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Surveys

A review of transdisciplinary research in sustainability science

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ABSTRACT

Achieving the goal of sustainability requires understanding and management of unprecedented and interconnected challenges. A transdisciplinary approach is a key component of sustainability science. However, there are considerable barriers to implementing transdisciplinary projects. We undertake a mixed quantitative and qualitative analysis of peer-reviewed sustainability science studies where the transdisciplinary approach has been applied. We assess the growth and scientific impact of transdisciplinary sustainability research, the methods used and how three key characteristics of transdisciplinarity research—process phases, knowledge types and the intensity of involvement of practitioners—are implemented. While transdisciplinary research is growing there is no common glossary, no focused communication platform and no commonly shared research framework. Transdisciplinary research utilizes a broad, but not clearly defined, set of methods for knowledge production. While the intensity of practitioner involvement varied within the case studies analyzed, very few realized empowerment. Based on our review of transdisciplinary case study papers we conclude that transdisciplinary research must be clearly framed, including the use of a common terminology and the development of a broad suite of appropriate methods. Despite the challenges highlighted here, science needs to move beyond classical disciplinary approaches and should consider interdisciplinary work that engages with practitioners to achieve sustainable transitions.

1. Introduction

Social–ecological systems currently face multiple unprecedented challenges including, but not limited to, the degradation of ecosystems, over exploitation of natural resources, climate change, wealth inequalities, and human conflicts. These interconnected challenges are threatening the sustainable development of society (Kates and Parris, 2003; Rockstrom et al., 2009). Attempts to meet the demands of the current generation without compromising the ability of future generations to meet their needs, "the essence of sustainable development "(Kates, 2001), remains at best a distant goal. Sustainability science is an emerging interdisciplinary alliance, which is better defined by the problems it addresses rather than by the disciplines it employs (Aronson, 2011; Bettencourt and Kaur, 2011; Clark, 2007; Hirsch Hadorn et al., 2006). Naturally, this is highly relevant to the management of natural resources across scales, since ecosystem services and ecological diversity are threatened by current global change. Steering socio-ecological systems towards a more sustainable path is an inherently transdisciplinary problem, requiring cooperation between different scientific domains and society at large — here we define transdisciplinarity as a research approach that includes multiple scientific disciplines (interdisciplinarity) focusing on shared problems and the active input of practitioners from outside academia. Yet the implementation is fraught with practical and institutional difficulties (Lang et al., 2012). We identify five key challenges to undertaking transdisciplinary approaches to sustainability science.

Challenge one: lack of coherent framing. A lack of a shared framing of the problems might occur when scientists from several scientific traditions take different perspectives on the same problem and the same is true for different practitioners (Gibbons, 1999; Jahn, 2008; Tress et al., 2005). In addition, the lack of interaction between scientists and practitioners poses further challenges to produce socially robust knowledge and solve sustainability problems (Funtowicz and Ravetz, 1993; Gibbons et al., 1994). Attempts to link scientists and practitioners in sustainability science aim to strengthen the exchange and integration of different disciplinary and non-academic

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knowledge, enabling mutual learning between scientists and practitioners (Lang et al., 2012; Scholz, 2011; Stahl et al., 2011).

In recent years numerous studies have discussed the requirements of a coherent research framework for transdisciplinary projects (e.g., Bergmann and Schramm, 2008; Jahn, 2008; Jahn et al., 2012; Pohl, 2008; Scholz, 2011). However, a broadly accepted and utilized research framework for transdisciplinarity – with the accompanying consistent use of language and terminology – has not yet been fully established. This lack of common research framing hampers scientific communication and knowledge exchange between scientific disciplines that do not share methodological or conceptual definitions (Tress et al., 2005; Winder, 2003). For example, commonly used terms to describe interdisciplinary research involving the active engagement of non-scientists have been discussed under terms that include; 'transdisciplinary' (Becker, 2006; Scholz, 2011), 'mode 2' (Nowotny et al., 2001), 'participatory research' (Blackstock et al., 2007; Newig et al., 2008), and 'public participation' (Kasemir, 2003).

Challenge two: Integration of methods. Besides developing coherent terminologies and research frameworks, transdisciplinarity requires both the integration of different disciplinary methods (Bergmann, 2010) and the development of novel research methods to enable efficient and effective learning processes at the science-society interface (Bergmann and Schramm, 2008; Lawrence and Despres, 2004). Establishing reproducible and coherent methods remains a challenging process due to the diversity of methods used in transdisciplinary research — see Scholz and Tietje (2002) and Bergmann (2010) for structured summaries of the diverse methods used. Method integration makes transdisciplinary research a time consuming and potentially onerous task (Hering et al., 2012). Thus a thorough understanding of the methods used in transdisciplinary research is crucial if efficient and coherent research frameworks are to be established.

Challenge three: research process and knowledge production. The focus of sustainability science moves beyond system description, thus includes problem definition, analysis and generation and application of solutions to real world problems. The implementation of transdisciplinary research within sustainability science studies can be characterized in terms of three key components (following Lang et al., 2012); the process phases undertaken within the research project (Pohl and Hirsch Hadorn, 2008a), the types of knowledge which is produced within the project (Pohl and Hirsch Hadorn, 2008a) and the intensity of the involvement of practitioners in the project (Kruetli et al., 2010).

Transdisciplinary projects can be divided into three distinct process phases (i) "problem identification and structuring" where the problem is collaboratively identified, (ii) "problem analysis" the co-creation of solution-oriented and transferable knowledge and (iii) "integration and application" — the implementation of the results into practice (Pohl and Hirsch Hadorn, 2008a; see Appendix 1 text box 1).

Knowledge shared between scholars and practitioners within transdisciplinary projects can be categorized in terms of three knowledge types: (i) "system knowledge" the observation of the system, (ii) "target knowledge" the knowledge of the desired target state, and (iii) "transformation knowledge" the knowledge necessary for fostering transformation processes (ProClim, 1997: 15; see Appendix 1 text box 2).[1] While not all transdisciplinary research has to engage with all three process phases or knowledge types, at present it is unclear as to where the focus currently lies or how process phases and knowledge type are related in the peer reviewed literature.

Challenge four: practitioners' engagement. The link between practitioners and scientists defines a further crucial element of transdisciplinary approaches; however the involvement of practitioners within transdisciplinary projects can occur at very different intensities. Intensity of involvement ranges from: (i) "Information" which involves one-way communication of information in a more limited form, (ii) "Consultation" which demands closer communication including responses, (iii) "Collaboration" which demands that participants have notable influence on the outcome, and (iv) "Empowerment" where the authority to decide is given to the practitioners (Kruetli et al., 2010; see Appendix 1 text box 3; see also Collins and Ison, 2009). While involvement of practitioners and knowledge exchanges are vital goals within transdisciplinary projects, it remains unclear to what extent these goals are realized within published transdisciplinary research.

Challenge five: generating impact. Despite the existence of some transdisciplinary research approaches on a supra-regional or global scale, the need to intensively engage with practitioners tends to constrain the focus of transdisciplinary research to local or regional scales. Much transdisciplinary research originates from developed countries, yet sustainability problems are not limited to the regions in which the research is currently focused (Kengeya-Kayondo, 1994). It is not clear whether there is a platform where transdisciplinary sustainability science is published, or how it impacts on the broader science community.

The challenges of transdisciplinary projects outlined above (coherent framing; method integration; research process and knowledge production; practitioner involvement; generating impact) suggest that it is questionable as to what extent transdisciplinarity is being fully implemented and acknowledged in peer-reviewed sustainability science literature. To date it is unclear how much transdisciplinary sustainability science is being undertaken; to what extent the challenges of transdisciplinary research are being addressed; the relations between method choices, research phases, knowledge types and intensity of involvement, or the impact this research is having on the wider academic community.

While there are comprehensive, rather qualitative reviews of transdisciplinary research (e.g. Bergmann and Schramm, 2008; Jahn et al., 2012; Scholz and Tietje, 2002) we present a novel qualitative and quantitative review using a reproducible research protocol (see Newig and Fridge, 2009) of transdisciplinary sustainability research based on the available peer-reviewed literature. It is our hope that by providing a clear, reproducible approach it will be possible to better track future developments in the implementation of transdisciplinary sustainability research.

Based on a review of peer-reviewed transdisciplinary, sustainability science case studies we quantify (1) whether the term "transdisciplinary", the number and the scientific impact of transdisciplinary peer-reviewed studies in sustainability science have increased over time. (2) We identify geographic bias in both authorships and study locations—this is of interest given the (general) regional focus of transdisciplinary research. (3) We investigate the relation between knowledge types, transdisciplinary process phases, intensity of involvement and different methods applied within transdisciplinary projects. In a final step we identify central issues relating to meeting the key challenges for a further development of transdisciplinary sustainability science.

2. Methods

Our approach was based on a mixed quantitative and qualitative bibliometric content analysis of the available literature (Table 1), broadly following the approach of Newig and Fritsch (2009). The intention is to provide a broad overview of the state of the science, with a particular focus on the key challenges to undertaking transdisciplinary sustainability science. We identified articles via the Scopus database (see Appendix 2 for the search string), which revealed bibliographical information of "full articles" published between January 1970 and August 2011. Conference papers, abstracts, reports, books and letters were excluded from the search. We acknowledge that—especially in the field of transdisciplinary research—there is a large body of literature not

[1] We acknowledge that there are other typologies of knowledge types (e.g. Raymond et al., 2010), but believe that the typology presented here is the most suitable for characterizing and investigating sustainability science, where there is an explicit focus on solving real-world problems.

Table 1
Overview of applied paper review-protocol.

	Review protocol stages	Review procedure	Result
1.	Data gathering	Joint definition of Scopus search query	Bibliographical information of 1507 potentially relevant papers
2.	Data screening	Segmentation of data load into bundles of 250 papers per reader analyst	Pre-classified set of potentially relevant papers
3.	Data cleaning	Screening of papers, guided by the question: „Does the abstract offer any clues on stakeholder involvement in research and an interdisciplinary approach? " Each paper was screened independently by two analysts	Consensus amongst analyst readers about validity of joined classification. A total of 266 relevant papers identified.
4.	Data scoping	Download of all papers classified as likely relevant or unsure.	Total number N = 236 (30 papers not found)
5.	Paper classification	Scoping of downloaded papers as to whether or not they actually describe the application of methods (= case study papers) Coding the variable „Methods application" Each paper was independently scoped by two analyses with subsequent discussion and final consensus decision.	N = 236 papers with coherently assigned variables. In summary N = 104 case studies fitted the coding scheme criteria
	Consensus review	Pairwise review of variable "application". Consensus based review. All disagreement had to be discussed and solved.	Verified set of relevant papers
6.	Paper review	Reader analysis of papers classified as case studies.	Coherent dataset of N = 104 case study papers with 24 variables each. 2520 data points in total.
7.	Statistical analysis	Analysis of all relevant data points using R.	Results are given in the part below.

Table 2
Derived sets of methods and number of different methods per set. Two of the most frequently used methods in each set are given as example.

Method set	Times applied	Definition and examples of included methods
Evaluation and validation	47	Application of assessment and validation methods. Examples are impact assessment, decision-making matrix, or, feedback group.
Modelling	24	Application and development of environmental and social-economic modelling approaches. Examples are land-use, food web, or material flow modelling
Visioning	34	Collaborative exploration of desirable/possible target states. Examples are scenario development or using of scenario techniques.
Data collection	157	Methods of gathering information in a structured procedure. Examples are survey, interview, or experiment.
Description	49	Analysis of obtained data with statistical approaches. Examples are correlation, regression analysis or statistical tests.
Learning and exchange	175	Sharing of knowledge, experiences and opinions based on open communications within collaborative environments. Examples are workshop, conference or meeting.
Visualizing and structuring	125	Structuring of ideas, problem or project constellations/environments and applying visualization techniques and tools to design visual representations of thoughts, concepts, and results. Examples are mind map, diagramming, or GIS-tools.

recorded in Scopus, which was beyond the focus of our analysis. We reviewed the initial database for articles, which we defined as potentially transdisciplinary by straightforwardly assessing that at least two scholarly disciplines as well as practitioners outside academia were involved in the research process (see Table 1). With regard to "sustainability science" we included all articles mentioning this term, in order to cover a broad spectrum of—self defined—contributions to this research area. Each paper fulfilling these two criteria was double-checked by two reviewers and categorized in terms of paper type. As the focus here is on the implementation of transdisciplinarity in real-world situations the following analyses were limited to only those papers identified as "case studies" (i.e. concrete projects following a transdisciplinary approach). For an overview of the complete review process see Appendix 3.

Each case study paper was categorized with regard to the three key components of transdisciplinarity (categories given in parenthesis):

- *Process phases* (i. problem identification and structuring, ii. problem analysis and iii. integration and application), with multiple phases per study being noted.
- *Knowledge type* (system knowledge, target knowledge and transformation knowledge).
- *The intensity of involvement of non-scientists (*information, consultation, collaboration and empowerment).[2]

Based on an initial inspection of all methods applied in the case studies, we grouped the methods used in the papers into seven categories (Table 2). The number of case study papers published per year was used as a proxy to test if transdisciplinary sustainability science studies have increased over time; journal impact factor was used to gauge the influence of a given study within the scientific community.[3] We counted the country affiliations of authors divided by the number of authors as well as countries in which the study was conducted. All statistical analyses and graphics were made using the R 2.14 software (www.r-project.org), using network analysis plots from the package "bipartite" to visualize relations within the data via networks. All relations were tested with chi-square tests for significance.

3. Results

236 transdisciplinary papers were identified and subsequently classified as follows: 33 emphasized the importance of transdisciplinarity only in the conclusion (call for transdisciplinarity); 71 paper discussed transdisciplinary approaches throughout the text (argumentation); 28 papers developed methods for undertaking transdisciplinary research (methods) or transdisciplinary frameworks within which methods could be applied (frameworks) yet did not apply them. 104 papers were identified as real-world case studies (application) following a transdisciplinary approach (Fig. 1).

The number of case studies clearly increased over time and the usage of the term "transdisciplinary" shows a similar trend (Fig. 2). Note that the 2011 data only covers January to mid July and there is a delay in the publication of papers and their indexing in the Scopus database.

The majority of the studies were conducted in Europe and North America, by authors located in these regions. In all other regions there was a stronger tendency for people from outside the region to

[2] Here it should be noted that intensity of involvement only provides a partial measure of non-scientist engagement in transdisciplinary approaches. Furthermore, the level of intensity should be adequate for the specific process (sub-)phase, rather being on the same level throughout the process (see Stauffacher et al., 2008). However, a full and dynamic description of the level of involvement of all individual stakeholders in each study was beyond the scope of this review.

[3] We acknowledge that this does not give any measure of the impact of a given study outside academia, which is difficult to measure though a very interesting and relevant question for further research.

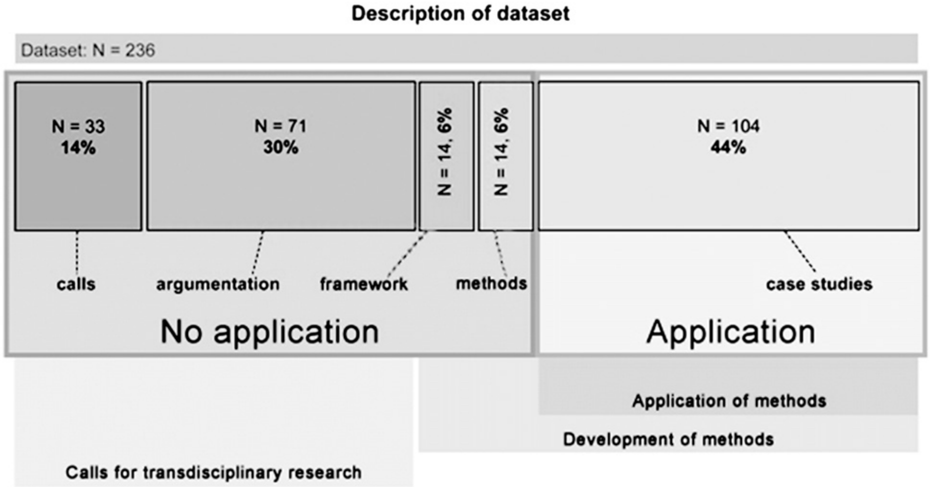

Fig. 1. Overview of the whole dataset.

work on transdisciplinary projects, this was most pronounced in South America and Africa (Fig. 3); relations between where the studies were conducted and where the authors are affiliated are significantly related ($p < 0.001$) based on a chi square test.

The relations between the sets of methods used, specific knowledge produced (Fig. 4) and process phases undertaken (Fig. 5) shows no specific patterns, and were not significant ($p = 0.58$ for knowledge types, $p = 0.74$ for process phases) based on a chi square test. The number of methods used within individual case studies varied widely, yet the data showed no trend over time (data not shown). The two characteristics used to structure transdisciplinary projects (process phases and knowledge types) showed an overall weak linkage (Fig. 6), which was however barely significant based on a chi square test ($p = 0.047$).

Our analysis of the maximum intensity of practitioner involvement in the projects indicates that collaboration is the most common level of involvement, with only 18 case studies engaging in practitioners empowerment within the transdisciplinary process (Fig. 7). There is a weak tendency that intensity of involvement is related to the knowledge types produced, which was however not significant in a chi square test ($p = 0.52$). For instance "consultation" was most strongly linked to system knowledge and target knowledge most strongly linked to collaboration.

4. Discussion

4.1. Challenge One: Coherent Framing. Transdisciplinary Research in Sustainability Science is Increasing, but Under Diverse Terms

The interest in tackling real world problems with transdisciplinary research approaches appears to be increasing within sustainability science, based on the peer-reviewed case studies examined here. An increasing body of publications dealing with transdisciplinary research has been identified previously, e.g. by Kueffer et al. (2007). However, the identification of this trend is difficult given the diversity of terminologies (Table 3), which potentially hampers communication (Tress et al., 2005). Nevertheless, the rising usage of the term transdisciplinary suggests that this rather heterogeneous research practice may be in a consolidation phase, at least with regard to the use of a single coherent term for these research practices. This is also indicated by the fact that various initiatives in this field emerged over the last few years (e.g. TdNet: http://www.transdisciplinarity.ch/ ITdNet: http://www.uns.ethz.ch/translab/itdnet) and the increasing number of handbook/textbook publications in the field (see. e.g. Hirsch Hadorn et al., 2008; Frodeman et al., 2010; Bergmann et al., 2012).

4.2. Challenge Two: Integration of Methods. Method Sets Used are Independent of Process Phases and Knowledge Types

Other studies have stressed the need to develop and establish a reproducible and transparent methodological framework for transdisciplinary research that holds both theoretical generality and applicability to problems in a given case study (Lang et al., 2012; Wiesmann et al., 2008). However, methods are often part of the repertoire of a given scientist, therefore the seemingly objective selection of methods can be expected to be unavoidably subjectively biased. More importantly, the selection of methods is based on different ontological approaches. Our results show that there are no clear relations between the methods used to produce different knowledge types occurring within

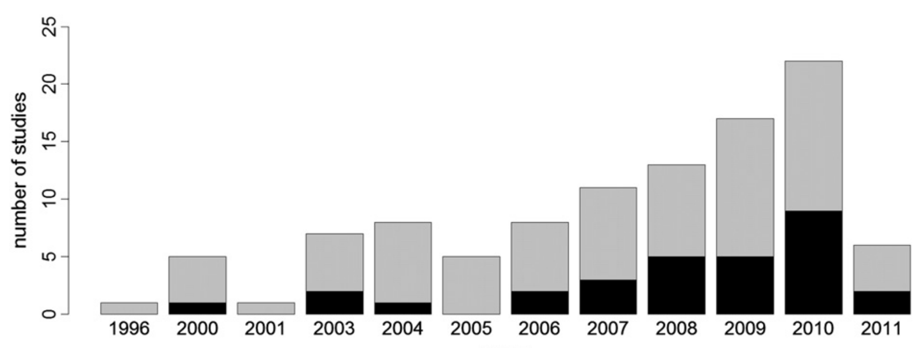

Fig. 2. Number of case studies employing transdisciplinary methods over time shown by grey bars. Black color indicates the proportion of studies that used the term "transdisciplinary". Search was conducted in 18.07.2011.

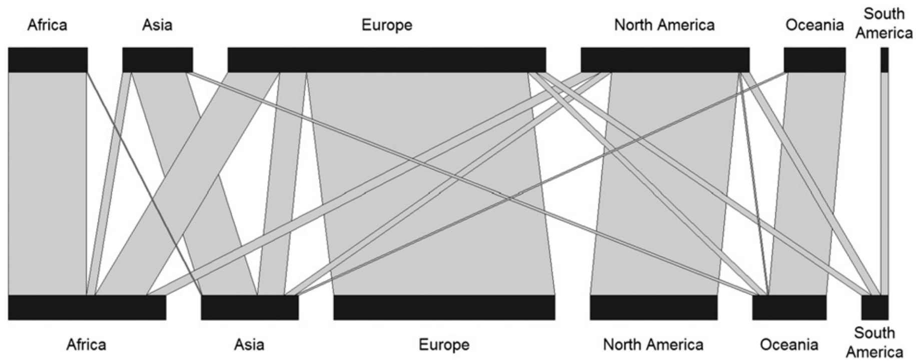

Fig. 3. Relations between affiliation of authors (upper part) and region where the study was conducted (lower part). Note that in multiple authors case studies all affiliations were considered, divided by the number of authors.

transdisciplinary research as judged from peer-reviewed publications examined. Seemingly the production of different knowledge demands a wide array of methods, as suggested by Pohl and Hirsch Hadorn (2008b). Thus knowledge production within transdisciplinary projects is entangled with a diversity of methods applied to identify, analyze and solve complex real-world problems. A similar pattern was found for transdisciplinary process phases, with no clear links observed between the method sets applied and the transdisciplinary process phases undertaken. One argument for this pluralistic approach to methods use is that methods in transdisciplinary science demand a freedom of choice, thus methods cannot be limited to a defined tool for a defined means. This differs considerably from most established scientific fields, which have well established and well tested sets of specific methods to tackle certain tasks. Our review is inconclusive as to whether in time the establishment of broadly agreed suite of transdisciplinary research methods will occur. However, it has been argued that each real world problem demands a specific solution and thus one or several specific methods to develop them (Ostrom, 2009). In an extreme scenario methodological restriction could hamper empowerment in a transdisciplinary project, since a constrained methodological toolkit may not allow proper access to the data necessary for problem framing. In addition, there are always various scientific disciplines involved in transdisciplinary research, making the identification of accepted methods even more complex. The plurality of methods used does however potentially compromise the notion of the reproducibility that is demanded by science, increasing the "costs" of method integration and hamper communication within, and outside, the transdisciplinary research community (Jahn et al., 2012). A completely reproducible, uniform approach to methods is probably neither possible nor desirable within the dynamic, problem and solution orientated field of sustainability science. Nevertheless it would be beneficial to apply methods consistently so as to generate reproducible approaches within projects and to allow communication between different projects.

Transdisciplinary research does not follow a linear process but relates to its own prior processes and states (Bergmann et al., 2012). Hence it can be assumed that the same sets of methods recur in more than one process phase. This possibly explains the weak linkages between methods and specific knowledge types and process phases, which yielded no clear relation pattern between those key aspects in our analysis. Interestingly, innovation of methods was rather low, with only 7% of case studies stating they developed new methods. These findings appear to partially contradict the claims that transdisciplinarity is leading to methodological advancement (Kueffer et al., 2007; Pohl and Hirsch Hadorn, 2008b). However, it is beyond the scope of our analysis to evaluate the rate of methodological innovation in transdisciplinary research compared to that found in other scientific disciplines.

4.3. Challenge Three: Research Process and Knowledge Production. There is a Gap Between 'Best Practice' Transdisciplinary Research as Advocated, and Transdisciplinary Research as Published in Scientific Journals

Clarity in transdisciplinary research requires that the process phases (Pohl et al., 2008) and the knowledge types used (ProClim, 1997) are stated in a given study. Within our review we encountered many studies, which failed to clearly do so. Moreover, while it has been proposed that process phases and knowledge types are related (Jahn et al., 2012), our empirical analysis suggests that in practice this is only partially the case, for example, system knowledge is integrated across all three process phases. The existing theoretical transdisciplinary research frameworks are not being fully implemented within the peer-reviewed literature. We identified two groups of papers: 1) research focusing on the development of theoretical transdisciplinarity frameworks and 2) solution-orientated research that seeks to apply transdisciplinarity to real-world projects (Fig. 1). Other scientific disciplines also have both conceptual and empirical papers, however,

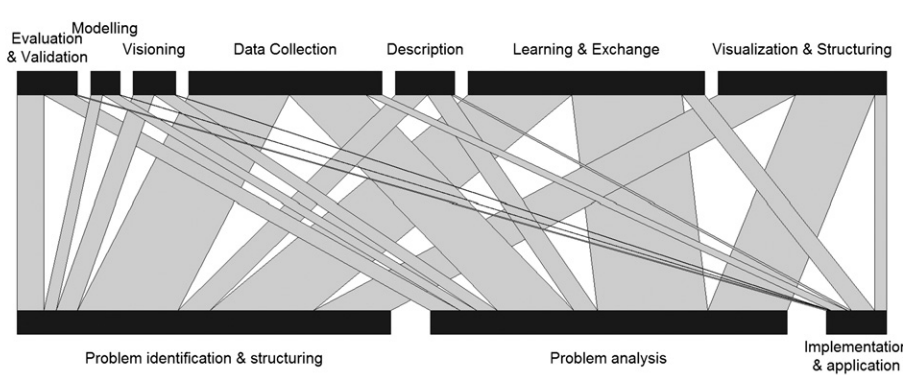

Fig. 4. Relations between different method sets and process phases.

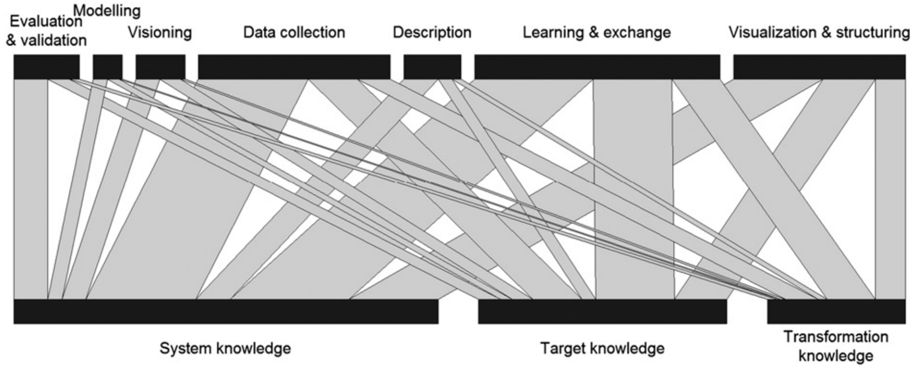

Fig. 5. Relations between method sets and knowledge types.

in transdisciplinary research conceptual papers are rather abundant. The transdisciplinary community is already beginning to establish a terminology of its own, which may be necessary, but hampers communication with both practitioners and various scientific disciplines involved (Cash et al., 2003). It is futile to use concepts such as process phases and knowledge types if these concepts cannot be clearly communicated to, and used by, practitioners and scientists seeking to engage in concrete transdisciplinary research.

4.4. Challenge Four: Practitioners' Engagement: Knowledge is Interchanged, Yet Empowerment is Rare

Based on the peer-reviewed publications we reviewed and analyzed, most studies intensively involved real-world partners in the research process. There are strong interchanges of knowledge and active participant engagement within in transdisciplinary sustainability science, with practitioners functioning as more than passive sources of information. However, with a few exceptions (e.g. in Reidsma et al., 2011), empowerment was rarely realized within the case studies. While a close link between scientists and real world practitioners is a key aim of transdisciplinarity only a few projects gave the authority to make decisions to the practitioners.

4.5. Challenge Five: Generating Impact: Generating Transdisciplinary Research with High-Scientific Impact Remains Challenging

Despite the inherent challenges in publishing inter- and transdisciplinary research with an above average impact factor (Rafols et al., 2012), transdisciplinary sustainability science is gaining importance in scientific peer-reviewed communication; however, except for two outliers published in PNAS it is widely restricted to journals with an impact below 3.5 (median 1.2; Appendix 4). One potential reason for that could be that project-based research is not primarily focused on peer-reviewed publication. Since transdisciplinary research by definition focuses on a tight communication between researchers and practitioners peer-reviewed publication may be judged as a secondary goal at best. In addition high impact peer-reviewed journals that seek to communicate with the many disciplines involved in transdisciplinary research are not well established. Transdisciplinary research is scattered among dozens of journals, and the journal with the highest number of studies only contains 10 % of the complete dataset (Environmental Management = 11 studies; Appendix 5) from which we surmise that high impact publication platforms dedicated to the transdisciplinary research community have not been established. We would note that it is beyond the scope of our review to identify whether institutional barriers, for instance funding schemes, hamper the publication of transdisciplinary research in traditional disciplinary focused, high impact journals as stated by Wiek et al. (2012).

We argue that transdisciplinary research in sustainability science, as a small field, needs high impact publications to gain the momentum (Clark, 2007) and visibility necessary to engage the wider scientific community in transdisciplinary research activities. A considerable body of non peer-reviewed literature on transdisciplinary research exists, but the lack of visibility of this work outside the existing community of transdisciplinary researchers may hamper communication with the wider scientific community. If editors of scientific journals would consider transdisciplinary research as a new research field further discussions would be triggered, with potential positive feedbacks regarding the communication to the broader public and policy makers (Kueffer et al., 2007; Wiesmann et al., 2008).

5. Conclusion

Transdisciplinary research is surely gaining momentum. To further strengthen this research approach we propose five central issues, derived from our review, that should be tackled.

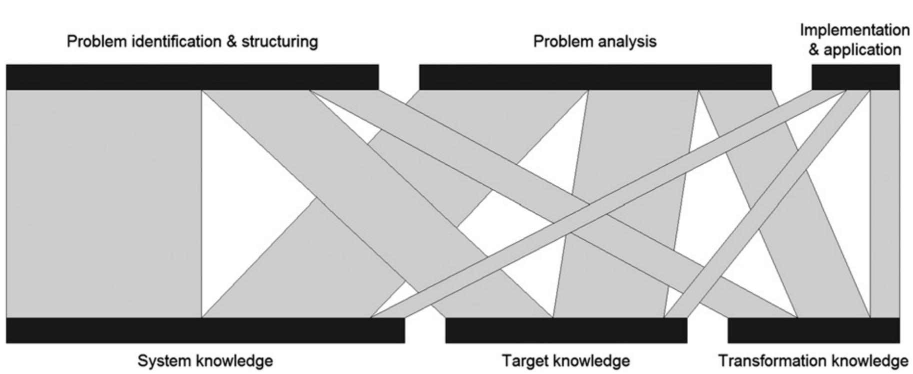

Fig. 6. Relations between transdisciplinary process phases and knowledge types.

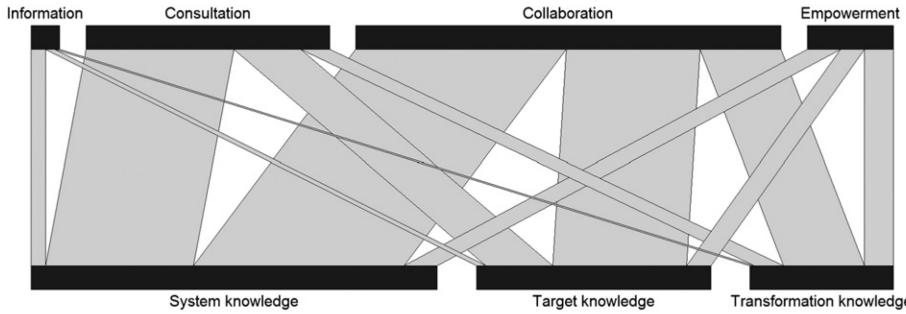

Fig. 7. Relations between maximum intensity of involvement and the knowledge types produced within the case studies.

1) With regard to peer-reviewed publishing, to date, the transdisciplinary research community in sustainability science has neither established nor focused on communication platforms (e.g. journals), or seamless network communication (yet see http://www.transdisciplinarity.ch) in terms of a shared research framework and use of key concepts. This is no doubt due to the different disciplinary backgrounds of the scientists involved. However, we suggest that the adoption of shared and coherent research frameworks within the field of transdisciplinary sustainability science, including explicit links to transdisciplinary process phases and knowledge types would enable a better exchange within transdisciplinary projects, and beyond.
2) Transdisciplinary research has recently been described as being at the edge of marginalization (Jahn et al., 2012). Based on our review of peer-reviewed publications, the field still has a high potential to develop. There is still limited awareness of transdisciplinary approaches in established scientific disciplines. Judging from the available peer-reviewed publications, transdisciplinarity is also still not yet a central component in sustainability science.
3) Transdisciplinary research is an approach (Jahn et al., 2012), thus it should not seal itself off by trying to establish its own scientific glossary and procedures. Instead the approach should try to use as simple language as possible, shared by many disciplines and with results ultimately also understandable by civil society.
4) Transdisciplinary sustainability research utilizes a broad range of different methods for knowledge integration and production, and there is no clear set of tools required for different process phases or integration of different types of knowledge. Nevertheless, it may be helpful to develop a broad suite of accepted and (to some extent) standardized methodological tools. This may increase the efficiency, effectiveness and repeatability of transdisciplinary research in sustainability science and help to communicate its findings to both other scientists and the wider public.
5) Although empowerment is not the ultimate goal of all transdisciplinary projects, a high level of practitioner involvement is certainly desirable for most sustainability science projects. Currently practitioner empowerment is rarely achieved in the peer-review published case studies, and only nine of the studies followed the entire transdisciplinary process from problem definition to implementation. We should note here that such empowerment can also only be realized in countries where governmental structures allow it and the lack of empowerment may not be due be a lack of desire on the part of the participants in the studies analyzed here.

Table 3
Examples from the literature for different terms of transdisciplinary research.

Used term: transdisciplinary	(Stauffacher et al., 2008)	"For such an encompassing and complex subject, […] knowledge and experience of science and from people outside academia are to be combined. We denote such an approach as transdisciplinary. […] Whereby a mutual learning process between science and society is aimed at"
Used term: interdisciplinary with a participatory approach	(Sherren et al., 2010)	"[…] transdisciplinarity: a research approach that is interdisciplinary, integrated and participatory."
	(Wolfe et al., 2007)	"[…] integrate approaches that span the natural and social sciences and traditional knowledge research process that is collaborative, interdisciplinary, policy-oriented, and reflective of northern priorities"
	(Payton et al., 2003)	"They were both designed to be interdisciplinary in approach, involving natural scientists […] as well as anthropologists and social scientists from Europe and the host countries. They were both participatory, […] involved the collection, integration and interpretation of local and scientific knowledge […]."
Used term: participatory action research	(Moller et al., 2009)	"Adaptive co-management and Participatory Action Research (PAR) promotes […] learning through a partnership […] between science and Traditional Ecological Knowledge (TEK) to determine the sustainability of titi (sooty shearwater, *Puffinus griseus*) harvests by Rakiura Maori in southern New Zealand."
	(Leclerc et al., 2009)	"[…] participatory approaches have been developed to help a variety of stakeholders engage in a learning process […] Similarly, some researchers have chosen to deal with complexity by integrating and stimulating more feedback from the field. Action-research is one such posture, and an instrument for sustainability science […] to improve a situation implies implementing actions and evaluating the consequences of these actions."
Used term: multidisciplinary with a participatory approach	(Serrat-Capdevila et al., 2009)	"[…] multidisciplinary collaboration between academia and stakeholders can be an effective step toward collaborative management […] putting science at the service of a participatory decision-making process […]."
	(Gaulke et al., 2010)	"In an effort to prevent an ongoing series of failures, the administration of the Park requested an evaluation from a collaborative, multi-disciplinary project that included the Park, Sichuan University and the University of Washington."
More general terms have been used: scientists/researcher/stakeholder and a participatory approach	(Cabrera et al., 2008)	"This paper describes the interactive and iterative process by which farmers, researchers, extension agents, regulatory agencies, and other stakeholders collaborated"
	(El Ansari, 2005)	"In this report, a community-based collaborative research partnership is a 'community-centred' participatory approach to research that equitably involves community members, agency representatives and researchers."

Real empowerment that enables societal transitions requires commitment from all societal actor groups including scientists, policy makers and civil society. The sustainability problems society currently faces are severe enough that scientists will continue to generate drastic results and facts calling for action. However, scientists should not restrict themselves to generating objective observations, but need to participate in the realization of a sustainable future (Fischer et al., 2012; Wiek et al., 2012). They should seize the initiative to act together with real-world practitioners and take the responsibility to tackle real-world problems with objective and reproducible methods. This engagement requires that both scientific institutions and societal actors need to acknowledge and promote such transdisciplinary research approaches. Current lacks in communication and political will, result in scientific and governance structures that adapt too slowly to the rapid changes in socio-ecological systems. If such transformative and collaborative research endeavours are not fostered, we run the risk that the potential of sustainability science will never be fully realized and urgent sustainability problems remain unsolved.

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Appendix 1

Textbox 1
Process phases

Participatory and transdisciplinary research have been divided into three phases (Jahn, 2008; Kruetli et al. 2006; Pohl and Hirsch Hadorn, 2008a). Recently, Lang et al. (2012) presented a conceptual three-phase model for an ideal-typical process of transdisciplinary research:

(i) Collaborative problem framing: identification and structuring of the real-world problem. Conceptualization of a methodological framework enabling the reintegration of knowledge.
(ii) Co-creation of solution-oriented and transferable knowledge: adoption and application of integrative scientific methods. Integrating different knowledge bodies by goal-oriented collaboration among different disciplines as well as between researchers and real-world actors.
(iii) Integration and application of produced knowledge: (re-)integration of results into societal and scientific practice.

While previous studies did not strictly incorporate these ideal–typical process phases into the set of analyzed categories, we opted for an altered version taking into account different degrees of practitioner involvement in examined case studies. In order to examine the intensity of involvement, as further analysis category, a much broader definition of process phases was necessary. According to Pohl and Hadorn (2008a) we therefore used: phase 1 — problem identification and structuring, phase 2 — problem analysis, and phase 3 — implementation and application of results.

Textbox 2
Knowledge types

There is considerable complexity regarding how transdisciplinary knowledge is acquired, what targets are derived based on this knowledge, and how these targets can be achieved. The different types of knowledge needed for transformation towards sustainable development can be divided into: (i), system knowledge (ii) target knowledge, and (iii) transformation knowledge (ProClim, 1997).

(i) System knowledge refers to the observation of the context of a given system and interpretation of the underlining drivers and buffers that causes and determine the extent of change. System knowledge therefore refers to the current state of a system and its ability to change. Understanding and interpreting the natural factors and social actors within the investigated system entities in order to produce target knowledge in the next step (Hirsch Hadorn et al., 2006).
(ii) Target knowledge refers to the scope of action and problem-solving measures given by the natural constraints, social laws, norms and values within the system, and the interests of actors and their individual intentions (Jahn, 2008). Therefore a comprehensive evaluation of desired target states, potential risks and benefits under prevailing uncertainties is needed. Thereby target knowledge determines the plausible system development (ProClim, 1997).
(iii) Transformation knowledge refers to the practical implications that can be derived from target knowledge to change existing habits, practices and institutional objectives. Transformation knowledge enables practitioners to evaluate different problem solving strategies and to achieve the competence to foster, implement, and monitor progress and to adapt and change behavioural attitudes (Hirsch Hardorn et al., 2006).

Effective transdisciplinary research relies on all knowledge types due to their mutual interdependencies. Even though some research projects might focus on one knowledge type assumptions from other knowledge types are potentially necessary (Pohl and Hirsch Hadorn, 2008a,b).

Textbox 3
Intensity of involvement

The category intensity of involvement includes four types: information (i), consultation (ii), collaboration (iii) and empowerment (iv) (Kruetli et al., 2010). The first two refer to one-way communication between academia and practice actors. “Information” (i) is restricted to participation which contains a limited degree of commitments and potential influencing power for the public. In addition to that “consultation” (ii) describes a one-directional information flow, from the practice actor to the academia mainly retained by e.g. questionnaires and interviews. “Collaboration”(iii) is used to describe higher levels of involvement in which the participants have notable influence on the process and the outcome (e.g. binding rules, competences). “Empowerment” (iv) presents the highest level of involvement in which the authority to decide has been given to the public or they are directly involved in the decision-making process at the collaboration level.

Appendix 2

We only included full articles covering original research written in English and excluded articles in the fields of medicine, engineering, psychology, computer science, arts and nursery. The access to some journals was limited thus 30 articles could not be included in the analysis of this review.

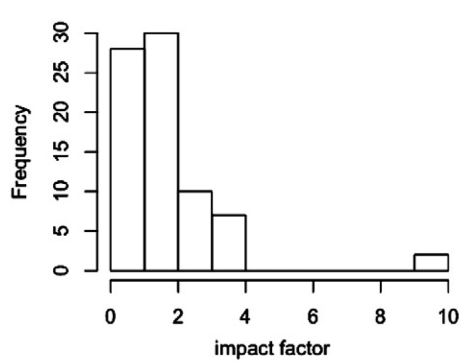
TITLE-ABS-KEY(transdisci* OR interdisci* OR "sustainability science" OR "mode 2" OR "postnormal" OR stakeholder* OR collaborat* OR participat* OR engagement*) AND (LIMIT-TO(DOCTYPE, "ar")) AND (EXCLUDE(SUBJAREA, "MEDI") OR EXCLUDE(SUBJAREA, "ENGI") OR EXCLUDE(SUBJAREA, "PSYC")) AND (LIMIT-TO(LANGUAGE, "English")) AND (EXCLUDE(SUBJAREA, "COMP") OR EXCLUDE(SUBJAREA, "ARTS")) AND (EXCLUDE(SUBJAREA, "NURS")) AND (LIMIT-TO(SUBJAREA, "ENVI") OR LIMIT-TO(SUBJAREA, "SOCI") OR LIMIT-TO(SUBJAREA, "AGRI") OR LIMIT-TO(SUBJAREA, "EART") OR LIMIT-TO(SUBJAREA, "BUSI") OR LIMIT-TO(SUBJAREA, "ECON") OR LIMIT-TO(SUBJAREA, "MULT")).

Appendix 3

Table: description of the review variables.

Variable	Field name	Description	Scaling
1	Paper type	Article is a case study (1), journal article which writes about the method (methodology approach) but doesn't apply it (2), framework conditions are explained but not applied (3), recommendation through argumentation (more transdisciplinary research) (4), journal article which recommend it in the conclusion but doesn't apply it (5)	1, 2, 3, 4, 5
2	Intensity of involvement (Kruetli et al., 2010)	1: Information, 2: consultation/ 3: collaboration/ 4: empowerment	1,2,3,4
3	Used_term	Paper uses the term "transdisciplinary research"	0,1
4	Discipline	Scientific discipline of authors	Text
5	Method_name	Used methods	Text
6	New_method	Introduced with paper	0;1
7	Morescientists_thanpractitioners	Number of authors/number of actors involved	0;1
8	Impact_factor	Impact factor of journal	Number
9	Country_of_origin	Country of authors origin	Text
10	Country_of_study	Country where the study took place	Text
11	Acknowledgement	Mentioned stakeholders	0;1
13	Number_of_tables	Number of tables	Number
14	Number_of_figures	Number of figures	Number
17	Method_type	Quantitative, qualitative, or both methods	0;1;2
18	Knowledge_type (Cass/ProClim, 1997: 15)	System: knowledge concerning the current situation of systems Target: develop knowledge concerning the target situation Transformation: shaping the transition from the current to the target situation	0;1
19	T_process_phases (Kruetli et al., 2010)	1: Problem framing 2: Analytical process/generation of transferable knowledge 3: Integration of results/bringing results into fruition	0;1

Appendix 4



Frequency distribution of impact factors journal in which the case study articles have been published. Note that not all journals had an impact factor when the articles were published (n = 77).

Appendix 5

Papers included in the review.

Authors	Title	Year
Adams K.T., Phillips P.S., Morris J.R.	A radical new development for sustainable waste management in the UK: the introduction of local authority Best Value legislation	2000
Adomssent M., Godemann J., Michelsen G.	Transferability of approaches to sustainable development at universities as a challenge	2007
Ahamed T., Khan M.I.N., Takigawa T., Koike M., Tasnim F., Zaman J.M.Q.	Resource management for sustainable development: a community- and GIS-based approach	2009
Alam M., Furukawa Y., Harada K.	Agroforestry as a sustainable land use option in degraded tropical forests: a study from Bangladesh	2010
Allison E.H., McBride R.J.	Educational reform for improved natural resource management: fisheries and aquaculture in Bangladeshi universities	2003
Andrews S.S., Flora C.B., Mitchell J.P., Karlen D.L.	Growers' perceptions and acceptance of soil quality indices	2003
Anton C., Young J., Harrison P.A., Musche M., Bela G., Feld C.K., Harrington R., Haslett J.R., Pataki G., Rounsevell M.D.A., Skourtos M., Sousa J.P., Sykes M.T., Tinch R., Vandewalle M., Watt A., Settele J.	Research needs for incorporating the ecosystem service approach into EU biodiversity conservation policy	2010
Armitage D.R.	Community-based Narwhal management in Nunavut, Canada: change, uncertainty, and adaptation	2005
Ashman D.	Civil society collaboration with business: bringing empowerment back in	2001
Aswani S., Lauer M.	Benthic mapping using local aerial photo interpretation and resident taxa inventories for designing marine protected areas	2006
Bacon C.M., Mulvaney D., Ball T.B., DuPuis E.M., Gliessman S.R., Lipschutz R.D., Shakouri A.	The creation of an integrated sustainability curriculum and student praxis projects	2011
Ball J.	Towards a methodology for mapping 'regions for sustainability' using PPGIS	2002
Baptista S.R.	Metropolitan land-change science: a framework for research on tropical and subtropical forest recovery in city-regions	2010
Barnaud C., Bousquet F., Trebuil G.	Multi-agent simulations to explore rules for rural credit in a highland farming community of Northern Thailand	2008
Barrington K., Ridler N., Chopin T., Robinson S., Robinson B.	Social aspects of the sustainability of integrated multi-trophic aquaculture	2010
Bebbington A.J., Bury J.T.	Institutional challenges for mining and sustainability in Peru	2009
Bethune S., Schachtschneider K.	How community action, science and common sense can work together to develop an alternative way to combat desertification	2004
Bezak P., Lyytimaki J.	Complexity of urban ecosystem services in the context of global change	2011
Bohnet I.C.	Integrating social and ecological knowledge for planning sustainable land- and sea-scapes: experiences from the Great Barrier Reef region, Australia	2010
Bouma J.	The role of soil science in the land use negotiation process	2001
Bouma J.	The new role of soil science in a network society	2001
Breukers S.C., Heiskanen E., Brohmann B., Mourik R.M., Feenstra C.F.J.	Connecting research to practice to improve energy demand-side management (DSM)	2011
Bruges M., Smith W.	Participatory approaches for sustainable agriculture: a contradiction in terms?	2008
Brunckhorst D.J.	Integration research for shaping sustainable regional landscapes	2005
Brundiers K., Wiek A.	Educating students in real-world sustainability research: vision and Implementation	2011
Buck B.H., Krause G., Michler-Cieluch T., Brenner M., Buchholz C.M., Busch J.A., Fisch R., Geisen M., Zielinski O.	Meeting the quest for spatial efficiency: progress and prospects of extensive aquaculture within offshore wind farms	2008
Burger J., Gochfeld M., Greenberg M.	Natural resource protection on buffer lands: integrating resource evaluation and economics	2008
Byron C., Bengtson D., Costa-Pierce B., Calanni J.	Integrating science into management: ecological carrying capacity of bivalve shellfish aquaculture	2011
Cabrera V.E., Breuer N.E., Hildebrand P.E.	Participatory modeling in dairy farm systems: a method for building consensual environmental sustainability using seasonal climate forecasts	2008
Caille F., Riera J.L., Rodriguez-Labajos B., Middelkoop H., Rosell-Mele A.	Participatory scenario development for integrated assessment of nutrient flows in a Catalan river catchment	2007
Cantrill J.G., Senecah S.L.	Using the 'sense of self-in-place' construct in the context of environmental policy-making and landscape planning	2001
Carpenter R.A.	Ecology should apply to ecosystem management: a comment	1996
Casagrande D.G., Hope D., Farley-Metzger E., Wook W., Yabiku S., Redman C.	Problem and opportunity: integrating anthropology, ecology, and policy through adaptive experimentation in the urban U.S. southwest	2007
Castles S.	Studying social transformation	2001
Chen X., Wu J.	Sustainable landscape architecture: implications of the Chinese philosophy of "unity of man with nature" and beyond	2009
Cockerill K., Daniel L., Malczynski L., Tidwell V.	A fresh look at a policy sciences methodology: collaborative modeling for more effective policy	2009
Cohen L., McAuley J., Duberley J.	Continuity in discontinuity: changing discourses of science in a market economy	2001
Cohen S.J.	Integrated regional assessment of global climatic change: lessons from the Mackenzie Basin Impact Study (MBIS)	1996
Corfee-Morlot J., Cochran I., Hallegatte S., Teasdale P.-J.	Multilevel risk governance and urban adaptation policy	2011
Cortner H.J.	Making science relevant to environmental policy	2000
Crivits M., Paredis E., Boulanger P.-M., Mutombo E.J.K., Bauler T., Lefin A.-L.	Scenarios based on sustainability discourses: constructing alternative consumption and consumer perspectives	2010
Cummins V., McKenna J.	The potential role of sustainability science in coastal zone management	2010
Dale A.	A perspective on the evolution of e-dialogues concerning interdisciplinary research on sustainable development in Canada	2005
Danby R.K., Hik D.S., Slocombe D.S., Williams A.	Science and the St Elias: an evolving framework for sustainability in North America's highest mountains	2003
Davis A., Hanson J.M., Watts H., MacPherson H.	Local ecological knowledge and marine fisheries research: the case of white hake (*Urophycis tenuis*) predation on juvenile American lobster (*Homarus americanus*)	2004
Day J.C., Gunton T.I., Frame T.M.	Toward environmental sustainability in British Columbia: the role of collaborative planning	2003
de Greef K.H., Vermeer H.M., Houwers H.W.J., Bos A.P.	Proof of principle of the comfort class concept in pigs. Experimenting in the midst of a stakeholder process on pig welfare.	2011

Appendix 5 (*continued*)

Authors	Title	Year
Decamps H.	Demanding more of landscape research (and researchers)	2000
Dennison W.C.	Environmental problem solving in coastal ecosystems: a paradigm shift to sustainability	2008
Diedrich A., Tintore J., Navines F.	Balancing science and society through establishing indicators for integrated coastal zone management in the Balearic Islands	2010
Dong S., Wen L., Zhu L., Li X.	Implication of coupled natural and human systems in sustainable rangeland ecosystem management in HKH region	2010
Dramstad W.E., Fjellstad W.J.	Landscapes: bridging the gaps between science, policy and people	2011
Duff G., Garnett D., Jacklyn P., Landsberg J., Ludwig J., Morrison J., Novelly P., Walker D., Whitehead P.	A collaborative design to adaptively manage for landscape sustainability in north Australia: lessons from a decade of cooperative research	2009
Dumreicher H.	Chinese villages and their sustainable future: the European Union-China-Research Project "SUCCESS"	2008
Eden S.	Lessons on the generation of usable science from an assessment of decision support practices	2011
Edwards S.E., Heinrich M.	Redressing cultural erosion and ecological decline in a far North Queensland aboriginal community (Australia): the Aurukun ethnobiology database project	2006
Eksvard K., Rydberg T.	Integrating participatory learning and action research and systems ecology: a potential for sustainable agriculture transitions	2010
El Ansari W.	Collaborative research partnerships with disadvantaged communities: challenges and potential solutions	2005
El-Zein A., Nasrallah R., Nuwayhid I.	Determinants of the willingness-to-participate in an environmental intervention in a Beirut neighborhood	2006
Ervin D.E., Glenna L.L., Jussaume R.A.	Are biotechnology and sustainable agriculture compatible?	2010
Evely A.C., Fazey I., Pinard M., Lambin X.	The influence of philosophical perspectives in integrative research: a conservation case study in the Cairngorms National Park	2008
Fabusoro E.	Use of collective action for land accessibility among settled Fulani agro-pastoralists in southwest Nigeria	2009
Falkenmark M.	Towards integrated catchment management: opening the paradigm locks between hydrology, ecology and policy-making	2004
Farley J., Batker D., De La Torre I., Hudspeth T.	Conserving mangrove ecosystems in the Philippines: transcending disciplinary and institutional borders	2010
Fernheimer J.W., Litterio L., Hendler J.	Transdisciplinary itexts and the future of web-scale collaboration	2011
Fidler C.	Increasing the sustainability of a resource development: aboriginal engagement and negotiated agreements	2010
Fitzgerald L.A., Stronza A.L.	Applied biodiversity science: bridging ecology, culture, and governance for effective conservation	2009
Frame B., Brown J.	Developing post-normal technologies for sustainability	2008
Fraser D.A., Gaydos J.K., Karlsen E., Rylko M.S.	Collaborative science, policy development and program implementation in the transboundary Georgia Basin/Puget sound ecosystem	2006
Garaway C.J., Arthur R.I., Chamsingh B., Homekingkeo P., Lorenzen K., Saengvilaikham B., Sidavong K.	A social science perspective on stock enhancement outcomes: lessons learned from inland fisheries in southern Lao PDR	2006
Gasparatos A., El-Haram M., Horner M.	The argument against a reductionist approach for measuring sustainable development performance and the need for methodological pluralism	2009
Gaulke L.S., Weiyang X., Scanlon A., Henck A., Hinckley T.	Evaluation criteria for implementation of a sustainable sanitation and wastewater treatment system at Jiuzhaigou National Park, Sichuan Province, China	2010
Gibbons M.	Transfer sciences: management of distributed knowledge production	1994
Giller K.E., Leeuwis C., Andersson J.A., Andriesse W., Brouwer A., Frost P., Hebinck P., Heitkonig I., Van Ittersum M.K., Koning N., Ruben R., Slingerland M., Udo H., Veldkamp T., Van de Vijver C., Van Wijk M.T., Windmeijer P.	Competing claims on natural resources: what role for science?	2008
Gottschick M.	Participatory sustainability impact assessment: scientific policy advice as a social learning process	2008
Greenaway A., Carswell F.	Climate change policy and practice in regional New Zealand: how are actors negotiating science and policy?	2009
Gupta J., Van Asselt H.	Helping operationalise Article 2: A TRANSdisciplinary methodological tool for evaluating when climate change is dangerous	2006
Gutrich J., Donovan D., Finucane M., Focht W., Hitzhusen F., Manopimoke S., McCauley D., Norton B., Sabatier P., Salzman J., Sasmitawidjaja V.	Science in the public process of ecosystem management: lessons from Hawaii, Southeast Asia, Africa and the US Mainland	2005
Haag F., Hajdu F.	Perspectives on local environmental security, exemplified by a rural South African village	2005
Hai L.T., Hai P.H., Dung T.A., Hens L.	Influencing factors on sustainable development: a case study in Quang Tri province, Vietnam	2010
Hall G.B., Moore A., Knight P., Hankey N.	The extraction and utilization of local and scientific geospatial knowledge within the Bluff oyster fishery, New Zealand	2009
Hart D.D., Calhoun A.J.K.	Rethinking the role of ecological research in the sustainable management of freshwater ecosystems	2010
He J., Zhou Z., Yang H., Xu J.	Integrative management of commercialized wild mushroom: a case study of Thelephora ganbajun in Yunnan, Southwest China	2011
Heimeriks G., van den Besselaar P., Frenken K.	Digital disciplinary differences: an analysis of computer-mediated science and 'Mode 2' knowledge production	2008
Hellstrom T., Jacob M., Wenneberg S.B.	The 'discipline' of post-academic science: Reconstructing the paradigmatic foundations of a virtual research institute	2003
Helmfrid H., Haden A., Ljung M.	The role of Action Research (AR) in environmental research: learning from a local organic food and farming research project	2008
Helming K., Diehl K., Bach H., Dilly O., Konig B., Kuhlman T., Perez-Soba M., Sieber S., Tabbush P., Tscherning K., Wascher D., Wiggering H.	Ex ante impact assessment of policies affecting land use, part A: analytical framework	2011
Helming K., Diehl K., Kuhlman T., Jansson T., Verburg P.H., Bakker M., Perez-Soba M., Jones L., Verkerk P.J., Tabbush P., Morris J.B., Drillet Z., Farrington J., LeMouel P., Zagame P., Stuczynski T., Siebielec G., Sieber S., Wiggering H.	Ex ante impact assessment of policies affecting Land use, part B: application of the analytical framework	2011
Heneghan L., Umek L., Bernau B., Grady K., Iatropulos J., Jabon D., Workman M.	Ecological research can augment restoration practice in urban areas degraded by invasive species-examples from Chicago Wilderness	2009
Hessels L.K., van Lente H.	Re-thinking new knowledge production: a literature review and a research agenda	2008
Hirschfeld J., Dehnhardt A., Dietrich J.	Socioeconomic analysis within an interdisciplinary spatial decision support system for an integrated management of the Werra River Basin	2005
Ho K.C., Hui K.C.C.	Chemical contamination of the East River (Dongjiang) and its implication on sustainable development in the Pearl River Delta	2001
Holden M.	Community interests and indicator system success	2009
Hosseini S.J.F., Niknami M., Hosseini Nejad G.H.	Policies affect the application of information and communication technologies by agricultural extension service	2009

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Appendix 5 (*continued*)

Authors	Title	Year
Huge J., Le Trinh H., Hai P.H., Kuilman J., Hens L.	Sustainability indicators for clean development mechanism projects in Vietnam	2010
Hurley L., Ashley R., Molyneux-Hodgson S., Moug P., Schiessel N.	"Measuring" sustainable living agendas	2010
Jakobsen C.H., McLaughlin W.J.	Communication in ecosystem management: a case study of cross-disciplinary integration in the assessment phase of the Interior Columbia Basin Ecosystem Management Project	2004
Jensen M.B., Persson B., Guldager S., Reeh U., Nilsson K.	Green structure and sustainability — developing a tool for local planning	2000
Johnson H., Wilson G.	Institutional sustainability: 'community' and waste management in Zimbabwe	2000
Johnston E., Soulsby C.	The role of science in environmental policy: an examination of the local context	2006
Jonsson A., Danielsson I., Joborn A.	Designing a multipurpose methodology for strategic environmental research: the Rönneå catchment dialogues	2005
Kajikawa Y., Inoue T., Goh T.N.	Analysis of building environment assessment frameworks and their implications for sustainability indicators	2011
Kara F., Demirci A.	Spatial analysis and facility characteristics of outdoor recreational areas in Istanbul	2010
Karjala M.K., Dewhurst S.M.	Including aboriginal issues in forest planning: a case study in central interior British Columbia, Canada	2003
Kassam K.-A.S.	Coupled socio-cultural and ecological systems at the margins: Arctic and alpine cases	2010
Kastenhofer K., Bechtold U., Wilfing H.	Sustaining sustainability science: the role of established inter-disciplines	2011
Kato S., Ahern J.	'Learning by doing': adaptive planning as a strategy to address uncertainty in planning	2008
Kaufmann A., Kasztler A.	Differences in publication and dissemination practices between disciplinary and transdisciplinary science and the consequences for research evaluation	2009
Keleman A., Uromi M.G., Dooley K.	Conservation and the agricultural frontier: collapsing conceptual boundaries	2010
Klepeis P., Laris P.	Contesting sustainable development in Tierra del Fuego	2006
Klintenberg P., Seely M.	Land degradation monitoring in Namibia: a first approximation	2004
Kluge T., Liehr S., Lux A., Moser P., Niemann S., Umlauf N., Urban W.	IWRM concept for the Cuvelai Basin in northern Namibia	2008
Koh L.P., Sodhi N.S.	Conserving Southeast Asia's imperiled biodiversity: scientific, management, and policy challenges	2010
Kreps G.L., Maibach E.W.	Transdisciplinary science: the nexus between communication and public health	2008
Kumpel N.F., Milner-Gulland E.J., Cowlishaw G., Rowcliffe J.M.	Incentives for hunting: the role of bushmeat in the household economy in rural equatorial guinea	2010
Larsen K., Gunnarsson-Ostling U.	Climate change scenarios and citizen-participation: mitigation and adaptation perspectives in constructing sustainable futures	2009
Larsen K., Gunnarsson-Ostling U.	Climate change scenarios and citizen-participation: mitigation and adaptation perspectives in constructing sustainable futures	2009
Larson K.L., White D.D., Gober P., Harlan S., Wutich A.	Divergent perspectives on water resource sustainability in a public-policy–science context	2009
Lavelle P.	Ecological challenges for soil science	2000
Leclerc G., Bah A., Barbier B., Boutinot L., Botta A., Dare W., Diop Gaye I., Fourage C., Magrin G., Soumare M.A., Toure I.	Managing tricky decentralised competencies: case study of a participatory modelling experiment on land use in the Lake Guiers area in Northern Senegal	2009
Lemos M.C., Morehouse B.J.	The co-production of science and policy in integrated climate assessments	2005
Lienert J., Monstadt J., Truffer B.	Future scenarios for a sustainable water sector: a case study from Switzerland	2006
Ling C., Hanna K., Dale A.	A template for integrated community sustainability planning	2009
Mabogunje A.L.	Tackling the African "poverty trap": the Ijebu–Ode experiment	2007
Macharia P.N.	Community based interventions as a strategy to combat desertification in the arid and semi-arid rangelands of Kajiado District, Kenya	2004
Manuel-Navarrete D., Slocombe S., Mitchell B.	Science for place-based socioecological management: Lessons from the Maya forest (Chiapas and PetÃ©n)	2006
Martinez-Santos P., Llamas M.R., Martinez-Alfaro P.E.	Vulnerability assessment of groundwater resources: a modelling-based approach to the Mancha Occidental aquifer, Spain	2008
Marttunen M., Hamalainen R.P.	The decision analysis interview approach in the collaborative management of a large regulated water course	2008
Mazouni N., Loubersac L., Rey-Valette H., Libourel T., Maurel P., Desconnets J.-C.	SYSCOLAG: a transdisciplinary and multi-stakeholder approach towards integrated coastal area management. An experiment in Languedoc–Roussillion (France)	2006
McCarthy N., Bentsen N.S., Willoughby I., Balandier P.	The state of forest vegetation management in Europe in the 21st century	2011
McIntyre-Mills J.	Participatory design for democracy and wellbeing: narrowing the gap between service outcomes and perceived needs	2010
Meppem T.	The discursive community: evolving institutional structures for planning sustainability	2000
Meppem T., Gill R.	Planning for sustainability as a learning concept	1998
Meul M., Passel S.V., Nevens F., Dessein J., Rogge E., Mulier A., Hauwermeiren A.V.	MOTIFS: a monitoring tool for integrated farm sustainability	2008
Miller K., Charles A., Barange M., Brander K., Gallucci V.F., Gasalla M.A., Khan A., Munro G., Murtugudde R., Ommer R.E., Perry R.I.	Climate change, uncertainty, and resilient fisheries: institutional responses through integrative science	2010
Mishra B.K., Badola R., Bhardwaj A.K.	Social issues and concerns in biodiversity conservation: Experiences from wildlife protected areas in India	2009
Moller H., O'B Lyver P., Bragg C., Newman J., Clucas R., Fletcher D., Kitson J., McKechnie S., Scott D.	Guidelines for cross-cultural participatory action research partnerships: a case study of a customary seabird harvest in New Zealand	2009
Morse W.C., Nielsen-Pincus M., Force J.E., Wulfhorst J.D.	Bridges and barriers to developing and conducting interdisciplinary graduate-student team research	2007
Muller D.B., Tjallingii S.P., Canters K.J.	A transdisciplinary learning approach to foster convergence of design, science and deliberation in Urban and regional planning	2005
Munoz-Erickson T.A., Aguilar-Gonzalez B., Loeser M.R.R., Sisk T.D.	A framework to evaluate ecological and social outcomes of collaborative management: lessons from implementation with a Northern Arizona collaborative group	2010
Nautiyal S.	Can conservation and development interventions in the Indian Central Himalaya ensure environmental sustainability? A socioecological evaluation	2011
Naveh Z.	Towards a sustainable future for Mediterranean biosphere landscapes in the global information society	2009
Naveh Z.	Epilogue: toward a transdisciplinary science of ecological and cultural landscape restoration	2005
Neuhauser L., Richardson D., Mackenzie S., Minkler M.	Advancing transdisciplinary and translational research practice: issues and models of doctoral education in public health	2007
Newig J., Haberl H., Pahl-Wostl C., Rothman D.S.	Formalised and non-formalised methods in resource management-knowledge and social learning in participatory processes: an introduction	2008
Niepold F., Herring D., McConville D.	The role of narrative and geospatial visualization in fostering climate literate citizens	2008
Oettle N., Arendse A., Koelle B., Van Der Poll A.	Community exchange and training in the Suid Bokkeveld: a UNCCD pilot project to enhance livelihoods and natural resource management	2004
O'Flaherty R.M., Davidson-Hunt I.J., Manseau M.	Indigenous knowledge and values in planning for sustainable forestry: Pikangikum first nation and the white feather forest initiative	2008

Appendix 5 (*continued*)

Authors	Title	Year
Olsson L., Jerneck A.	Farmers fighting climate change—from victims to agents in subsistence livelihoods	2010
Onuki M., Mino T.	Sustainability education and a new master's degree, the master of sustainability science: the Graduate Program in Sustainability Science (GPSS) at the University of Tokyo	2009
Oyono P.R., Kouna C., Mala W.	Benefits of forests in Cameroon. Global structure, issues involving access and decision-making hiccoughs	2005
Page S., Hoscilo A., Wosten H., Jauhiainen J., Silvius M., Rieley J., Ritzema H., Tansey K., Graham L., Vasander H., Limin S.	Restoration ecology of lowland tropical peatlands in Southeast Asia: current knowledge and future research directions	2009
Pahl-Wostl C.	The implications of complexity for integrated resources management	2007
Paige K., Lloyd D., Chartres M.	Moving towards transdisciplinarity: an ecological sustainable focus for science and mathematics pre-service education in the primary/middle years	2008
Partidario M.R., Sheate W.R., Bina O., Byron H., Augusto B.	Sustainability assessment for agriculture scenarios in Europe's mountain areas: lessons from six study areas	2009
Partington D.	Building grounded theories of management action	2000
Payne-Sturges D., Gee G.C., Crowder K., Hurley B.J., Lee C., Morello-Frosch R., Rosenbaum A., Schulz A., Wells C., Woodruff T., Zenick H.	Workshop summary: connecting social and environmental factors to measure and track environmental health disparities	2006
Payton R.W., Barr J.J.F., Martin A., Sillitoe P., Deckers J.F., Gowing J.W., Hatibu N., Naseem S.B., Tenywa M., Zuberi M.I.	Contrasting approaches to integrating indigenous knowledge about soils and scientific soil survey in East Africa and Bangladesh	2003
Pearson D.M., Gorman J.T.	Exploring the relevance of a landscape ecological paradigm for sustainable landscapes and livelihoods: a case-application from the Northern Territory Australia	2010
Pellant M., Abbey B., Karl S.	Restoring the Great Basin Desert, U.S.A.: integrating science, management, and people	2004
Pennington D.D.	Cross-disciplinary collaboration and learning	2008
Perz S.G., Brilhante S., Brown I.F., Michaelsen A.C., Mendoza E., Passos V., Pinedo R., Reyes J.F., Rojas D., Selaya G.	Crossing boundaries for environmental science and management: combining interdisciplinary, interorganizational and international collaboration	2010
Pesek T., Abramiuk M., Fini N., Rojas M.O., Collins S., Cal V., Sanchez P., Poveda L., Arnason J.	Q'eqchi' Maya healers' traditional knowledge in prioritizing conservation of medicinal plants: culturally relative conservation in sustaining traditional holistic health promotion	2009
Phil-Eze P.O., Okoro I.C.	Sustainable biodiversity conservation in the Niger Delta: a practical approach to conservation site selection	2009
Phillips C., Allen W., Fenemor A., Bowden B., Young R.	Integrated catchment management research: Lessons for interdisciplinary science from the Motueka Catchment, New Zealand	2010
Pohl C.	Transdisciplinary collaboration in environmental research	2005
Pohl C., Hadorn G.H.	Methodological challenges of transdisciplinary research	2008
Poudel D.D., Ferris H., Klonsky K., Horwath W.R., Scow K.M., Van Bruggen A.H.C., Lanini W.T., Mitchell J.P., Temple S.R.	The sustainable agriculture farming system project in California's Sacramento Valley	2001
Pretty J.	Interdisciplinary progress in approaches to address social–ecological and ecocultural systems	2011
Pretty J.N.	Participatory learning for sustainable agriculture	1995
Pulzl H., Rametsteiner E.	Indicator development as 'boundary spanning' between scientists and policy-makers	2009
Rametsteiner E., Pulzl H., Alkan-Olsson J., Frederiksen P.	Sustainability indicator development-science or political negotiation?	2011
Rarieya M., Fortun K.	Food security and seasonal climate information: Kenyan challenges	2010
Rasmussen B., Andersen P.D., Kristensen A.S.	Challenges in transdisciplinary technology foresight: cognition and robotics	2007
Rauschmayer F., van den Hove S., Koetz T.	Participation in EU biodiversity governance: how far beyond rhetoric?	2009
Ray A.J., Garfin G.M., Wilder M., Vasquez-Leon M., Lenart M., Comrie A.C.	Applications of monsoon research: opportunities to inform decision making and reduce regional vulnerability	2007
Reidsma P., Konig H., Feng S., Bezlepkina I., Nesheim I., Bonin M., Sghaier M., Purushothaman S., Sieber S., van Ittersum M.K., Brouwer F.	Methods and tools for integrated assessment of land use policies on sustainable development in developing countries	2011
Renting H., Rossing W.A.H., Groot J.C.J., Van der Ploeg J.D., Laurent C., Perraud D., Stobbelaar D.J., Van Ittersum M.K.	Exploring multifunctional agriculture. A review of conceptual approaches and prospects for an integrative transitional framework	2009
Reyers B., Roux D.J., Cowling R.M., Ginsburg A.E., Nel J.L., Farrell P.O.	Conservation planning as a transdisciplinary process	2010
Reyers B., Roux D.J., O'Farrell P.J.	Can ecosystem services lead ecology on a transdisciplinary pathway?	2010
Roberts A.M., Pannell D.J.	Piloting a systematic framework for public investment in regional natural resource management: dryland salinity in Australia	2009
Roling N.	Pathways for impact: scientists' different perspectives on agricultural innovation	2009
Roux D.J., Rogers K.H., Biggs H.C., Ashton P.J., Sergeant A.	Bridging the science-management divide: moving from unidirectional knowledge transfer to knowledge interfacing and sharing	2006
Rutherford M.B., Gibeau M.L., Clark S.G., Chamberlain E.C.	Interdisciplinary problem solving workshops for grizzly bear conservation in Banff National Park, Canada	2009
Saliba G., Jacobs K.	Saving the San Pedro River: science, collaboration, and water sustainability in Arizona	2008
Sall S., Norman D., Featherstone A.M.	Quantitative assessment of improved rice variety adoption: the farmer's perspective	2000
Salmi O.	Drivers for adopting environmental management systems in the post-Soviet mining industry	2008
Salo M., Pyhala A.	Exploring the gap between conservation science and protected area establishment in the Allpahuayo–Mishana National Reserve (Peruvian Amazonia)	2007
Scholz R.W., Mieg H.A., Oswald J.E.	Transdisciplinarity in groundwater management — towards mutual learning of science and society	2000
Schreider S.Yu., Mostovaia A.D.	Model sustainability in DSS design and scenario formulation: what are the right scenarios?	2001
Scott S.L.	Discovering what the people knew: the 1979 Appalachian land ownership study	2009
Seely M., Moser P.	Connecting community action and science to combat desertification: evaluation of a process	2004
Serrat-Capdevila A., Browning-Aiken A., Lansey K., Finan T., Valdes J.B.	Increasing social–ecological resilience by placing science at the decision table: the role of the San Pedro Basin (Arizona) decision-support system model	2009
Sessa C., Ricci A.	Working with and for the citizens	2010
Shannon L.J., Jarre A.C., Petersen S.L.	Developing a science base for implementation of the ecosystem approach to fisheries in South Africa	2010
Sheate W.R., Partidario M.R.D., Byron H., Bina O., Dagg S.	Sustainability assessment of future scenarios: methodology and application to mountain areas of Europe	2008
Sherren K., Fischer J., Clayton H., Schirmer J., Dovers S.	Integration by case, place and process: transdisciplinary research for sustainable grazing in the Lachlan River catchment, Australia	2010
Simpson A., Jarnevich C., Madsen J., Westbrooks R., Fournier C., Mehrhoff L., Browne M., Graham J., Sellers E.	Invasive species information networks: collaboration at multiple scales for prevention, early detection, and rapid response to invasive alien species	2009
Spink A., Hillman M., Fryirs K., Brierley G., Lloyd K.	Has river rehabilitation begun? Social perspectives from the Upper Hunter catchment, New South Wales, Australia	2010
Stamieszkin K., Wielgus J., Gerber L.R.	Management of a marine protected area for sustainability and conflict resolution: lessons from Loreto Bay National Park (Baja California Sur, Mexico)	2009
Stauffacher M., Flueler T., Krutli P., Scholz R.W.	Analytic and dynamic approach to collaboration: a transdisciplinary case study on sustainable landscape development in a Swiss prealpine region	2008

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Authors	Title	Year
Stead S.M., Burnell G., Goulletquer P.	Aquaculture and its role in Integrated Coastal Zone Management	2002
Steingrover E.G., Geertsema W., van Wingerden W.K.R.E.	Designing agricultural landscapes for natural pest control: a transdisciplinary approach in the Hoeksche Waard (The Netherlands)	2010
Stilma E.S.C., Vosman B., Korevaar H., Poel-Van Rijswijk M.M., Smit A.B., Struik P.C.	Designing biodiverse arable production systems for the Netherlands by involving various stakeholders	2007
Sturtevant B.R., Fall A., Kneeshaw D.D., Simon N.P.P., Papaik M.J., Berninger K., Doyon F., Morgan D.G., Messier C.	A toolkit modeling approach for sustainable forest management planning: achieving balance between science and local needs	2007
Stuth J.W.	Harry Stobbs Memorial Lecture, 1995. Managing grazing lands: critical information infrastructures and knowledge requirements for the future	1996
Sulser T.B., Duryea M.L., Frolich L.M., Guevara-Cuaspud E.	A field practical approach for assessing biophysical sustainability of alternative agricultural systems	2001
Sunderland T., Sunderland-Groves J., Shanley P., Campbell B.	Bridging the gap: how can information access and exchange between conservation biologists and field practitioners be improved for better conservation outcomes?	2009
Svejcar T., Havstad K.	Improving field-based experimental research to compliment contemporary management	2009
Termorshuizen J.W., Opdam P.	Landscape services as a bridge between landscape ecology and sustainable development	2009
Thering S.	A methodology for evaluating transdisciplinary collaborations with diversity in mind: an example from the green community development in Indian country initiative	2009
Thompson Klein J.	Prospects for transdisciplinarity	2004
Tippett J.	"Think like an ecosystem"—embedding a living system paradigm into participatory planning	2004
Totlandsdal A.I., Fudge N., Sanderson E.G., van Bree L., Brunekreef B.	Strengthening the science–policy interface: experiences from a European Thematic Network on Air Pollution and Health (AIRNET)	2007
Tress B., Tress G.	Scenario visualisation for participatory landscape planning — a study from Denmark	2003
Tress B., Tress G., Fry G.	Researchers' experiences, positive and negative, in integrative landscape projects	2005
van Assche J., Block T., Reynaert H.	Can community indicators live up to their expectations? The case of the Flemish city monitor for livable and sustainable urban development	2010
Van De Kerkhof M., Leroy P.	Recent environmental research in the Netherlands: towards post-normal science?	2000
VanWynsberghe R., Moore J., Tansey J., Carmichael J.	Towards community engagement: six steps to expert learning for future scenario development	2003
Veron R.	The "new" Kerala model: lessons for sustainable development	2001
Walz A., Lardelli C., Behrendt H., Gret-Regamey A., Lundstrom C., Kytzia S., Bebi P.	Participatory scenario analysis for integrated regional modelling	2007
Weber E.P., Memon A., Painter B.	Science, society, and water resources in New Zealand: recognizing and overcoming a societal impasse	2011
Welp M., de la Vega-Leinert A., Stoll-Kleemann S., Jaeger C.C.	Science-based stakeholder dialogues: theories and tools	2006
White P.C.L., Cinderby S., Raffaelli D., de Bruin A., Holt A., Huby M.	Enhancing the effectiveness of policy—relevant integrative research in rural areas	2009
White P.C.L., Ward A.I.	Interdisciplinary approaches for the management of existing and emerging human–wildlife conflicts	2010
Wickham J.	Something new in old Europe? Innovations in EU-funded social research	2004
Wiek A., Zemp S., Siegrist M., Walter A.I.	Sustainable governance of emerging technologies—critical constellations in the agent network of nanotechnology	2007
Wienhold B.J., Power J.F., Doran J.W.	Agricultural accomplishments and impending concerns	2000
Williams A., Holden B., Krebs P., Muhajarine N., Waygood K., Randall J., Spence C.	Knowledge translation strategies in a community–university partnership: examining local Quality of Life (QoL)	2008
Witcomb M., Dorward P.	An assessment of the benefits and limitations of the shamba agroforestry system in Kenya and of management and policy requirements for its successful and sustainable reintroduction	2009
Wolfe B.B., Armitage D., Wesche S., Brock B.E., Sokal M.A., Clogg-Wright K.P., Mongeon C.L., Adam M.E., Hall R.I., Edwards T.W.D.	From isotopes to TK interviews: towards INTERDISciplinary research in Fort Resolution and the Slave River Delta, Northwest Territories	2007
Wood S., Geldart A., Jones R.	Crystallizing the nanotechnology debate	2008
Yarnal B.	Integrated regional assessment and climate change impacts in river basins	1999
Yuan W., James P., Hodgson K., Hutchinson S.M., Shi C.	Development of sustainability indicators by communities in China: a case study of Chongming County, Shanghai	2003
Zemp S., Stauffacher M., Lang D.J., Scholz R.W.	Generic functions of railway stations—a conceptual basis for the development of common system understanding and assessment criteria	2011
Ziegelmayer K., Clark T.W., Nyce C.	Biodiversity and watershed management in the Condor Bioreserve, Ecuador: an analysis and recommendations	2004

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