TRANSDICIPLINARY RESEARCH (TDR) AND SUSTAINABILITY

Overview report prepared for the
Ministry of Research, Science and Technology (MoRST)

By

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TRANSDICIPLINARY RESEARCH (TDR) AND SUSTAINABILITY

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"The world has problems, but universities have departments."[1]

[1] Brewer, G.D. (1999) *The Challenges of Interdisciplinarity*. Pol Sci 32, 327-337

1. INTRODUCTION

Starting in mid 2007, the Ministry of Research, Science and Technology (MoRST) initiated a project on ‘sustainability science’ in order to identify trends in sustainable development and implications for future science and research in New Zealand. This has highlighted the growing importance of transdisciplinary research (TDR).

Transdisciplinary research is a new field of research emerging in the ‘knowledge society’, which links science and policy to address issues such as environmental degradation, new technologies, public health and social change. Through transdisciplinary approaches, researchers from a wide range of disciplines work with each other and external stakeholders to address real world issues (Hadorn et al, 2008).

MoRST has commissioned a brief investigation into the emergence of TDR, including theoretical and practical developments internationally and in New Zealand, and its potential to contribute to sustainability outcomes.

This report provides a brief overview, focused on the following questions:

- What is TDR?
- How is it defined?
- What are the characteristics of TDR and how is it practised?
- How does TDR relate to sustainability – and what are the implications for ‘sustainability science’?
- What is happening in the TDR field internationally and how has this been measured?
- What is happening in NZ, and has it been measured?
- What are the key barriers and opportunities in TDR?
- How can the potential of TDR be taken further in New Zealand in relation to sustainability?

2. DEFINING TRANSDISCIPLINARY RESEARCH (TDR)

2.1 The emergence of Transdisciplinary Research

"In a world characterised by rapid change, uncertainty and increasing interconnectedness, there is a growing need for science to contribute to the solution of persistent, complex problems" (Hadorn et al, 2008: vii).

An early call for 'Transdisciplinary Research' can be found in the report of an international conference on education sponsored by the OECD in 1970. The linear structure of universities was seen as emphasising 'one track' careers and failing to serve the needs of society: interdisciplinary linkages were needed along with greater self-renewal and judgement to respond to complex and dynamically changing situations in society at large (Klein, 2008: 399).

Transdisciplinary Research (TDR) is now a well established and expanding field of science. It is an approach in which researchers from a wide range disciplines work together with stakeholders. TDR aims to overcome the gap between knowledge production on the one hand and the demand for knowledge to contribute to the solution of social problems, on the other.

In a recent publication, Hadorn et al (2008) trace the emergence of transdisciplinary thinking in the context of the history of science. Starting in antiquity, the development of Western Science was originally based on a strict dissociation of scientific knowledge from practical knowledge. This distinction gave rise to the ideal that scientific knowledge is universal, explanatory and demonstrated to be true by a standard method. The Enlightenment saw the separation of the natural sciences from philosophy, followed in the 19th century by the establishment of the humanities and the social sciences as separate disciplines in universities. Science in the modern period was concerned with empirical laws and carried out by intervening in nature through technically equipped experiments. There was a separation between the branches of knowledge production - and between the creation of scientific knowledge in the technical world, and its consequences in the 'life world'.

In the industrial age, science-based technological innovation supported the expansion of industry and the production of commercial goods, and led to the view that progress in society depended on progress in science. The large scale application of scientific knowledge has had both beneficial and harmful consequences. Increasingly, there is an expectation that the drivers and impacts of modern science and technology are understood in a wider social and environmental context. This has led to a demand for new forms of research and science to understand and mitigate the effects of some earlier innovations - and also to stimulate the development of 'sustainable' science and technology.

In order to define and understand what is meant by 'transdisciplinary research' it is useful first to consider other forms of knowledge production.

2.2 Disciplinary Research

Disciplines are constituted by defined academic research methods and objects of study. They include frames of reference, methodological approaches, topics, theoretical canons and technologies. Disciplines can also be seen as ‘sub cultures’ with their own language, concepts, tools and credentialed practitioners (Petts et al, 2008: 596).

2.3 Multidisciplinary Research

Multidisciplinary research occurs when a range of different disciplines are assembled for a research task.

Different disciplines come together (typically to deal with a real world problem) but with each group working primarily in its own framings and methods. The disciplines co-exist in a specific context while retaining their own boundaries and identities (Petts et al, 2008: 596). This is a research approach that juxtaposes rather than combines separate disciplinary perspectives, adding a breadth of knowledge, information and methods. Work is done independently following separate perspectives (Klein, 2007:37).

2.4 Interdisciplinary Research

The term ‘interdisciplinary research’ refers to a range of approaches from the simple communication of ideas to mutual integration of organising concepts, methodology, epistemology etc (OECD,1972 cited in Klein 2007: 37). Rather than disciplines operating in parallel, it involves a synthesis of knowledge, in which understandings change in response to the perspectives of others. The aim is to seek coherence between the knowledges produced by different disciplines (Petts et al, 2008: 596).

The US National Academy of Sciences defines interdisciplinarity as “a mode of research that integrates information, data, techniques tools perspectives, concepts and/or theories from two or more disciplines or bodies of specialised knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice” (US National Academy of Sciences, 2004:2).

Klein (2007) notes that the aim of such integrated research is to create a holistic view or a common understanding of a complex issue. She distinguishes between ‘narrow interdisciplinarity’ i.e. between disciplines with compatible methods and paradigms (e.g. history and literature); and ‘wide interdisciplinarity’ i.e. between disciplines with little compatibility (e.g. sciences and humanities). Interdisciplinary research may include bridge-building between complete and firm disciplines, or restructuring where parts of disciplines are detached to form a new coherent whole (Klein, 2007:37-38).

2.5 Transdisciplinary research

Going a step further, we can understand ‘transdisciplinary’ research (TDR) as a practice that transcends the narrow scope of disciplinary views. It challenges existing boundaries

and ‘redraws the map’. TDR leads to the evolution of disciplines, hybridisation and outcomes that are greater than the sum of the parts (Petts et al, 2008: 597). It not only integrates across disciplines but includes a set of approaches that can generate new, comprehensive knowledge and an overarching synthesis (Klein, 2007).
TDR is aimed at understanding complex issues. Key examples of research processes that deal with complexity include general systems theory, structuralism, policy sciences, socio biology, and feminist theory (Klein, 2007:41,42).

It also includes a focus on real world problems, through collaborative work involving academic and non academic stakeholders. Transdisciplinary research is therefore “driven by problem solving and integrates perspectives from public agencies, the private sector and civil society in the research process” (Swiss Academy of Sciences, 2008).

2.6 Summary of definitions

Reviewing the various approaches in this field, Tress et al (2006) provide the following summary of definitions:

- **Disciplinary** studies: projects that take place within the bounds of a single, currently recognized academic discipline.

- **Multidisciplinary** studies: several different academic disciplines researching one theme or problem but with multiple disciplinary goals. Participants exchange knowledge, but do not aim to cross subject boundaries to create new knowledge and theory. The research process progresses as parallel disciplinary efforts without integration but usually with the aim to compare results.

- **Participatory** studies: academic researchers and non-academic participants working together to solve a problem. The participants exchange knowledge, but the focus is not on the integration of the different knowledge cultures to create new knowledge.

- **Interdisciplinary** studies: several unrelated[2] academic disciplines [involved] in a way that forces them to cross subject boundaries to create new knowledge and theory and solve a common research goal.

- **Transdisciplinary** studies: projects that both integrate academic researchers from different unrelated disciplines and non-academic participants, such as land managers and the public, to research a common goal and create new knowledge and theory. Transdisciplinarity combines interdisciplinarity with a participatory approach.

[2] By ‘unrelated’, Tress et al mean that they have contrasting research paradigms e.g. the differences between qualitative and quantitative approaches or between analytical and interpretative approaches that bring together disciplines from the humanities and the natural sciences.

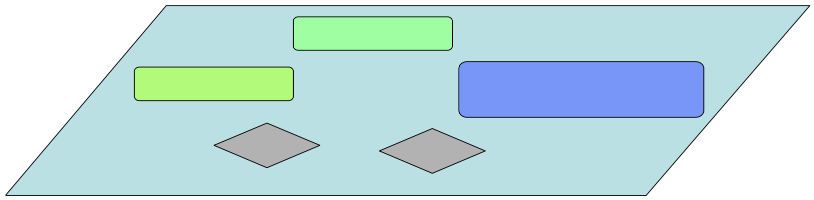
- **Integrative** studies: either interdisciplinary or transdisciplinary, in that new knowledge and theory emerges from the *integration* of disciplinary knowledge. Different knowledge cultures are bridged and fused together when answering a research question.

2.7 Graphic representation of TDR and related research approaches.

Further to the definitions above, the following diagrams illustrate the distinctions between different sorts of knowledge production.

Multidisciplinary research can be seen as an assemblage of different disciplines in a defined research setting, illustrated as follows:

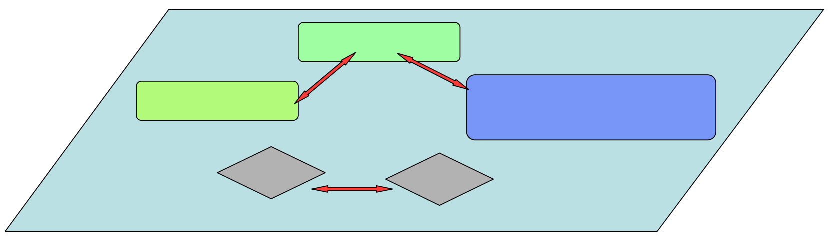
Figure 1 Multi Disciplinary Research



Multi Disciplinary Research

Interdisciplinary research involves connections being made across disciplinary boundaries:

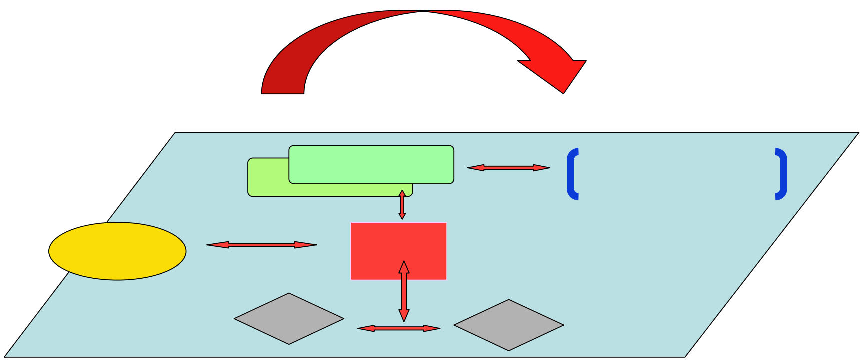
Figure 2 Inter Disciplinary Research



Inter Disciplinary Research

Transdisciplinary research involves a range of approaches that may see the breaking down of disciplinary boundaries, the merging of existing disciplines and the introduction of non-disciplinary knowledge from external stakeholders. It also holds the potential to create a new knowledge frameworks and an overarching synthesis from the diverse perspectives in the research setting.

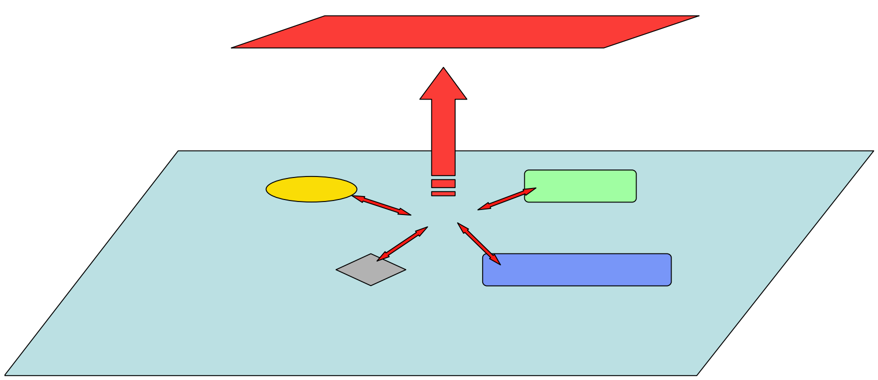
Figure 3 Trans Disciplinary Research #1



Trans Disciplinary Research #1

This, in turn may lead to a 'transcendent' process of knowledge production (Klein, 2007), creating a whole new plane of understanding and knowledge, beyond the interactions among current knowledge bases:

Figure 4 Trans Disciplinary (transcendent) Research #2



Trans Disciplinary (transcendent)
Research #2

3. CHARACTERISTICS OF TRANSDISCIPLINARY RESEARCH

"We are not students of some subject matter, but students of problems. And problems may cut right across the boundaries of any subject matter or discipline" Karl Popper. [3]

The characteristics of transdisciplinary research (TDR) can be understood, first, by considering it as an extension of interdisciplinary research. Describing the growth in interdisciplinarity, the US National Academy of Science (2004:2) observes that as a mode of discovery it has delivered much and already promises a lot more. Many of the great research triumphs of the past are products of interdisciplinary enquiry and collaboration including: discovery of the structure of DNA, magnetic resonance imaging, the Manhattan Project, laser eye surgery, radar, human genome sequencing, the 'green revolution' and manned space flight. Today, many 'hot topics' are interdisciplinary and of strong interest to students and researchers alike, including: nantotechnology, genomics, proteomics, neuroscience, and conflict resolution (op cit: 17).

The Academy notes that this form of research has resulted from four powerful drivers: the inherent complexity of nature and society; the desire to explore problems and questions not confined to a single discipline; the need to solve societal problems; and the power of new technologies. In recent decades the growth of scientific knowledge has prompted scientists, engineers, social scientists and humanists to join in addressing complex problems that must be attacked simultaneously with deep knowledge from different perspectives. Priority social issues today include world hunger, biomedical ethics, sustainable resources, security, child development, along with pressing research questions such as the evolution of virulence in pathogens and the relationship between biodiversity and ecosystem function (op cit: 26).

Communication is at the heart of interdisciplinarity: "the conversations, connections, and combinations that bring new insights to virtually every kind of scientist and engineer" (p. 19). There is no doubt about the productivity and effectiveness of interdisciplinary research. For individual scientists, the exposure to ideas outside one's own discipline can have a positive impact on research: "prolific and influential researchers are more likely to keep up with developments outside their own domains, and this interdisciplinary curiosity can lead to major breakthroughs on their own projects" (op cit: 18).

The Academy concludes that interdisciplinarity is not merely a concept that is philosophically attractive or that serves the special interests of a few neglected fields:

> It has been vital since the creation of our great universities – and critical during times of national emergency. It has led to major new industries and opened up the world to the creation of wealth, to international collaboration, and to enhanced technology and scientific exchange. To hinder this activity is to diminish our ability to address the great questions of science and to hesitate before the scientific and societal challenges of our time (op cit: 24-25).

[3] Popper, K. R. (1963) Conjectures and Refutations: the Growth of Scientific Knowledge. New York. Routledge and Kegan Paul. P.88

TDR includes these key components of interdisciplinarity, along with the incorporation of external non-academic knowledge, applied to solve practical problems.
TDR is usually applied to complex problems where there are uncertainties in technical knowledge, and a range of actors and interests involved. It succeeds by building joint visions of the issue of concern, finding a common language, jointly discussing trade-offs of particular choices and through collaborative learning (Jager, J. in Hadorn et al, 2008: viii). It is pluralistic in methods and focus. It may be conducted by individuals or groups and driven by a mix of goals including scientific curiosity, societal values and practical needs.

Hadorn et al (2008: 32-5) make a distinction between basic, applied and transdisciplinary research. Basic research occurs in the context of a generally accepted set of valid principles within a discipline. "Members of a discipline share examples of good quality problems and solutions, concepts, methods and standards for research, using institutions journals textbooks and educational programmes" (op cit: 33). These elements constitute the paradigm of the discipline (Kuhn, 1963). To arrive at theoretical explanations in basic research, problems are investigated under standardised conditions, an idealisation of what happens in real world settings. This requires the exclusion of factors that may be addressed by other disciplines. For example, a basic research focus on human disease in molecular biology would not consider issues such as cultural practices or economic conditions that might contribute to the cause of the disease. Thus basic research advances the state of the art knowledge in the discipline but not the knowledge requirements for dealing with the problem in its real world setting.

In an applied setting the focus is on how the problem occurs in the 'problem field'. Applied research describes and explains the variable process involved and develops specific measures and support for the actors concerned. A range of basic research findings might be applied, including interdisciplinary knowledge along with the knowledge and interests of different actors i.e. those affected by the problem, with influence on the situation, or whose interests are involved. To extend the example above, molecular biology and economics might be applied to a certain disease, to develop a drug that could be produced by a pharmaceutical firm. Applied knowledge is often funded by the private sector or public agencies searching for knowledge to improve their ability to manage issues in the lifeworld (p. 34).

It is important to stress that not all forms of research are expected to be interdisciplinary or transdisciplinary. Basic and applied research is essential to knowledge production and will continue to be needed. Indeed, even within TDR, expertise in specific disciplines and in basic research is a vital component – specialist knowledge in one field is complementary to other fields and essential to the generation of new knowledge. Nevertheless, the evolution of scientific disciplines, the challenge and implications of new research methods and technologies, and the changing social context of research, science and technology are increasingly generative of TDR.

TDR has arisen partly in response to the effects of increasing academic specialisation. The pursuit of research within university departments has given rise to thematic fields

with fuzzy and shifting boundaries. Incentives in academia result in what has been called the ‘ethnocentrism of disciplines’ (Campbell, 1969). Concepts in basic research are becoming ever more sophisticated, leading to a high degree of fragmentation of scientific knowledge (Hadorn et al, op cit: 4). This differentiation becomes a risk for modern civilisation as specialisation can inhibit cross-fertilisation and innovation, prevent the recognition of possible negative side effects, and may inhibit the achievement of common social values in the education- innovation system (p. 24).
At the same time, serious problems such as poverty, sickness, crime and environmental degradation demand new knowledge, and a new commitment from science in its social contract with society. This is generating a demand for new research capacity and institutional responsiveness, and creating new frontiers in the conception and practice of science itself.

Across all research fields, an external orientation for science is becoming more important, rather than “putting forward endless, internal scientific frontiers” (p. 27). In the modern knowledge society, disciplines are developing applied, problem-solving capacities, and new approaches beyond their traditional cognitive domain. In the context of sustainability, science is not only a resource but an agent of change. Society is absorbing scientific knowledge about the state of the biophysical and social system, while looking to science for new solutions and innovation.

Increasingly however, the complexity of modern problems means that technical, scientific knowledge on its own will not be enough to support decision-making. The paradigm of normal science is often inadequate to deal with situations of high uncertainty and where there are significant values, and thus high political stakes. Funtowicz and Ravetz (1993) developed the concept of ‘post normal’ science to describe situations where routine scientific and professional knowledge is insufficient to address complex policy issues. This recognises that in many circumstances, science cannot delivery certainty, nor is it free from values, personal judgements or institutional agendas (Funtwicz and Ravetz, 2008:364). For many policy issues, the facts may be incomplete or inconclusive. The selection of issues will depend on the framing of the problem itself – which is often a matter of politics. This, in turn, creates the need for dialogue between scientists and other stakeholders, which recognises the special knowledge that scientists hold of technical matters but also gives voice to other perspectives and forms of knowledge. People with local and practical knowledge can offer new information to complement experts trained in a standard doctrine. In such cases, science must engage with others who have a stake in the decision, creating a process of ‘extended peer review’ (Funtwicz and Ravetz, 2008:363-4).

With TDR, researchers and actors in the lifeworld jointly work on identifying and understanding the nature of the problem, framing the issues involved, establishing future preferences, and designing action. Through scientists entering into dialogue and mutual learning with societal stakeholders, science becomes part of societal processes. This has been described as a move towards ‘socially robust knowledge’ (Nowotny, 1999).

Transdisciplinary research can also be understood in relation to the concept of Mode 1 and Mode 2 science. Gibbons et al (1994) contrasted Mode 1 knowledge production (the Newtonian model of objective, discipline-based science) with Mode 2 knowledge production which has features of transdisciplinarity, heterogeneity, reflectivity and social accountability (Hardon et al, 2008: 25). An important feature of Mode 2 science is the relationship with the context of knowledge production and end users. Collaborative research that crosses disciplinary boundaries and involves academic participants can stimulate new scientific knowledge and support the successful application of knowledge (Hollaender et al, 2008: 388).

Others have suggested that transdisciplinary research is a new form of intellectual endeavour, conceiving of it as a 'theoretical unity of all knowledge' needed to respond to problems in the lifeworld. This characteristic of TDR can be traced back over the centuries where, at various points, scholars have sought to create a unified social science (Klein, 2007: 32). In the 20th century, various intellectual syntheses emerged. In 1972, for example, Jantsch used the term 'transdisciplinary' to refer to a systems theory approach for the integration of knowledge to grasp the complexities of the modern world at a purpose oriented level. Systems theory led to a range of TD schools including human ecology, 'man and the biosphere', 'ecological economics' and 'socio-ecological research' (Hadorn et al, 2008: 29).

In summary, there are four core characteristics evident in the literature on TDR: a focus on lifeworld problems; transcending and integrating disciplinary paradigms; participatory research; and the search for a unity of knowledge beyond disciplines. Hadorn et al (2008) conclude that TDR is itself an evolving and 'fuzzy' field: currently there is wide agreement on the first two characteristics and less on the latter. Accordingly, Pohl and Hadorn (2007) offer a broad conception of TDR as follows:

There is a need for transdisciplinary research (TR) when knowledge about a societally relevant problem field is uncertain, when the concrete nature of problems is disputed, and when there is a great deal at stake for those concerned by problems and involved in dealing with them. TR deals with problem fields in such a say that it can: a) grasp the complexity of problems, b) take into account the diversity of life world and scientific perceptions of problems, c) link abstract and case specific knowledge and d) constitute knowledge and practices that promote what is conceived to be the common good.

4. THE PROCESS OF TDR

Hadorn et al (2008: 30-31) specify that TDR involves three types of knowledge:

- *System knowledge* is knowledge about the current system or problem situation. This recognises that there may be uncertainties about the genesis of the problem, along with different interpretations depending on the goals of participants.
- *Target knowledge* is about the desired future status. This recognises the pluralism of norms and values that may be present, depending on actors' perceptions of the system, system relations and options for change.
- *Transformation knowledge* is about how to make the transition to the target status. This includes technical, social, legal, cultural, institutional and other changes.

Each of these elements is addressed in relation to the other e.g. research questions about 'target knowledge' are examined on the basis of assumptions about systems relations and with a view to finding specific options to transform existing practices.
TDR includes approaches for dealing with the challenges in the research process. Uncertainties in technical knowledge may be reduced through real world experiments. Multiple interests and attitudes of stakeholders may be met by clarifying the variety of positions, ensuring effective deliberation and referring to the common good. Transformational change may require flexibility in existing infrastructure, laws and also within social power structures and personal opinions. This requires enhancing the capacity for individual and social learning (p.32).

While these elements are mutually interactive, Pohl and Hadorn (2007: 42) suggest that TDR involves three key steps:

1. Problem identification and structuring: taking into account the current state of disciplinary knowledge and among social actors, to define the problem, identify important aspects, and determine the research question and who should be involved.
2. Problem analysis: determining what forms of collaboration and organisation are needed to take into account different interests and circumstances
3. Bringing results to fruition: embedding the project into social and scientific contexts; testing the expected impact.

These phases of the research may require adjustment and iteration, so that researchers and other actors can collaborate to achieve recurrent validation and adaptation of empirical models in concrete situations; ongoing deliberation about goals; and recurrent monitoring of experiments and effects to adapt concepts and transformation strategies (p. 36).

The development of TDR capacity in universities has attracted increasing attention. The US National Academy of Sciences report (2004) concluded that it involves students crossing boundaries between disciplines and taking a broad range of courses, while developing a solid background in one discipline. In most visions of TD education, disciplines do not disappear; rather there is a cultivation of disciplinary depth, multidisciplinary breadth, and interdisciplinary integration (Klein, 2008: 406).

TDR involves a capacity to ability to articulate knowledge in one's own discipline, compare different approaches, generate a synthesis and use an integrated framework to develop a more holistic understanding of a question or problem. Key skills include the ability to communicate across boundaries and with external stakeholders and to develop a basked of options. Methods may include modelling, scenario analysis, systems approaches, integrated risk assessment, group facilitation and participatory models for joint decision-making, including collaboration and negotiation (op cit: 407). The underlying theme is cognitive flexibility – a willingness to see beyond one's own discipline (p. 408).

5. TDR AND SUSTAINABILITY

Following key initiatives such as the Stockholm UN Conference on the Human Environment in 1972[4], and the UNESCO 'Man and the Biosphere' programme in the 1970's, there is now a substantial international consensus about the impacts of interactions between human societies and the environment. It is now well understood that the Earth is "a single system, within which the biosphere is an active and essential component." Furthermore, "human activities are now so pervasive and profound in their consequences that they affect the Earth at a global scale, in complex, interactive and accelerating ways; humans now have the capacity to alter the Earth system in ways that threaten the very processes and components… upon which humans depend" (Steffen, et al, 2004:2).

Sustainable Development is a late 20th century development paradigm given significant momentum by the report of the World Commission on Environment and Development (1987) and at the UN Conference on Development in Rio de Janiero in 1992. It has been defined as:

> A global socio-political model for changing practices and institutions in order to achieve more equitable opportunities within and between generations while taking into account the limitations imposed by the state of technology and social organisation on the environment's ability to meet present and future needs (World Commission on Environment and Development, 1990).

The sustainability concept aims at overcoming the separation between the society world and the biophysical environment, and between the ecological, social and economic dimensions of development. Achieving sustainable development requires the involvement of diverse areas of expertise and of wide stakeholder interests, including participants from civil society, the private sector and public agencies.

Most decisions about the environment involve scientific information about the biophysical system, along with human values and beliefs. Thus to understand current issues or to predict sustainability outcomes requires "an identification of the characteristics of resilient systems and it needs dynamical relationships between knowledge production, policy formulation and decision-making" (Wasson and Unerdal, 2002).

Sustainability inherently involves the TDR practices of identifying system knowledge, target knowledge and transformational knowledge. The management of sustainability is itself now an important and growing research field, reflective of TDR principles and practices e.g. sustainability research is seen as a social process involving natural and social science disciplines, and experts and non experts, and cooperation across institutions (Hollaender et al, 2008: 388).

Many of the most complex and challenging issues in areas such as water, energy and waste management are those that occur at the interfaces between disciplines and thus

[4] http://www.unep.org/Documents.Multilingual/Default.asp?documentID=97&ArticleID=1503

require integrative research and synthesis. TDR may be needed within a science field e.g. ecologists, hydrologists, hydrogeologists working together to understand river systems; or across research domains e.g. to deal with the complex dimensions of urban sustainability (Petts et al, 2008: 596-7).

Hadorn et al (2006) argue that research for sustainable development has to be issue oriented and reflect the diversity, complexity and dynamics of processes, and variability between problem situations. The knowledge of people and their needs and interests also have to be taken into account. A TDR research orientation would ask these questions: (1) In which way do processes constitute a problem field and where are the needs for change? (2) What are more sustainable practices? (3) How can existing practices be transformed?

TDR practices have been widely applied in land and water management, landscape design and urban design, and sustainable resource use, public health, risk research, new technology development and environmental conflict resolution. TDR approaches are also applied to the teaching of sustainability. [5] There is now an expanding body of literature on of the use of TDR for sustainability. The following case studies [6] are presented to illustrate how TDR is used in practice:

Sustainable River Basin Management in Kenya – As in many other parts of the world, pressure on catchment systems has led to a major sustainability crisis in regions of Kenya. A research programme was developed to understand socio-economic dynamics and ecological processes over a number of decades, in a process combining scientific knowledge and local knowledge systems. A multi-stakholder participation strategy meant there was wide input into the problem structuring and strategies for management.

Fisheries management in Switzerland – Decline in the health status and numbers of brown trout was raising sustainability concerns for key Swiss fisheries. A process was set up with a network of participants including anglers, public authorities, scientists and the fishing industry to develop an understanding of declining fish yields and measures for protection. This integrated existing data and stakeholder 'know how' to identify knowledge gaps. A joint inquiry approach was used to formulate research questions and projects. Collaboration throughout the project ensured an efficient exchange of ideas, leading to the setting of new priorities and an agreement on proposed control measures.

Retrofitting suburbs through collaborative urban design in Canada – A five year research and planning project was set up by an Interdisciplinary Research Group to revive aging post-war suburbs in Quebec city. The aim was to generate knowledge that could be applied to urban design, planning, management and policy. A consensus approach was used to diagnose the issues, define planning objectives and develop a master plan for suburban redevelopment.

[5] See for example a programme at Murdoch University in Australia at http://lsn.curtin.edu.au/tlf/tlf2004/marinova.htmlad and the TD network sponsored by the Swiss Academy of Sciences at www.transdisciplinary.ch

[6] Examples taken from Hadorn et al, 2008: 8-15.

Climate change mitigation in Germany – A project was developed for the integrated assessment of climate change mitigation. It considered an optimal mix of investments in energy efficiency, renewable sources, carbon capture and sequestration. It addressed the perceived tensions between emission reductions and impacts of economic growth. A social optimum was determined by identifying measures that would guarantee that global warming would not exceed 2 degrees C; and that welfare loss from protection measures would not exceed 1%. The project integrated paradigms from natural science, economic growth theory and engineering. It was thus able to identify avoidance and mitigation measures consistent with knowledge of the climate system and 'target knowledge' or goals of various interest groups, creating a consensus for policy.

Further examples [7] of the use of TDR in relation to sustainability include:

- Ground water (Pereira and Funtowicz, 2006)
- Urban environments (Petts et al, 2008)
- Landscape /land use planning (Tress et al, 2006)
- Landscape ecology (Brandt, 1998)
- Academic/industry collaboration (Garrett Jones et al, 2005)
- Antarctic research- ecosystem response to climate change (Howard-Williams et al, 2006)
- Environmental Management– water research (Knopman, 2006)
- Pharmaceutical agents in the environment (Schulte-Ohehlmann et al, 2007)
- Built environment and health/well being (Spokane et al, 2007)
- Combining development metrics with ecological thresholds (Wilson et al, 2008)
- Combining an environmental justice framework with catchment management (Hillman, 2004)
- Computing CO2 emissions in Tokyo (Komiyama, 2006).

[7] Full references in appendix.

6. THE CHALLENGES AND BENEFITS OF DOING TDR

"Interdisciplinarity is widely regarded as a virtue but working across disciplines is hard"
(Petts et al, 2008: 593)

TDR can be both transformational and challenging. As the field has developed, attention has been drawn to those factors that arise in practice and contribute to its effectiveness.

The success of TDR research depends on institutional commitment and research leadership. Many institutions work on the basis of traditions, reward structures and practices that support disciplinary research rather than encouraging the growth of interdisciplinary or transdisciplinary research. Private industrial research labs may be better organised than universities to support TDR because they are more focused on problem solving and enterprise (US National Academy of Sciences, 2004: 2-3). There may often be barriers within the academic community, where scientists continue to prefer basic research and may not want to confront issues and questions raised by non-scientists. Furthermore, there are barriers in research funding, where funding agencies struggle with the notion of participatory research and whether it is seen as 'scientific' (Jager, J. in Hadorn et al, 2008: viii).

TDR is a different form of practice from traditional research. It is typically collaborative and involves people from different backgrounds. It requires extra time to build consensus and for participants to learn new approaches from other knowledge systems (US National Academy of Sciences op cit: 3). In an applied setting, TDR has to transgress the disciplinary paradigms held by individual scientists, including working across the humanities and natural sciences, along with the practical issues raised by other actors. It is also challenged by the need to grasp the complexity of problems, to link abstract and case specific knowledge, and to generate information aimed at problem solving for 'the common good' (Hadorn et al, 2008: 19).

Within a TDR process, participants come from different academic traditions and use different theories, methods and language. Different disciplines will take a different approach as to what constitutes a 'research problem', and this can make communication difficult (Petts et al 2008:598). This heterogeneity may lead to disagreements about the framing of issues and the validity of different knowledges, creating conflict and instability. On the other hand, a wide mix of perspectives is the core strength of TDR, enabling the team to develop a fuller picture, a 'complex representation' of the problem situation. The active involvement of researchers with different backgrounds, and of non-academic stakeholders from a range of interest groups, from the outset, is fundamental to effective TDR (Hollaender et al, 2008: 386-8). In some academic settings the focus on real world problems may create a disadvantage for TD researchers. There may be suspicion from within disciplinary silos and the applied approach of TDR may be seen as instrumental and 'less pure' than disciplinary research. Commenting on this concern, Petts et al cite CP Snow (1964) who observed that the pure scientist would not recognise that many of the problems of applied science were “as intellectually exacting as pure problems, and that many of the solutions were as satisfying and beautiful” (op cit:597).

In a review of the experience of researchers in TDR projects, Petts et al (2008: 598) found that some areas of knowledge may be given more attention than others e.g. in a project on energy efficiency, the scientific and technical dimensions of energy systems were privileged over the social context in which they were used. The discourse focused on technical potential and tended to discount social, political and cultural factors as ‘annoying constraints’. Social scientists found themselves cast in the role of overcoming these ‘barriers’ or smoothing the way for technical solutions. Social scientists may also find their contribution is perceived as ‘soft science’ and sidelined as incompatible with dominant, hard knowledges, which may in turn reduce the effectiveness of the research in producing policy relevant outcomes.

In addition, the integration of science, policy and civil society actors in a TDR process carries its own challenges, when different world views and expectations come together in participatory research settings. Societal engagement in TDR has to be more than a reductionist or quantitative analysis of social statistics and to actively embrace social actors deploying their own knowledge base. And ‘institutional ears’ have to be created so that there is actual uptake of the knowledge produced. Thus TDR entails more than just the acknowledgement of different perspectives, but also ‘language’ harmonisation and social, cultural and political contextualistation (Pereira and Funtowicz, 2006:41, 47).

The management of TDR teams requires active leadership. The aim is to integrate diverse perspectives and ensure that all the dimensions of complexity are recognised, thus allowing new problem definitions and research questions to emerge. This requires skills in collaborative planning of the research process, effective ground rules for decision-making and communication, clear definition of roles, conflict resolution measures, consensus building, and inter-agency cooperation. Effective TDR requires a clear formulation of shared goals among participants and the effective flow of knowledge to stimulate mutual learning (op cit: 390). Importantly, participants have to be open to other perspectives, exhibiting reflexivity to consider contextual issues and review their own assumptions and responses.

Members of TDR teams may also find that they are pursing a range of objectives e.g. young researchers may be interested in academic qualifications, and other stakeholders in practical benefits and visible results. Team members usually have commitments in other institutional groups, and may only be in the TDR project for a limited period of time.

TDR researchers have found that the ‘hard wiring’ of organisations can make it difficult for researchers in discipline based departments to ‘climb up and look around’. TDR projects require close and continuous collaboration, time for networking, and for knowledge transfer to other stakeholders and this adds cost. While now strongly advocated in research institutions, TDR nevertheless operates against a background of competition between individuals and groups for funding and recognition (Petts et al, 2008:599).

The US National Academy of Science report (2004) identified a range of institutional barriers to TDR including:

Limited resources – Time and resources devoted to TDR are diverted from other research programmes and thus TDR projects need to be outstanding to attract funding. Centralised funding regimes may have few spare resources for research across rather than within departments.
Academic reward system – Traditional systems for hiring, tenure and promotion etc are controlled by departments and there is often little reward for teaching or research outside one's disciplinary area.

Institutional cultures – Collaborators may have different concepts of 'proof' or 'precision'.
The culture of a mathematics department, for example, differs from a biology department.

Programme evaluation – Academic institutions rely on tradition evaluation mechanisms to benchmark their programme and allocate resources. When emerging fields are left out of assessments, they may not receive funding.

Departmental procedures – Different departments have different methods for allocating resources, organising research, authoring papers, control of space and facilities and criteria for recruitment, which may impede or fail to reward TDR.

Start up time for TDR projects – Arranging staff, equipment etc for a collaborative project may take longer than within-department projects, thus reducing the time for research and reporting results.

Similarly there are issues for funding agencies, who may hesitate to support TDR rather than single discipline programmes. These barriers include:

- funders have insufficient knowledge about how to solicit and evaluate TDR work
- applicants seeking funding for TDR work encounter difficulties with practical issues such as page limits on proposals, a tendency to understate costs of TDR work, setting up TDR teams across different institutions and lack of a well defined review process for proposals
- review of TDR proposals may be difficult as traditional peer review relies on discipline experts
- TDR programmes take time to build consensus and combine research methods and cultures, thus making them more difficult to plan than single discipline projects.

The US report also noted that the most prestigious outlets for research scholars tend to be high impact, single discipline journals published by professional societies; although the number of interdisciplinary journals is now increasing. TDR education is also often hindered by limited availability of supervisors with skills in TDR methods; and TDR projects may take longer because of the need to incorporate literature or methods from a range of disciplines (Klein, J. in Hadorn et al 2008: 402).

A central part of a TDR process is the integration of research results. This can be achieved through an iterative adaptive process, achieved by not establishing strict expectations for outcomes at the start. The reluctance among scientists to avoid overlap and not intrude on other disciplinary worldviews has to be managed carefully. Hollaender et al (2008) suggest that this requires a process of 'controlled confrontation' which enables the consideration of research results and divergent views and then checking that all perspectives have been taken into account. This can be done through dialogue, and concentrating on a joint social problem, or through formal systems models (op cit: 393).
There is a lack of strong institutional structures for TDR. TDR groups form to deal with a particular issue – often across research groups and institutions - but relationships may not extend past the life of the project. Thus lessons learned may not be passed on and the development of TDR itself as a mainstream research endeavour is not supported.

Having noted some challenges, there are also considerable advantages and benefits of TDR.

The key benefit of TDR is the creation of new knowledge. Reviewing range of international TD based education programmes, Klein (2008:406) found that in most visions of TD, disciplines do not disappear but they provide essential building blocks to creating new knowledge. TD education equips students with:

- the ability to scope problems and determine how an integrative approach can be used, ensuring multi disciplinary and multi sector involvement
- the knowledge and ability to apply processes such as modelling and group facilitation
- an appreciation of different research epistemologies and an ability to draw on them in a common task
- an understanding of policy, practice and product development, and how these are influenced by research
- the ability to foster research collaboration.

In some areas, mechanistic or single discipline frameworks have failed to explain the full complexity of current issues and problems. In the health sciences, for example, Ratcliffe (1993) has argued that a new science of health is needed as an alternative to current biomedical thinking, which will draw on a broad knowledge base and a variety of approaches, and bridge the gap between personal experience and scientific knowledge. TDR is now emerging as a research orientation in the health sciences, providing systematic frameworks for analysing the social, economic, political, environmental and institutional factors in human health and well being (Rosenfield, 1992 cited in Klein 2008:400).

With TDR, different knowledge cultures can be bridged and their knowledge fused together in answering a research question. Both tacit and explicit knowledge can be drawn into the research process, including knowledge that is usually not accessible, thus creating a broader framework. New methods and theory can thus emerge through integration. Policy makers often see integration as providing a better solution to a research problem than other approaches (Tress et al, 2006).

Many contemporary issues require the integration of knowledge from a range of disciplines and sources. Researchers have found the practical experience in TDR projects and the exposure to other perspectives to be rewarding and stimulating. A review of Integrative Research in Finland (Bruun et al 2005, cited in Klein, 2008:406) found that the benefits of an interdisciplinary approach included breadth of preparation of research projects, networking with experts from other fields, learning to combine different knowledge, methods and views. Projects organised on an interdisciplinary basis experienced more synergies between the issue and project design, and benefits of networking and creativity. The process involves creating new spaces for knowledge representation and for the co production of knowledge. New methodologies are developing in what Pereira and Funtowicz (2006: 40) describe as a 'knowledge conviviality' including the use of metaphors, patterns, multi media visualisation, etc to acknowledge and work with diversity and complexity.

The US Academy of Sciences report found that interdisciplinary research can be one of the most productive and inspiring of human pursuits. It noted that successful interdisciplinary researchers have found ways to integrate and synthesise disciplinary depth with a breadth of interests, visions and skills. Students are strongly attracted to interdisciplinary courses and subjects. Collaborative partnerships among universities, industry and government have increased and diversified rapidly. The Academy concluded there is now well documented evidence of the research benefits and their effectiveness.

It recommended that academic institutions should develop new funding, policy and practices that remove barriers to interdisciplinarity, develop joint programmes across the university and with industry and government, and should support training in this field for students and faculty. It also recommended that funding agencies should provide mechanisms to support interdisciplinary research and education and review their assessment criteria to make them more effective. The government was urged to maintain a proper balance between funding disciplinary and interdisciplinary research (op cit: 1-5).

7. MEASURING THE GROWTH OF TDR INTERNATIONALLY AND IN NEW ZEALAND

The growth of transdisciplinary research internationally is indicated by the growing number of research programmes, institutes, professional networks and academic journals dedicated to promoting this kind of research. The structuring of tertiary education is increasing developing an orientation towards TD learning and teaching.

Klein (2008: 401 -405) notes a number of examples, including:

- The International University Reforms Observatory, a network of European, Latin American and South African academics that promotes discussion of university reform with a TD perspective.
- The Centre International de Recherches et Etudes Transdisciplinaire (CIRET) is developing a new type of education informed by the world view of complexity in science. The CIRET website at http://perso.club-internet.fr/nicol/ciret/) has many examples of TD education initiatives, as does the td-net website http://transdisciplinary.ch.
- In the USA, the Texas Tech Department of Mechanical Engineering offers courses in TD design, process and systems.
- There are numerous examples in the health sciences e.g. the Ecosystem Health Programme at the University of Western Ontario, Canada; and the Centre for Behavioural and Preventive Medicine at Brown University, USA.
- The Holistic Education Network of Tasmania fosters TD inquiry, and transformational learning (http://www.hent.org/).
- The Institute for Sustainability and Technology Policy at Murdoch University in Australia has developed TD approaches in their programmes.

The International Journal of Transdisciplinary Research [8] was established in 2006, with the goal of extending and integrating the study of economics with disciplines within the natural and social sciences, as well as the humanities. The journal aims to develop an economic paradigm that "realistically portrays economic systems as a whole", and develop new approaches to real world problems. In its first issue, Polimeni (2006) argued that: "Our world today is full of instability, transition, and nonlinearities. There will not always be a transition to a stable steady-state as the traditional approaches claim. Therefore, new paradigms and tools are necessary to understand, explain, and learn how behaviour shapes the dynamics of the world."

It is not possible to provide a precise measure of the extent of TDR internationally. One approximation can be found in the report of the US Academy of Sciences (op cit) which noted the growth in multi disciplinary research between 1982 and 2001. This trend was represented by a steady increase in the funding provided by the US National Science Foundation for projects with more than one principle investigator (PI). While most recent awards went to favour single investigators, there was significant growth in multiple PI

[8] http://www.ijtr.org/aims_and_scope.htm

awards over that period. Single PI's won about half of the funding in 2001 compared with 78ths in 1982 (Op cit:118)

In contrast, figures for New Zealand from the Marsden fund indicate a steady decline in the number of proposals received and contracts let with more than one PI: from 356 down to 221 proposals, and from 32 down to 22 contracts for the period 2000 to 2007.[9]
A recent review of the social sciences, however, reported that a high number of social scientists were undertaking interdisciplinary research (63%) and transdisciplinary research (28%). Only 16.9% indicated they undertake research informed by a single disciplinary perspective (Witten et al, 2006:53).

[9] Figures supplied by the Marsden Fund, pers.comm., July 2008.

8. TDR AND THE FUTURE DIRECTION OF SCIENCE – IMPLICATIONS FOR NEW ZEALAND

TDR approaches are now a key theme in international discussion about the future of science and research. In an increasingly globalised world where a high premium is placed on building capacity in the 'knowledge economy', and where issues of sustainability are paramount, TDR offers an important perspective.

Wickson et al (2006:1047) note that an increasing emphasis on the development of knowledge economies is promoting the generation of knowledge aimed at solving consequential problems. Furthermore, "the need for sustainability is underpinning a growing demand for research that takes account of complex contexts and interactions between natural and social systems In the social context, calls for interaction with an increasingly engaged populace are driving research in more participatory, consultative and deliberate directions." Taken together, these drivers indicate a changing landscape for knowledge production.

"Transdisciplinary research" is driven by problem solving and integrates perspectives from public agencies, the private sector and civil society in the research process. A major European initiative on TDR initiated by the Swiss Academy of Sciences is supporting exchange among individuals and teams involved in TDR projects on a diversity of issues (public health, migration, new technologies, climate change, globalisation, etc.) to develop integrative methods and approaches for knowledge-based solutions to pressing problems in the life-world. [10] They suggest that TDR provides a platform for science to examine important public problems and to develop effective strategies for politics, business and civil society. In effect, this provides a new social agenda for science. TDR researchers are emphasising that complex spatial and temporal processes of different scales need to be researched (systems knowledge) and the related management problems and possibilities of creating developmental options (transformation knowledge) need to be probed. Consequently, a basis is needed upon which a societal consensus can be reached on the aims to be pursued (target knowledge). For an effective translation of knowledge into action, all stakeholders need to be involved. The conditions under which science operates and research is funded need to be adapted accordingly.

Current global issues represent the most significant challenge for science policy in the 21st century. TDR provides an essential research framework to support sustainable development. Increasingly complex issues in the economic sphere and in the quality of the human habitat require a major technical, economic and social reorientation. However, we lack the fundamental scientific knowledge and efficient methods for its implementation. [11] The long-term protection of our natural resources (soil, air, water, biological diversity), cultural wealth and functioning social structures is essential for the conservation of a healthy and productive environment for coming generations. Science

[10] see http://www.transdisciplinarity.ch/
[11] See Ackermann-Liebrich, U. et al (1997) the background document 'Visions in Science Policy', at the above website http://www.proclim.ch/Reports/Visions97/Visions_E.html

needs to supply fundamental knowledge concerning natural and social factors and processes, and their connections. Moreover, science needs to stimulate public discussion on the value and targets of future development.

In terms of a future vision for science and research policy, a group of 34 European scientists, through the Swiss Academy of Sciences, have made the following observations and calls for action [12]:

1. Improved **systems knowledge** is needed on:

- climate change land use and soil degradation
- destruction of ecosystems and loss of biodiversity
- increasing scarcity and pollution of water, soil and air
- natural disasters caused by humans
- population dynamics and disparities in development
- health risks and food security
- energy and resource securities.

2. Earlier scientific achievements - primarily in the natural sciences - have mostly been founded upon the analysis of narrowly defined areas of research. In recent years, much knowledge has been gained about individual systems, but comparatively little is known concerning their **interactions**. The often purely reductionist study of environmental problems in separate academic disciplines is increasingly encountering its limitations. The inter or transdisciplinary approach promotes synergies and communication across disciplinary boundaries and between researchers, decision-makers and affected parties. However, there are also limits to interdisciplinarity. In applied research, the whole can only be approximated by means of several complementary models.

3. The need for more knowledge about the interactions between **social and natural systems** is especially great. Understanding coupled systems requires a broad approach to research and education which focuses on interactions, variability, problems of scale and proportions, and system properties, and which will search for explanations in simple sub-systems only if required - rather than starting and remaining there.

3. Apart from studying the problems and phenomena of global change, science also needs to consider specific **political, economic and social needs** and constraints, and to find and supply adequate responses. In this way, science will bear its part of the social responsibility for the future of humans and the environment.

4. Research projects increasingly need to focus on human **problems of perception and assessment**. It is necessary to reveal, visualize and communicate complex and long-term

[12] This summary is taken from the 'Visions in Science Policy' document cited above

interrelations. Science is required to reveal the complex social and environmental tendencies that are not immediately accessible to our senses.

5. However, knowledge is not the most critical factor determining the solution of such problems. Any concept of sustainability implies a certain understanding of nature and the position of humans as part of nature. It will not suffice to meet the challenges of today simply by amassing more knowledge. Both the concept of sustainability and the image of humans and their position in nature require **ethical clarification**. Only when the philosophical and anthropological requirements of sustainability have been clarified can they be implemented in a meaningful way. Ethics should ask uncomfortable questions and critically examine fundamental problems, as well as the prerequisites for the solution of social problems. One aspect of such examinations would therefore be the conceptual and terminological/ideological foundations required by social and environmental policy.

6. Future environmental and sustainability research needs to place significantly greater emphasis on **target and transformation knowledge** as well as systems knowledge in the human and social sciences, including how this knowledge can be efficiently integrated into problem-solving.

7. Knowledge is not usually directly translated into **action**; human actions are not directed by knowledge alone but are also influenced by perceptions, attitudes and conditions (e.g. basic needs, cultural diversity and tradition, state of technology, access to resources, balance of power, institutional restrictions, ethics, social networks, ecological dynamics, etc.) Only if scientists are prepared to reflect on and to study these complex interrelations will they be able to conduct research relevant to practice, and make a contribution towards the solution and prevention of environmental problems. Moreover, research is also required into why and how certain instruments applying scientific knowledge are successful and why others are not. This is the only way to improve existing instruments and develop new ones.

8. The involvement of decision-makers (from the government, the private sector) and non-governmental organisations in the planning and realization of research projects needs to be increased in order for implementation to begin early. **Participatory approaches** are especially relevant for applied research; however, basic research will also be able to benefit from these learning processes and an enhanced acceptance of research. Participation complements expert-centred governmental advisory groups and strengthens the democratic decision-making process, which is an important principle of sustainability.

9. An important contemporary issue in the practical application of TDR is problem framing. 13 Identifying and structuring the problem and defining research questions within an unstructured or pluralistically-viewed field can constrain analysis of the problem. This limits what can be captured by early detection, what can be addressed by research and which problem-solving options are investigated. The perspectives of researchers from different disciplinary backgrounds (natural or social sciences, the

[13] See http://www.transdisciplinarity.ch/conference/upcoming_conference.html

humanities or the engineering and medical sciences) as well as perspectives of actors from the private sector, civil society or public agencies need to be interrelated.

10. Changes are needed in **science policy**. Institutions promoting research need to reorient themselves to encourage more inter- and transdisciplinary proposals for research projects. This will require flexible funding structures. The selection of research projects needs to place greater emphasis on their orientation towards application. Improved cooperation between universities and funding institutions with research and development activities pursued in the private sector, in government as well as state and private institutions, is required.

What are the implications for New Zealand?

In terms of future science and research, it needs to be emphasised that not all science has to be oriented towards transdisciplinary research. While TDR is an important field – with much to offer in terms of applied problems – many areas of science will continue to operate under a disciplinary or multi disciplinary framework. Indeed, the ongoing enhancement of fundamental knowledge is a pre requisite for TDR.

TDR has a major role to play in advancing sustainability science in New Zealand. In a national survey conducted by MORST in October 2007, [14] involving participants from science, industry, the government and the community, there was a clear view that New Zealand needs to be doing more to respond to the sustainability challenge. This response was re enforced at a business seminar hosted by MoRST in December, 2007.[15] Global challenges around sustainability are the dominant issue on the horizon, and require an urgent and focused response. Research needs to be more strongly linked to real world environmental and social problems - and to action. Business leaders are keenly aware of the strategic issues in the international market and are already moving ahead to anticipate and respond to sustainability. Social preferences, in the New Zealand community, and international consumer markets, are also rapidly evolving. This has major implications for the future of New Zealand research, science and technology (RS&T).

Science is not simply a 'sector' or component in future sustainable development, but rather provides the central analytical platform on which sustainability is based. Without scientific knowledge, there would be little understanding of the changes in the environment that have alerted modern societies to the present global and national problems. Without science, we would lack the ability to monitor system capacities and responses, on which policy and investment decisions are based. And without science, we will be unable to adapt to change and develop the new technical, economic and social solutions required to shift gear and move into a more sustainable future.

New knowledge and innovation are imperative for New Zealand and RS&T has a vital role to play in our future transformation. [16] TDR provides an important framework for:

[14] See survey report at www.morst.govt.nz
[15] See meeting report at www.morst.govt.nz
[16] Hon Pete Hodgson, Minister of Research, Science and Technology, July 2008 p. 5.

- measuring key indicators of the state of the biophysical and social systems
- improving knowledge and predictive capacity around the interaction between biophysical and social systems
- understanding and analysing the drivers behind sustainability current challenges, including those forms of science and technology that may in the past have contributed to non sustainable outcomes
- developing new social processes to identify preferred sustainable future pathways, including public awareness, social engagement and policy mechanisms
- developing new fields of knowledge, applied technologies and products to implement sustainable development pathways.

REFERENCES

Ackermann-Liebrich, U. et al (1997) *Visions in Science Policy*. Proclim Forum for Climate and Global Change. Berne: Swiss Academy of Sciences. Retrieved 16 September 2008 from http://www.proclim.ch/Reports/Visions97/Visions_E.html

Brandt, J. (1998) Key concepts and interdisciplinarity in Landscape Ecology: a summing-up and outlook. In Dover, J.W. and Bunce, R.G.H. (Eds) (1998) *Key Concepts in Landscape Ecology*. Preston UK: IALE European Congress : 421-434

Brewer, G.D. (1999) *The Challenges of Interdisciplinarity*. Pol Sci 32, 327-337

Bruun, H., Hukkinen, J., Huutoniemi, K., and Klein, J.T. (2005) *Promoting Interdisciplinary Research: The Case of the Academy of Finland.* Helskink: Academy of Finland.

Campbell, D.T. (1969) Ethnocentrism of Disciplines and the Fish-scale Model of Omniscience. In Sherif, M and Sherif, C.W. (Eds) *Interdisciplinary Relationships in the Social Sciences*. Chicago: Aldine: 328-348

Funtowicz, S.O. and Ravetz, J.R. (1993) Science for the Post-Normal Age. *Futures* 25, 739-755

Funtowicz, S.O. and Ravetz, J.R. (2008) Values and Uncertainties. Chapter 23 in Hadorn, G.H., Hoffman-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., and Zemp, E. (Eds) (2008) *Handbook of Transdisciplinary Research*. Springer.

Garrett-Jones, S., Turpin, T., Burns, P., Diment, K. (2005) Common purpose and divided loyalties: the risks and rewards of cross sector collaboration for academic and government researchers. *R&D Management.* Vol 35. Issue 5 : 535-544

Gibbons, M., Limoge, C., Nowotny, H., Schwartzman, S., Scott, P. and Trow, P. (1994) The New Production of Knowledge. *The Dynamics of Science and Research in Contemporary Societies.* London: Sage.

Hadorn, G.H., Hoffman-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., and Zemp, E. (Eds) (2008) *Handbook of Transdisciplinary Research*. Springer.

Hadorn, Gertrude Hirsch; Bradley, David; Pohl, Christian; Rist, Stephan; Wiesmann, Urs (2006) Implications of transdisciplinarity for sustainability research. *Ecological Economics* [Ecol. Econ.]. Vol. 60, no. 1, pp. 119-128. Nov 2006.

Hillman, M. (2004) The importance of environmental justice in stream rehabilitation. *Ethics, Place and Environment.* Vol. 7. Issue 1&2. :19-43

Hodgson, P. 2008. Foreward to the *Government's Agenda for New Zealand Research, Science and Technology*. Wellington. Ministry of Research, Science and Technology

Hollaendar, K., Loibl, M.C. and Wilts, A. Management. Chapter 25 in Hadorn, G.H., Hoffman-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., and Zemp, E. (Eds) (2008) *Handbook of Transdisciplinary Research.* Springer.

Jager, J. (2008) Foreward in Hadorn, G.H., Hoffman-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., and Zemp, E. (Eds) (2008) *Handbook of Transdisciplinary Research.* Springer.

Klein, J.T. (2007) Interdisciplinary Approaches in Social Science Research. In Outwaite,W. and Turner, S.P. (Eds) *The Sage Handbook of Social Science Methodology*. Los Angeles. Sage Publications ISBN 0978-1-4129-0119-2. pp 32-49.

Klein, J.T. (2008) Education – Chapter 26 in Hadorn, G.H., Hoffman-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., and Zemp, E. (Eds) (2008) *Handbook of Transdisciplinary Research*. Springer.

Knopman, D.S. (2006) Success matters: recasting the relationship among geophysical, biological and behavioural scientists to support decision-making on major environmental challenges. *Water Resources Research*. Vol 42. Issue 3.

Kuhn, T. (1963) *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press

Komiyama, H. and Takeuchi, K. (2006) Sustainability Science: building a new discipline. Editorial. *Sustainability Science* 1: 1-6.

Nowotny, H. (1999) The Need for Socially Robust Knowledge. *TA – Datenbank-Nachricten, 8, 12-16*

OECD (1972) *The University and the Community: The Problems of Changing Relationships* Paris: Organisation for Economic Cooperation and Development.

Pereira, A.G., Funtowicz, S. (2006) Knowledge Representation and Mediation for Transdisciplinary Frameworks: Tools to Inform Debates, Dialogues and Deliberations. *International Journal of Transdisciplinary Research*. Vol.1, No. 1 2006:34-50.

Petts, J., Owens, S. and Bulkeley, H. (2008) Crossing boundaries: interdisciplinarity in the context of urban environments. *Geoforum* 39 (2008) 593-601

Pohl, C. and Hirsch Hadorn, G. (2007) *Principles for Designing Transdisciplinary Research. Proposed by the Swiss Academy of Arts and Sciences*. Munchen: Oekem.

Polimeni, J. M. (2006) Transdisciplinary Research: moving forward. *International Journal of Transdisciplinary Research.* Vol.1 No. 1: 1-3

Popper, K. R. (1963) *Conjectures and Refutations: the Growth of Scientific Knowledge*. New York. Routledge and Kegan Paul. P.88

Ratcliffe, J.W. (1993) Integrative, transdisciplinary research methodology. In Fulder,S. and Lafaile, R. (Eds) *Towards a New Science of Health*. Vol. 1 Part 4. October 1993: 169-182

Rosenfield, P.L. (1992) The potential of transdisciplinary research for sustaining and extending linkages between the health and social sciences *Social Science and Medicine* 35 (11): 1343-57

Schulte-Oehlmann, U., Oehlmann, J. Puttmann, W. (2007) Pharmaceutical agents in the environment, their entries, occurrence and an inventory of them. *Humanpharmakawirkstoffe in der Umwlt: Eintrage, Vorkommen und der Versuch einer Bestandsaufnahme*. Vol 19. Issue 3: 168-179

Spokane, A.R., Lombard, J.L. et al (2007) Identifying streetscape features significant to well being. *Architectural Science Review*. Vol. 50. Issue 3: 234-245.

Steffen, W. et al (2004) *Global Change and the Earth System. A planet under pressure.* Springer, Berlin. (Executive Summary, IBBP Secretariat, Stockholm) Cited in Hadorn et al (Eds) 2008: 57.

Swiss Academy of Sciences (2008) – td research conference 2008 http://www.transdisciplinarity.ch/conference/upcoming_conference.html

Tress, B; Gunther, R. and Fry, G. (2006) Defining concepts and the process of knowledge production in integrative research. Chapter 2 in Tress, B. et al *From Landscape Research to Landscape Planning – aspects of integration, education and application.* Wageningen UR Frontis Series 12 ISBN 1402039786 pp 13-26. Retrieved 25 July 2008 from http://library.wur.nl/frontis/landscape_research/02_tress.pdf

US National Academy of Sciences, National Academy of Engineering and Institute of Medicine (2004) Facilitating Interdisciplinary Research. Washington, D.C. The National Academies Press. http://www.nap.edu/catalog/11153.html

Wasson, B. and Underdal, A. (2002) Human-Environment Interactions: methods and theory. Global Change Newsletter Nr. 49 IGBP Secretariat, Stockholm. Pp. 22-23. Cited in Hadorn et al (Eds) 2008: *Handbook of Transdisciplinary Research*. Springer: 57.

Wickson, F., Carew, A.L., Russell, A.W. (2006) Transdisciplinary research: characteristics, quandaries and quality. *Futures* 38 (2006) 1046–1059

Wilson, J., Pelot, R. and Tyedmers, P. (2008) Ensuring that development metrics consider environmental sustainability – a proposal to combine development metrics with an ecological threshold variable. *International Journal of Transdisciplinary Research*. Vol.3 No. 1.: 44-68

Witten, K., Rose, E. et al (2006) *National Survey of Social Scientists*. Building Research Capacity in the Social Sciences Report. Available at http://www.brcss.net/images/brcss_docs/brcss%20survey%20report.pdf

World Commission on Environment and Development (1987*) Our Common Future.* Oxford University Press.