Res. Policy* **2010**, *39*, 79-88.
56. Schmidt, J.C. Towards a philosophy of interdisciplinarity. *Poiesis Praxis: Int. J. Technol. Assess. Ethics Sci.* **2008**, *5*, 53-69.
57. Guyer, J.I.; Lambin, E.; Cliggett, L.; Walker, P.; Amanor, K.; Bassett, T.; Colson, E.; Hay, E.; Homewood, K.; Linares, O.; *et al.* Temporal heterogeneity in the study of African land use: Interdisciplinary collaboration between anthropology, human geography and remote sensing. *Hum. Ecol.* **2007**, *35*, 3-17.
58. Santelmann, M.V.; White, D.; Freemark, K.; Nassauer, J.I.; Eilers, J.M; Vaché, K.B.; Danielson, B.J.; Corry, R.C.; Clark, M.E.; Polasky, S.; *et al.* Assessing alternative futures for agriculture in Iowa, USA. *Landsc. Ecol.* **2004**, *19*, 357-374.
59. Hoffman, M.T.; Allsopp, N.; Rohde, R.F. Sustainable land use in Namaqualand, South Africa: Key issues in an interdisciplinary debate. *J. Arid Environ.* **2007**, *70*, 561-569.
60. Harris, F.; Lyon, F.; Clarke, S. Doing interdisciplinarity: Motivation and collaboration in research for sustainable agriculture in the UK. *Area* **2009**, *41*, 374-384.
61. Kumpula, T.; Pajunen, A.; Kaarlejärvi, E.; Forbes, B.C.; Stammler, F. Land use and land cover change in Arctic Russia: Ecological and social implications of industrial development. *Global Environ. Change* **2011**, *21*, 550-562.
62. Lotfi, A.; Javelle, A.; Baudry, J.; Burel, F. Interdisciplinary analysis of hedgerow network landscapes' sustainability. *Landsc. Res.* **2010**, *35*, 415-426.
63. Irvine, K.N.; Devine-Wright, P.; Payne, S.R.; Fuller, R.A.; Painter, B.; Gaston, K.J. Green space, soundscape and urban sustainability: An interdisciplinary, empirical study. *Local Environ.* **2009**, *14*, 155-172.
64. Drury, R.; Homewood, K.; Randall, S. Less is more: The potential of qualitative approaches in conservation research. *Anim. Conserv.* **2011**, *14*, 18-24.
65. Pohl, C. Transdisciplinary collaboration in environmental research. *Futures* **2005**, *37*, 1159-1178.
66. Tress, B.; Tress, G.; Décamp, H.; d'Hauteserre, A.-M. Bridging human and natural sciences in landscape research. *Landsc. Urban Plann.* **2001**, *57*, 137-141.

67. Walter, A.I.; Helgenberger, S.; Wiek, A.; Scholz, R.W. Measuring societal effects of transdisciplinary research projects: Design and application of an evaluation method. *Eval. Program Plann.* **2007**, *30*, 325-338.
68. Aeberhard, A.; Rist, S. Transdisciplinary co-production of knowledge in the development of organic agriculture in Switzerland. *Ecol. Econ.* **2009**, *68*, 1171-1181.
69. Rapport, D.J. Transdisciplinarity: Transcending the disciplines. *Tree* **1997**, *12*, 289.
70. Stock, P.V. Sociology and the mix tape: A metaphor of creativity. *Am. Soc.* **2010**, *41*, 277-291.
71. Muldavin, J. The time and place for political ecology: An introduction to the articles honoring the life-work of Piers Blaikie. *Geoforum* **2007**, *39*, 687-697.
72. Girard, N.; Hubert, B. Modelling expert knowledge with knowledge-based systems to design decision aids the example of a knowledge-based model on grazing management. *Agric. Syst.* **1999**, *59*, 123-144.
73. Giri, A.K. The calling of a creative transdisciplinarity. *Futures* **2002**, *34*, 103-115.
74. Höchtl, F.; Lehringer, S.; Konold, W. Pure theory or useful tool? Experiences with transdisciplinarity in the Piedmont Alps. *Environ. Sci. Policy* **2006**, *9*, 322-329.
75. Lawrence, R.; Deprés, C. Futures of transdisciplinarity. *Futures* **2004**, *36*, 397-405.
76. Vandermuelen, V.; van Huylenbroeck, G. Designing transdisciplinary research to support policy formulation for sustainable agricultural development. *Ecol. Econ.* **2008**, *67*, 352-361.
77. Tintoré, J.; Medina, R.; Gómez-Pujol, L.; Orfila, A.; Vizoso, G. Integrated and interdisciplinary scientific approach to coastal management. *Ocean Coastal Manage.* **2009**, *52*, 493-505.
78. Kroon, F.J. Integrated research to improve water quality in the Great Barrier Reef region. *Mar. Freshwater Res.* **2009**, *60*, i-iii.
79. White, R.M.; Fischer, A.; Marshall, K.; Travis, J.M.J.; Webb, T.J.; di Falco, S.; Redpath, S.M.; van der Wal, R. Developing an integrated conceptual framework to understand biodiversity conflicts. *Land Use Policy* **2009**, *26*, 242-253.
80. Wagner, M.M.; Gobster, P.H. Interpreting landscape change: Measured biophysical change and surrounding social context. *Landsc. Urban Plann.* **2007**, *81*, 67-80.
81. Nuijten, E. Combining research styles of the natural and social sciences in agricultural research. *NJAS—Wageningen J. Life Sci.* **2011**, *57*, 197-205.
82. Hunt, L.; Benge, J.; Campbell, H.; Fairweather, J.; Greer, G.; Lucock, D.; Manhire, J.; Moeller, H.; Reid, J.; Rosin, C.; *et al.* Experiences of Transdisciplinarity in Research on Agricultural Sustainability. In *Proceedings of the 10th European International Farming System Association Symposium*, 4–7 July 2010, Vienna, Austria.
83. Moller, H.; Campbell, H.; Rosin, C.; Hunt, L.; Fairweather, J. Questing for the Transdisciplinary Utopia: An Untrodden Pathway to Achieve Agricultural Resilience in New Zealand? In *Proceedings of the Sustainable Consumption and Alternative Agri-Food Systems*, 27–30 May 2008, University of Liege, Arlon, Belgium.
84. Rosin, C.; Perley, C.; Moller, H.; Dixon, K. For want of the social, was the biodiversity battle lost? On the need to approach social-ecological resilience through transdisciplinary research. *N. Z. J. Agric. Res.* **2008**, *51*, 481-484.

85. Birkes, F. *Sacred Ecology: Traditional Ecological Knowledge and Resource Management*; Taylor and Francis: Philadelphia, PA, USA, 1999.
86. Sillitoe, P. Local Science *vs.* Global Science: An Overview. In *Local Science* vs. *Global Science: Approaches to Indigenous Knowledge in International Development*; Sillitoe, P., Ed.; Bergham Books: New York, NY, USA, 2007; pp. 1-22.
87. Perz, S.G. Reformulating modernization-based environmental social theories: Challenges on the road to an interdisciplinary environmental science. *Soc. Natl. Resour.* **2007**, *20*, 415-430.
88. Eigenbrode, S.D.; O'Rourke, M.; Wulfhorst, J.D.; Althoff, D.M.; Goldberg, C.S.; Merrill, K.; Morse, W.; Nielsen-Pincus, M.; Stephens, J.; Winowiecki, L.; *et al.* Employing philosophical dialogue in collaborative science. *BioScience* **2007**, *57*, 55-64.
89. Hegarty, K. Sustaining collegiality through the imperative of interdisciplinary practice. *London Rev. Educ.* **2009**, *7*, 83-90.
90. Kumazawa, T.; Saito, O.; Kozaki, K.; Matsui, T.; Mizoguchi, R. Toward knowledge structuring of sustainability science based on ontology engineering. *Sustainability Sci.* **2009**, *4*, 99-116.
91. Lafuente, J.G.; Ruiz, J. The Gulf of Cádiz pelagic ecosystem: A review. *Prog. Oceanogr.* **2007**, *74*, 228-251.