# Integrated Earth System Science: Research Practice and Communication for Solutions to Twenty-First Century Sustainability Challenges

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**Thesis by papers**
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**Submitted τ April 2014**

## Statement of candidate

I certify that the work in this thesis entitled *Integrated Earth System Science: Research Practice and Communication for Solutions to Twenty-First Century Sustainability Challenges* has not previously been submitted for a degree nor has it been submitted as part of a requirement for a degree to any other university or institution other than Macquarie University.

I also certify that the thesis is an original piece of research and it has been written by me, except as otherwise indicated. Any help and assistance that I have received in my research work and the preparation of the thesis itself have been appropriately acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This research has been approved by the Macquarie University Ethics Committee, with protocol numbers 5201000624 and 5201200684.

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## Abstract

Scientists' growing awareness of human transformation of an interconnected Earth system (ES) and the need to pursue global sustainability has led to continued calls for integrated ES research. Yet, there have been few studies that consider if ES research is integrated enough to contribute to solutions to twenty-first century global environmental problems. This thesis, therefore, aims to: (i) describe what integrated ES research is and what it has accomplished, (ii) illuminate the level of opportunity to practise and publish integrated ES research that identifies, analyses and communicates ES-derived challenges, and (iii) elucidate how ES research can become more integrated and better positioned to support humanity's responsible engagement within the Earth system.

This research analyses the accomplishments of ES science and synthesises the experiences of the global environmental change research community at bringing natural and social sciences together to study changes to an integrated ES and the implications for global sustainability. Despite advances in ES science, this study reveals how, to date, integration of the natural and social sciences has been limited. Furthermore, this research reveals a pattern where the same barriers to integrated research have persisted over the past three decades. In addition to barriers to science integration, the communication of ES research findings can be challenging. Yet, effective communication is vital in order to help governments and society understand and respond to global environmental challenges.

This thesis, therefore, examines the performance of two main channels of ES science information: interdisciplinary environmental journals and the mass media. The research

findings show that environmental journals possess narrow disciplinary reach and they pursue an integrative review process to varying degrees of intensity. The mass media has a vital role to inform the public as a prerequisite for democratic politics, yet a review of the literature describes tensions between science and the mass media. Such tensions and media coverage of alleged climate research misconduct formed the basis of a survey this project developed for an interface group of researchers and journalists knowledgeable in science who have a vested interest in evidence-based reporting.

The thesis contends that (i) interface journalists, by collaborating with scientists to communicate evidence-based ES science findings, can support mainstream journalists to better inform the public about the urgency to respond to ES-derived sustainability challenges; (ii) interdisciplinary environmental journals can help communicate solutions to global environmental challenges by integrating knowledge more broadly from different disciplines, pursuing rigorous interdisciplinary reviews, and publishing research at the nexus of science and action; and (iii) by collaborating together, researchers, funding agencies and academies can develop new opportunities to overcome persistent barriers and provide the necessary institutional support for integrated ES research. By transcending traditional disciplinary, sectoral and international boundaries, ES research can become integrated in ways that will better contribute to solutions to twenty-first century sustainability challenges.

## Preface

As a child growing up in Scotland, my playground was Fife's coastal trails with their panoramic, yet contrasting views: undulating hills dotted with farmland and woodland, Edinburgh castle posing atop a volcano, the majestic Forth railway bridge, a marine oil and gas terminal, and the stunning (on a rare sunny day) Firth of Forth estuary. It was here that I developed a fascination of human-nature interactions.

These interests motivated me to study geography as an undergraduate and then to complete a master of science in environmental studies at the University of Aberdeen. After graduating, I moved to Japan where I worked for the Asia-Pacific Network for Global Change Research. This was a defining experience for me. I felt privileged to interact with regional scientists and government officials on global change research projects in diverse settings from the Pacific Islands to the Himalayas. I loved the energy and diversity of the region, its people, cultures and landscapes. Yet, I became more acutely aware of how vulnerable the region and its population are to environmental change, particularly from food production, water security and human health perspectives.

After eight years in Japan, I moved to Paris, France to coordinate a global scientific partnership for integrated ES research. I had incredible colleagues and it was exciting working for an international network devoted to interdisciplinary research. As a science coordinator, I was impressed by emerging ES science findings, although I was becoming increasingly aware of the challenges of actually doing integrated research. Furthermore, I was struck by how under-valued science communication tends to be. Yet, it is a vital component of the ES science enterprise. This, in turn, stirred my interest in doing a systematic study of how integrated ES research has contributed to the identification, quantification, communication and response to global environmental changes over the past decades, and to consider the ways in which it needs to continue to evolve in order to effectively tackle the enormity of the challenges that we now face over the course of the rest of this century. Yet, I had no time and limited ability to conduct my own research.

These interests and concerns planted the seeds for this thesis, motivating me to challenge myself further by embarking on PhD studies in environment and geography at Macquarie University in Sydney, Australia.

## Acknowledgements

Embarking on a PhD is an incredibly tough, yet rewarding challenge. I am extremely grateful for all the support I have received throughout my candidature. It has been a fantastic experience.

I am indebted to Ann Henderson-Sellers for the opportunity to apply for a scholarship at Macquarie University. Ann has devoted an incredible amount of time, energy and commitment, first as my principal supervisor and then as an adjunct supervisor, guiding me through the rigours of academic research. Even after her retirement Ann has continued to be heavily engaged in my PhD project. I've benefited greatly from Ann and from my principal supervisor, Greg Walkerden. Greg has provided fantastic guidance and support. Both Ann and Greg have generously given their expert advice, and shared their breadth of interests and wealth of experience. I've enjoyed debating, brainstorming ideas and framing research with my supervisors. Both Ann and Greg have taught me to think analytically, to work hard on my writing and to open up my mind to different ideas and concepts. Ann also gave me great tips on fun things to do in and around Sydney – although I am still not hooked on vegemite. And I've enjoyed discussing Australian and world affairs with Greg. I am also extremely grateful to my associate supervisors, Tim Flannery and Mark Taylor, for their support and guidance. Doing a PhD is an apprenticeship, I have a lot more to learn and I look forward to continuing the connection with my supervisors.

I am grateful to Anne Larigauderie and Anne-Hélène Prieur-Richard for supporting my efforts to balance work and PhD research commitments. Rik Leemans has provided me with research opportunities, invaluable feedback on draft manuscripts, encouragement and support. I have had the pleasure of being involved in a global network of incredible colleagues devoted to integrated Earth system science. Throughout my candidature they have provided advice, support and words of encouragement at conferences and workshops, over dinner and drinks, email exchanges and telephone calls. Special thanks go to David Allen, Gerhard Breulmann, Wendy Broadgate, Lou Brown, Colin Butler, Pep Canadell, Liese Coulter, Valery Detemmerman, Kris Ebi, Roland Fuchs, Anita Ghosh, Leah Goldfarb, Ada Ignaciuk, John Ingram, Sari Kovats, Myanna Lahsen, Paul Leadley, Andrew Matthews, Tony McMichael, Hal Mooney, João Morais, Amir Muhammed, Alice Newton, Graeme Pearman, Mirjam Pulleman, Mark Rosenberg, Thomas Rosswall, Heike Schroeder, Will Steffen, Linda Stevenson, Hassan Virji, and Oran Young.

Academic staff at Macquarie University have provided me with fantastic collegial support. Thank you: Macro Amati, Paul Beggs, Jette Bollerup, Michael Chang, Kevin Cheung, Kirsty Davies, Peter Davies, Kelly Dombroski, Robyn Dowling, Grant Edwards, Ian Goodwin, Damian Gore, Sara Fuller, Sandy Harrison, Paul Hesse, Donna Houston, Richie Howitt, Lesley Hughes, Carol Jacobson, Alison Jaggard, Angela Maharaj, Ross MacKenzie, Jess McLean, Fiona Miller, Emily O'Gorman, Mike Poulsen, Colin Prentice, Tim Ralph, Anne-Louise Semple, Catherine Simpson, Sandie Suchet-Pearson, Frank Thomalla, and Kira Westaway. Thanks also to professional staff: Glenys Hale, Farhana Haque, Darina Nevicka, and Paula Wells; IT and building services staff: Michael Bastion, Ron Claassens and Phil Ingram; university librarian: Andrew Spencer; and Leigh Stass for Climate Futures seminar invites. I am also grateful to Macquarie University for a scholarship and to Higher Degree Research and Faculty of Science staff for their assistance.

I am indebted to Ann El Khoury, Brian Henderson-Sellers, Supriya Mathew, Kendal McGuffie, Liam Phelan, and Ros Taplin for research advice and feedback on draft manuscripts, survey interviews and questionnaires; and statistical analysis advice from John Crawford. I have also benefited from the input of my thesis examiners and anonymous reviewers of my published book chapter and journal articles, their insightful comments have helped shape this thesis.

Thank you fellow PhD-ers: Rebecca Bilous, Pam Box, Amy Chen, Claire Colyer, David Crew, Riyanti Djalante, Steph Gardham, Marnie Graham, Nguyen Hai, Laura Hammersley (writing collectives convenor), Gina Hammond, Minna Hsu, Rabiul Islam, Yaoyao Ji, Xiao Feng Li, Liz Morgan, Joseph Maina, Tom Mortlock, Tetsuya Okada, Benjamin Okwuofu-Thomas, Suresh Othayoth, Natasha Udu-gama (my office mate, for her support and good humour), Lang Wang, Mingzhu Wang, and Liqin Wu. We're all in it together!

Being able to (occasionally) relax is an important skill for surviving a PhD. Many thanks to friends (home and away) for good times. Special thanks to Sydney-based friends Jenny & Keith, Hannah & Keith, Nadia & Tom, and Steph & Andy for helping me find the 'off' switch and to friends - Ann & Jeremy, Greg & Cheryl, Joel & Jacqui, Neil & Laura, Marion & Peggy, Phil & Marie-Anne, Anne-Hélène & Vincent, Ayesha & Thierry, Brian, Hulda, Johanna, Julien, Michelle, and Rebekah – for their skype chats and emails providing support and encouragement. Thanks also to my family back home in Scotland: my Mum & Dad, my brother Mike and his wife, Jane, my Gran, the McGowans and the Robertsons.

Lastly, special thanks to my partner, Michelle, for her love and support. For always being there for me, through thick and thin.

# Contents

## Contributions to papers

This PhD is presented in thesis by papers form. Some chapters include stand-alone papers. These papers are published, in print or under review for publication, as indicated. Indicative of the interdisciplinary and international scope of this study, the papers included in this thesis were co-authored by the PhD candidate, supervisors and other co-authors from the candidate's professional network. The table below summarises the respective contributions of authors to each of the papers included in this thesis.

**Summary of authors' contributions to papers contained in this thesis**

| Paper | Conceptualisation | Data collection & research | Writing |
|---|---|---|---|
| **Paper A** (Chapter 2) | 70% Rice<br>30% Henderson-Sellers | 70% Rice<br>30% Henderson-Sellers | 70% Rice<br>30% Henderson-Sellers |
| **Paper B**[1] (Chapter 2) | 40% Rice<br>50% Ignaciuk<br>10% Leemans | 40% Rice<br>40% Ignaciuk<br>5% Ingram<br>5% Bogardi<br>5% Canadell<br>5% Dhakal | 35% Rice<br>30% Ignaciuk<br>10% Ingram<br>5% Bogardi<br>5% Canadell<br>5% Dhakal<br>5% Leemans<br>5% Rosenberg |
| **Paper C** (Chapter 3) | 100% Rice | 100% Rice | 100% Rice |
| **Paper D** (Chapter 3) | 70% Rice<br>15% Henderson-Sellers<br>15% Walkerden | 100% Rice | 70% Rice<br>15% Henderson-Sellers<br>15% Walkerden |
| **Paper E** (Chapter 4) | 70% Rice<br>15% Henderson-Sellers<br>15% Walkerden | 100% Rice | 90% Rice<br>5% Henderson-Sellers<br>5% Walkerden |
| **Paper F** (Chapter 4) | 50% Rice<br>50% Henderson-Sellers | 100% Rice | 80% Rice<br>20% Henderson-Sellers |

[1] Paper B is included in this project because it discusses issues central to this thesis. I am the corresponding author and I wrote the abstract and most of the introduction, genesis and transformation of the ESSP sections and I contributed to the opportunities and challenges section. The lead author confirms the PhD candidate's contributions to Paper B in Appendix One.

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[2] The figures, tables and boxes are not numbered here because corresponding figures in stand-alone papers would have different numbers.

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## Abbreviations and definitions

This listing includes abbreviated forms and defines some specific terms that appear in this PhD thesis.

| | |
|---|---|
| AAAS | American Association for the Advancement of Science |
| ABC | Australian Broadcasting Corporation |
| AIMES | (IGBP) Analysis, Integration and Modelling of the Earth System |
| APA | American Psychological Association |
| APN | The Asia-Pacific Network for Global Change Research |
| AR4 | Fourth Assessment Report of the Intergovernmental Panel on Climate Change |
| AR5 | Fifth Assessment Report of the Intergovernmental Panel on Climate Change |
| BBC | British Broadcasting Corporation |
| CCAFS | Climate Change, Agriculture and Food Security |
| CCN | Cloud Condensation Nuclei |
| CGIAR | Consultative Group of International Agricultural Research |
| CMIP | Coupled Model Intercomparison |
| COP | Conference of the Parties to the UNFCCC (the United Nations Framework Convention on Climate Change) referred to by number (e.g. COP15 or COP16) |
| CRU UEA | The Climatic Research Unit of the UK's University of East Anglia |
| DIVERSITAS | An international programme on biodiversity science |
| DMS | Dimethyl Sulfide |
| EMIC | Earth System Model of Intermediate Complexity |
| ES | Earth System |
| ESA | Earth System Analysis |
| ESS | Earth System Science |

| | |
|---|---|
| ESSP | Earth System Science Partnership |
| FAO | UN Food and Agriculture Organisation |
| FE | Future Earth |
| GARP | Global Atmosphere Research Programme |
| GCM | Global Circulation Model |
| GCP | Global Carbon Budget |
| GEC | Global Environmental Change |
| GECAFS | Global Environmental Change and Food Systems |
| GECHH | Global Environmental Change and Human Health |
| GHG(s) | Greenhouse Gas(es) |
| GMF | Global Media Forum |
| GWSP | Global Water System Project |
| IAI | Inter-American Institute for Global Change Research |
| ICSU | International Council for Science |
| IGBP | International Geosphere-Biosphere Programme |
| IHDP | International Human Dimensions Programme on Global Environmental Change |
| IPCC | Intergovernmental Panel on Climate Change |
| ISSC | International Social Science Council |
| JCR | Journal Citation Reports |
| LBA | Large-Scale Biosphere Atmosphere Experiment in Amazonia |
| MAIRS | Monsoon Asia Integrated Regional Study |
| MEA | Millennium Ecosystem Assessment |
| NASA | National Aeronautics and Space Administration |
| NOAA | National Oceanic and Atmospheric Administration |
| NSF (USA) | National Science Foundation |
| OSC | Open Science Conference |

| | |
|---|---|
| PB | Planetary Boundaries |
| PNAS | Proceedings of the National Academy of Sciences |
| ppmv | Parts per million ($10^6$) by volume |
| PR | Public Relations |
| RCP | Regional Concentration Pathways |
| RECCAP | REgional Carbon Cycle Assessment and Processes |
| SCOPE | Scientific Committee on Problems of the Environment |
| START | global change SyTem, Analysis, Research and Training |
| TDR | Transdisciplinary Research |
| UN | United Nations |
| UNEP | United Nations Environment Programme |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WCRI | World Conference on Research Integrity |
| WCRP | World Climate Research Programme |
| WG | Working Group (of the IPCC) either WG1, WG2 or WG3 |
| WGCM (WCRP) | Working Group on Coupled Modelling |
| WHO | World Health Organization |
| WMO | World Meteorological Organization |
| WSSD | World Summit on Sustainable Development |

# 1. Introduction

Unprecedented human transformation of the Earth system (ES) is a major cause of intertwined sustainability crises (Ehrlich et al., 2012), such as accelerating climate change (Richardson et al., 2009), increasing biodiversity loss (Cardinale et al., 2012), food shortfalls (Ingram et al., 2010), and water insecurity (Vörösmarty et al., 2010). Despite advances in Earth system science (ESS), that generates new data and provides robust analyses of global environmental changes (Zhao and Running, 2010), the transgression of planetary boundaries underscore the need for humanity to transition towards responsible engagement within the Earth system (Rockström et al., 2009a). This is one of the most important scientific and communication challenges of our time (Henderson-Sellers, 2012). However, regardless of repeated calls for broader disciplinary reach within ESS (interdisciplinary research) and more recently transdisciplinary research that brings together academics and non-academics to tackle increasingly complex global environmental challenges (Lubchenco, 1998; Steffen et al., 2004; Reid et al., 2010), the natural, social and human sciences remain poorly integrated (Pahl-Wostl et al., 2012; Mooney et al., 2013). Barriers to science integration, such as structural and evaluation biases (Kates, 1985; Mauser et al., 2013), attitudinal factors (Braddock et al., 1994; Phelan et al., 2013) and inadequate communication (Bradbeer, 1999; Phelan et al., 2013) have persisted for too long. It is vital that they are overcome. This thesis, therefore, investigates how ES research can become more integrated and better communicated to contribute to solutions to twenty-first century sustainability challenges.

The thesis takes as its starting point the Gaia hypothesis (Lovelock & Margulis, 1974), which helped advanced the notion of an integrated Earth system (ES). Through a climate science lens, 'Gaian-type experiments' have, for example, illuminated the role of algae in the ocean and their control of the Earth's climate through the dimethyl sulfide process (Charlson et al., 1987), while research on tropical forests and climate interactions (e.g. Henderson-Sellers et al., 1988) has helped advance the concept of planetary teleconnections and tipping points (e.g. Lenton et al., 2008). The Gaia hypothesis advocated by Lovelock and others has raised awareness of the Earth as an integrated system that "could hold so unstable an atmosphere in a steady state that was even more remarkably just right for life" (Lovelock, 1987, p. 13). Increasing recognition of an integrated Earth system has formed the basis of Earth system science (ESS), which is the study of the Earth and its response to anthropogenic change (Pitman, 2005).

Concurrent with an awareness of human transformations of the ES, scientists have become aware of the need for global sustainability and this has been coupled with repeated calls for integrated ES research on environmental changes (Lubchenco, 1998; Clark & Dickson, 2003; Steffen et al., 2004; Schellnhuber et al., 2005). There is a significant body of academic literature providing definitions of integrated (interdisciplinary and transdisciplinary) research (e.g. Klein, 2000; Newell, 2001; Scholz et al., 2006; Tress et al., 2006; Wagner et al., 2011). For the purpose of this thesis, interdisciplinary research is understood to be a priority scientific enterprise crossing natural, social and human science disciplines to address a complex challenge, while transdisciplinary research involves transcending disciplines and engaging with non-academics, such as users of scientific information from the outset and throughout the research process. A central tenet of interdisciplinary and transdisciplinary research is an integration of knowledge to tackle societally relevant problems (Morillo et al., 2001; Klein, 2008; Glaser et al., 2012). Societally relevant problems in ES research include, for example, climate change, biodiversity loss and emerging infectious diseases; water resources; energy security; human health; ocean acidification and food security.

Central to this thesis is the realisation that human behaviour is now a massive component of the ES. Humanity, particularly western material wealth-oriented societies (Lowe, 2008), is driving the planet from the stable Holocene into a new epoch, the Anthropocene (Crutzen, 2002). This thesis considers several responses by the ES research community, including (i) the recognition of an integrated ES under pressure from human transformation and the articulation of the Amsterdam Declaration; (ii) the need for interdisciplinary research and the establishment of a scientific partnership to study changes to an integrated ES and the implications for sustainability; (iii) the 'Planetary Boundaries' concept that sets parameters in which human society may continue successfully (Rockström et al., 2009a, 2009b; Steffen & Stafford Smith, 2013); and (iv) recent examples of transdisciplinary research to tackle complex ES-derived challenges. Staying within a safe operating system will require an integrated approach, linking economic, social and environmental dimensions (Lowe, 2010; Griggs et al., 2013).

Rather than mindlessly geo-modifying the ES, humanity has a unique opportunity and responsibility to contribute to humanity's responsible engagement within the Earth system. One of my assumptions is that integrated ESS is grounded by social goals to act in the publics' interest to identify, quantify, communicate and contribute to responses to global environmental challenges. However, after reviewing the literature, this thesis reveals persistent barriers that are debilitating broad science integration. Furthermore, ES-derived challenges require an international response, yet existing global environmental governance structures (e.g. the United Nations Framework Convention on Climate Change) are ill-equipped for grand sustainability challenges, such as anthropogenic climate change (Biermann et al., 2012). Nations have to implement their own policies to tackle climate change and their willingness to do so depends on public opinion (Pietsch & McAllister, 2010). Because climate change is such a critical societal problem, it is essential that the public receives evidence-based scientific information about ES-derived challenges. Interdisciplinary research, it is said, can help quantify, analyse, and communicate increasingly complex global environmental problems. This thesis, therefore, studies two major conduits of ES information: interdisciplinary environmental journals and the mass media. Additionally, this research discusses opportunities for ES research to become more integrated and better positioned to help society understand and respond to ES-derived sustainability challenges.

This research uses both qualitative and quantitative methods, including survey interviews, bibliometric measures and synthesis-type research. It is interdisciplinary in nature and scope.

### 1.1. Scope

Integrated ESS is an extremely broad enterprise and I have many interests, including emerging science findings, research practice, ES governance and science communication. A major challenge was, therefore, to set realistic and original research boundaries to this thesis. There are three dimensions that define the scope of this work. The first dimension relates to the genesis and evolution of integrated ESS and its major scientific accomplishments. The second dimension concerns how integrated ES research can contribute to the identification, analysis and communication of emerging global environmental challenges. The third dimension considers how ESS can become more integrated and better positioned in order to help society respond to global environmental challenges. The following schematic depicts the scope of this research (Figure 1).

**Figure 1: Thesis scope**

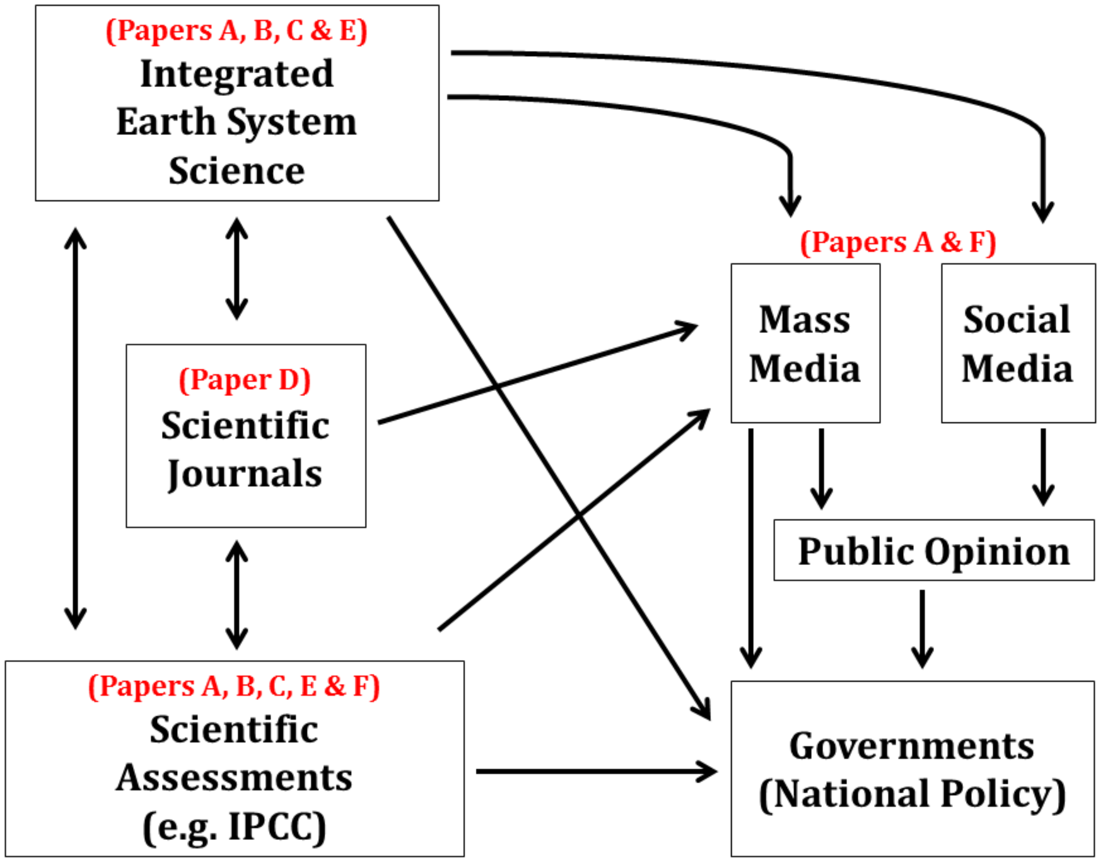


**Figure 1:** This schematic diagram shows the set of phenomena and their relationships examined in this thesis. Integrated ES science identifies and quantifies global environmental changes (Papers A, B, C and E). Research findings are usually communicated via two main channels: interdisciplinary environmental journals (Paper D) and the mass media (Paper F). ES science findings published in peer-reviewed

scientific journals contribute to scientific assessments, while governments receive information both directly from scientists and via assessments (synthesis of the scientific literature, for example, the Intergovernmental Panel on Climate Change (IPCC) and the Millennium Ecosystem Assessment (MEA)) (Papers A, B, C, E and F), and, via media reports of findings (Papers A and F). Public ES science information derives largely from the mass and social media and this view then influences policy (Paper F).

## 1.2. Research aim and questions

The overarching aim of this research is to examine if Earth system research is integrated enough to contribute to solutions to twenty-first century sustainability challenges. The specific research questions derived from the aim of this study are:

1. *What is integrated ES research and what has it accomplished?*

This research question is addressed in Chapter Two (Paper A: future climate & transdisciplinary ESS and Paper B: ESSP & interdisciplinary research).

2. *Are there opportunities commensurate to the task of practising and publishing integrated ES research that identifies, quantifies and communicates global environmental challenges?*

This research question is addressed in Chapter Three (Paper C: evolution & practice of integrated ESS and Paper D: interdisciplinary environmental journals) and Appendix Two.

3. *How can ES research become more integrated and better positioned to contribute to humanity's responsible engagement within the Earth system?*

This research question is addressed in Chapter Four (Paper E: inter-to-disciplinary lifecycle and Paper F: media & climate change) and Appendices Two and Three.

Responses to all of the specific research questions are spread across the papers located in the PhD's various chapters. Table 1 at the end of this chapter summarises the overarching research aim, specific research questions, and where the answers to these questions can be found in this thesis. At the end of Chapters Two, Three and Four a figure summarises the accumulated contributions of papers to the thesis research questions, as articulated in Section 1.2. Iterations of this figure culminate in a brief description of how the papers have responded to the overarching aim of the thesis and the articulation of future research directions in Chapter Five and thesis conclusions in Chapter Six.

### 1.3. Thesis structure

I chose to undertake a thesis by publication because my aim for this research is to contribute to (i) knowledge on integrated ES research practice and (ii) gain publication experience. Furthermore, published papers are likely to reach far more readers than a traditional thesis[3]. Unavoidably there is some overlap across these papers: whilst the research was conducted to contribute towards individual chapters for this PhD, the papers were written with the additional intention that each may stand-alone, publishable as journal articles or book chapters.

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[3] It is also Macquarie University's preferred thesis model. See: http://www.mq.edu.au/policy/docs/hdr_thesis/policy.html

Stand-alone papers included as chapters are presented in the format in which they were published or submitted for publication. A consolidated reference list of paper references and references for parts of the thesis not created in published paper format is included at the end of this document. The paper found in Appendix Two (transdisciplinary research) is a research output of a project I was extensively involved in, including contributions to project design, implementation and management, and as a co-convenor of a project-related workshop. This paper is relevant to this thesis because it describes what integration entails and it elucidates a framework that we developed for integrated ES research for sustainability. Appendix Three is a response to a Proceedings of the National Academy of Sciences (PNAS) published letter I wrote with my adjunct supervisor (Paper E: interdisciplinary-to-disciplinary lifecycle).

The thesis is structured in support of the research aim and research questions (Section 1.2). This chapter introduces the thesis overall, formalises the scope of the research and elucidates the guiding research aim and questions. Chapter Two describes the genesis and evolution of integrated ES science and what it has accomplished (Paper A: future climate & transdisciplinary ESS). Building on the notion of the need for integrated ES science, Chapter Two describes the experiences of a scientific partnership which was established to provide opportunities for natural and social scientists to work together to study the changes to an integrated ES and the implications for global sustainability (Paper B: ESSP & interdisciplinary research).

Chapter Three describes the conceptualisation and practise of integrated (interdisciplinary and transdisciplinary) ES research on global environmental changes.

Multidisciplinary research involves

> two or more disciplines addressing a common problem. There may be an exchange of information and ideas between different disciplinary partners, but participants generally frame their research goals and outputs in terms of their 'home' disciplines (Hinrichs, 2008, p. 210)

while interdisciplinary approaches "integrate separate [natural and social science] disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of a complex issue, question or problem" (Wagner et al., 2011, p. 16). Transdisciplinary research "integrates academic researchers from different disciplines and non-academic participants to research real world problems and create new knowledge and theory. Transdisciplinarity combines interdisciplinarity with a participatory approach [involving engagement of scientists and non-academic stakeholders throughout the research process]" (Cronin, 2008, pp. 4-5).

By reviewing literature, Chapter Three identifies an advanced conceptualisation of integrated research, yet barriers to integration persist (Paper C: evolution & practice of integrated ESS). Furthermore, this chapter presents a novel study of a major conduit of interdisciplinary research: environmental journals. The aim of this study is to examine the disciplinary reach of environmental journals that describe themselves as interdisciplinary, and their processes for evaluating the quality of the articles submitted to them (Paper D: interdisciplinary environmental journals).

Chapter Four does two things. Firstly, it considers what is required to help ESS become more integrated by overcoming persistent barriers to science integration (Paper E: inter-to-disciplinary lifecycle). Secondly, it reflects on how to better position ES research findings, focusing on the performance of the mass media and the engagement of an interface group of journalists and scientists with a vested interest in evidence-based reporting of climate change (Paper F: media & climate change).

Discussion of the study's findings and some potential directions for future research as a result of this project is provided in Chapter Five, including implications of the study's responses to the original research questions. Chapter Six concludes by summarising the main findings of this PhD research.

## 1.4. Research questions and response locations

Table 1 summarises the thesis structure with reference to research questions and locations of responses in this thesis.

**Table 1: Research questions and where answers are located**

<table>
<tr><td rowspan="2">1</td><td>Research question: What is integrated ES research and what has it accomplished?</td></tr>
<tr><td>This question is addressed in two parts, the first of which examines the evolution and genesis of ES research through a climate science lens (Paper A) and the second of which is a case study of an interdisciplinary scientific partnership established to study changes to an integrated ES and the implications for global sustainability (Paper B):<br><br><u>Chapter Two</u><br><br>• Paper A: Peer-reviewed book chapter. Rice M. and Henderson-Sellers A. (2012). Future Climate: One Vital Component of Trans-disciplinary Earth System Science, In: Ann Henderson-Sellers and Kendal McGuffie (Eds.), The Future of the World's Climate (Second Edition). Elsevier, Boston: 509-529. ISBN 9780123869173, 10.1016/B978-0-12-386917-3.00018-X.<br><br>• Paper B: Peer-reviewed paper. Ignaciuk A., Rice M., Bogardi J., Canadell J.G., Dhakal S., Ingram J., Leemans R., Rosenberg M. (2012). Responding to Complex Societal Challenges: A decade of Earth System Science Partnership (ESSP) interdisciplinary research. Current Opinion in Environmental Sustainability, 4 (1): 147-158.</td></tr>
<tr><td rowspan="2">2</td><td>Research question: Are there opportunities commensurate to the task of practising and publishing integrated ES research that identifies, quantifies and communicates global environmental challenges?</td></tr>
<tr><td>This question is answered in two parts, with additional information provided in Appendix Two. First, the conceptualisation and practice of integrated ES research are examined (Paper C). Second, interdisciplinary environmental journals are studied in order to determine the disciplinary reach of environmental journals that describe themselves as interdisciplinary, and their processes for evaluating the quality of the articles submitted to them (Paper D).</td></tr>
</table>

| | |
|---|---|
| | Chapter Three<br><br>• **Paper C:** Peer-reviewed paper. Rice M. (2013). Spanning Disciplinary, Sectoral and International Boundaries: A Sea Change towards Transdisciplinary Global Environmental Change Research? Current Opinion in Environmental Sustainability, 5 (3-4): 409–419. http://dx.doi.org/10.1016/j.cosust.2013.06.007.<br><br>• **Paper D:** Manuscript under review: Climatic Change. Rice M., Walkerden G., Henderson-Sellers A. Interdisciplinarity in Environmental Journals: What's in a Name?<br><br>Appendix Two |
| **3** | **Research question: How can ES research become more integrated and better positioned to contribute to humanity's responsible engagement within the Earth system?** |
| | This question is answered in two parts, with additional information provided in Appendices Two and Three. First, opportunities to overcome persistent barriers to integration are described (Paper E). Second, the performance of the mass media as a major channel of public climate information is examined (Paper F).<br><br>Chapter Four<br><br>• **Paper E:** Published letter (29 May 2013). Rice M. and Henderson-Sellers A. (2013). Surviving the growing pains of the inter-to-disciplinary lifecycle. Proceedings of the National Academy of Sciences, USA. Early edition, www.pnas.org/cgi/doi/10.1073/pnas.1306270110.<br><br>• **Paper F:** Article in press (accepted on 9 July 2013). Rice M., Henderson-Sellers A., Walkerden G. (2013). Overcoming A Diabolical Challenge: Comparing journalists' and researchers' views on the performance of the media as a channel of climate change information. International Journal of Science Education, Part B. Communication and Public Engagement. http://dx.doi.org/10.1080/21548455.2013.824131.<br><br>Appendices Two & Three |

# 2. Integrated Earth System Research and its Accomplishments

## 2.1. Introduction

Chapter Two is based on Paper A *'Future Climate: One Vital Component of Trans-disciplinary Earth System Science'* and Paper B *'Responding to complex societal challenges: A decade of Earth System Science Partnership (ESSP) interdisciplinary research'*. This chapter describes what integrated ES research is and what it has accomplished.

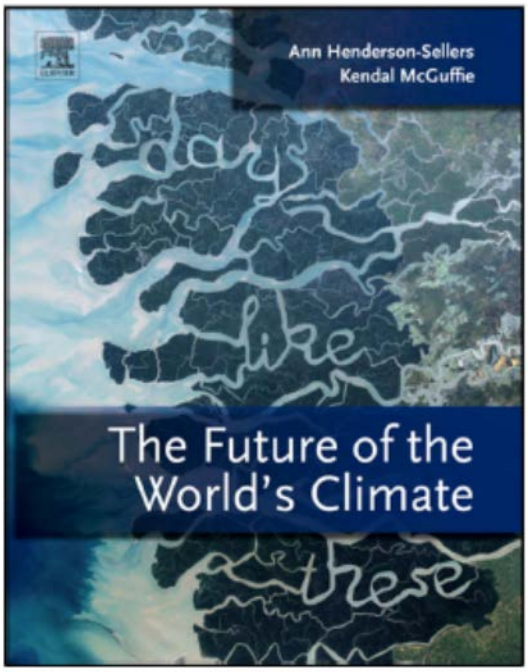
Chapter Two examines climate futures relative to ES study, describing how attempts to describe the way in which the complete ES may work have frequently used climate to illustrate processes and to demonstrate the emergence of new characteristics. Schematics and models of Gaian worlds have enabled ES thinking to move from a climate focus to more holistic views. Increasingly, thinking of the ES in terms of climate futures is being replaced by a new systems approach to the integrated study of the Earth that goes beyond traditional disciplinary boundaries. Increasing recognition of an integrated ES and the need to focus on the nexus between human and environmental systems in order to achieve sustainability led to the establishment of the Earth System Science Partnership (ESSP). This chapter reveals how the ESSP institutionally evolved to provide opportunities for interdisciplinary research on, for example, the carbon cycle, food systems, the global water system and global environmental change and human health.

The aim of Chapter Two is to describe the genesis and evolution of ES research, driven by the scientific community's increasing recognition that humans are a massive component of an integrated ES causing unprecedented global sustainability challenges. However, despite advances in ES research, this chapter contends that climate change is too narrow a framing of ES-derived challenges. To move forwards a more integrated, transdisciplinary ES approach is required to contribute to solutions to twenty-first century global environmental problems.

## 2.2. Paper A: 'Future Climate: One Vital Component of Trans-disciplinary Earth System Science'

Peer-reviewed book chapter: Rice M. and Henderson-Sellers A. (2012). Future Climate: One Vital Component of Trans-disciplinary Earth System Science. In: Ann Henderson-Sellers and Kendal McGuffie (Eds.) The Future of the World's Climate (Second Edition, pp. 509-529), Boston, USA: Elsevier.

http://www.sciencedirect.com/science/article/pii/B978012386917300018X[4].




[4] The references cited are included in the omnibus list at the end of this thesis.

Pages 16-36 of this thesis have been removed as they contain published material. Please refer to the following citation for details of the article contained in these pages.

Rice, M., & Henderson-Sellers, A. (2012). Future climate: one vital component of trans-disciplinary earth system science. In A. Henderson-Sellers, & K. McGuffie (Eds.), *The future of the world's climate* (2nd ed., pp. 509-529). Waltham; Oxford: Elsevier.

DOI: 10.1016/B978-0-12-386917-3.00018-X

## 2.3. Paper B: 'Responding to complex societal challenges: A decade of Earth System Science Partnership (ESSP) interdisciplinary research'

Peer-reviewed paper: Ignaciuk A., Rice M., Bogardi J., Canadell J.G., Dhakal S., Ingram J., Leemans R., Rosenberg M. Responding to Complex Societal Challenges: A decade of Earth System Science Partnership (ESSP) interdisciplinary research (2012) *Current Opinion in Environmental Sustainability*, 4 (1): 147-158.

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Current Opinion in Environmental Sustainability

# Responding to complex societal challenges: A decade of Earth System Science Partnership (ESSP) interdisciplinary research

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The Earth system is an integrated, self-regulating system under increasing pressure from anthropogenic transformation. The Earth System Science Partnership (ESSP), which was established by the international global environmental change research programs (i.e., DIVERSITAS, IGBP, IHDP and WCRP) facilitates the study of this system in order to understand how and why it is changing, and to explore the implications of these changes for global and regional sustainability. Crucial to this scientific enterprise are interdisciplinary Joint Projects on carbon, food, water and health. This paper analyses the scientific and institutional evolution of ESSP as a framework for interdisciplinary and integrative research of societal relevance. Case studies on food systems, carbon budgets, water security and biodiversity conservation illustrate how these projects have advanced integrated Earth system knowledge. At the institutional level, we explain the transformation of the ESSP governance and how this has further enabled interdisciplinary research. The lessons learnt from ESSP research can contribute to the development of the next generation of Earth system science for sustainability.

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**Current Opinion in Environmental Sustainability** 2012, **4**:147–158

This review comes from the Open issue
Edited by Rik Leemans

Received 22 October 2011; Accepted 20 December 2011
Available online 11th January 2012

1877-3435/$ – see front matter
Published by Elsevier B.V.

**DOI** 10.1016/j.cosust.2011.12.003

## Introduction

The Amsterdam Declaration, endorsed by participants at the 'Global Environmental Change Open Science Conference' in 2001 [1], describes the Earth system as a single, self-regulating system under rapid human transformation. It recognized both the scientific progress of the international Global Environmental Change (GEC) research programs (DIVERSITAS: the International Programme on Biodiversity Science; IGBP: International Geosphere-Biosphere Programme; IHDP: International Human Dimensions Programme for Global Environmental Change; and WCRP: World Climate Research Programme) and the need for a new partnership to further advance and integrate Earth system knowledge [2]. Acting on the Declaration, the four GEC research programs created the Earth System Science Partnership (ESSP). The ESSP facilitates the study of the Earth's environment as an integrated system in order to understand how and why it is changing, and to explore the implications of these changes for global and regional sustainability [3••]. A critical component of this scientific enterprise is the set of interdisciplinary Joint Projects on carbon, food, water and health.

The nonlinearity and complexity of natural and social processes are recognized and policy makers pose questions for which solutions require collaboration between various stakeholders (e.g., researchers, decision makers, engineers, private sector representatives). For instance, the problems of food, water and energy security need to be tackled in more holistic ways, allowing for a variety of different systemic feedbacks and inclusion of the expertise of many different disciplines. Working in their respective fields, the resulting ESSP Joint Projects integrate Earth system knowledge and contribute to the quantification of risks posed by GEC. The future solutions, however, will also have to be built on knowledge beyond the research community.

This paper critically assesses a decade of ESSP activities and draws conclusions of what can be learnt from all these effort to aggregate, integrate and synthesize GEC research. Such an assessment is especially important considering current plans for a new Earth System Sustainability Initiative, called Future Earth, which will shape the next generation of GEC research. This initiative is currently being planned by the International Council for Science (ICSU) and the International Social Science



Ignaciuk, A., Rice, M., Bogardi, J., Canadell, J. G., Dhakal, S., Ingram, J., ... Rosenberg, M. (2012). Responding to complex societal challenges: A decade of Earth System Science Partnership (ESSP) interdisciplinary research. Current Opinion in Environmental Sustainability, 4(1), 147-158. https://doi.org/10.1016/j.cosust.2011.12.003

Council (ISSC) in collaboration with the Belmont Forum (BF[9]) and other international organizations (e.g., UNEP and UNESCO) [4]. Future Earth strongly builds on experiences from current international GEC research but it calls for a stronger focus on joint research efforts by natural scientists, social scientists, humanists and engineers, and for working with stakeholders/users to contribute to the co-design of a globally and regionally sustainable future.

## The genesis of ESSP

The chairs and directors of the GEC research programs met annually throughout the 1990s to exchange information about scientific progress of their individual core projects and networks, and to identify potential areas of future research. These meetings were rather informal. However, with increased recognition of Earth as an integrated system, the chairs and directors started to consider how to embark on more collaborative, interdisciplinary Earth system research. In the late 1990s, therefore, they envisaged an additional research structure geared toward issues of greater interest to society at large. Rather than disciplinary focused research, novel interdisciplinary GEC research was proposed to address also the societal dimensions of complex themes such as carbon, energy, water resources, food security and health. Realizing that input for such endeavors would need to come from a range of disciplines, the chairs and directors discussed the necessity of a partnership with joint inputs from all programs. The chairs and directors therefore agreed to initiate a set of Joint Projects with members of the GEC research community dealing most closely with these issues [5]. In 2001, the Earth System Science Partnership (ESSP) was launched by DIVERSITAS, IGBP, IHDP and WCRP. In addition the Global Change SysTem for Analysis, Research, and Training (START) also became a partner of the ESSP. START, established in 1992, is a capacity building and research network co-sponsored by IGBP, IHDP and WCRP. Despite having no institutional home (secretariat) or significant resources (except initial GEC program support) to operate this new scientific framework (see also 'Transformation' section), it was envisioned that the ESSP would become an innovative approach for harnessing more relevant for society research benefiting from the expertise of the GEC research community.

The enthusiasm and willingness of the GEC research programs to work together in the early stages of ESSP's existence greatly stimulated the development of the Joint Projects: The Global Environmental Change and Food Systems (GECAFS [22]) and the Global Carbon Project (GCP [6]) were both established in 2001. At the same time, planning started for the third Joint Project, the Global Water System Project (GWSP [7]), which established its international project office in 2004 and launched its Science Plan and Implementation Strategy one year later. Global Environmental Change and Human Health (GECHH [8]) was planned at a later stage with the science plan and implementation strategy launched at the ESSP Open Science Conference in 2006 and established an operational project office in 2010. Each of the Joint Projects created research networks and published their own Science Plan and Implementation Strategy. The unique scientific niche of these projects was also identified, drawing on expertise and synthesized knowledge of the core projects and the GEC research community. New types of science products emerged and formal partnerships established with a range of UN agencies and other national and international bodies.

Below we discuss programs, partnerships, Joint Projects, core projects and networks. These are defined in the lexicon of GEC research (Table 1).

## Transformation

The governing body of the ESSP, for the first six years of its existence (2001–2006), consisted of the chairs and directors of the GEC programs. This body made the executive decisions and the Joint Project Executive Officers were invited to provide scientific input to the meetings. In September 2005, with financial support from the National Science Foundation (USA) and other funders, a small ESSP Coordination Office was established. International Project Offices were also established and the Joint Projects began to develop impressive networks of researchers involved in Joint Project interdisciplinary research. By 2006 around ten professional staff were involved in research coordinating activities and hundreds were actively pursuing the research agendas of the Joint Projects.

### Governance challenges

An integrated approach to the study of the Earth system is not only scientifically complex but it is also challenging at the institutional level. For example, despite their commitment to ESSP, the programs had to manage (and prioritize) challenges and opportunities of their own individual activities and constituents. The need for an improved governance structure that would ensure representation of all components of the ESSP, soon became evident. Therefore, at the 2006 meeting in Tutzing, Germany, of the chairs, directors and the Joint Projects and ESSP officers proposed to establish a Scientific Committee (SC) for the ESSP. The SC included: firstly, proportional representation by each of the sponsoring programs; secondly, representation for the ESSP Joint Projects, START and other major ESSP activities (e.g., Integrated Regional Studies); and finally, representation from 'outside' the ESSP network. The SC

[9] The Belmont Forum is an international Alliance of funding agencies who support GEC research.

**Table 1**

**The lexicon of global environmental change organizations.**

| | Definitions | Organizations |
|---|---|---|
| Global environmental change programs | Programs are legally recognized scientific organizations that coordinate GEC research. They are co-sponsored by major agencies, such as the International Council for Science, the United Nations Educational, Scientific and Cultural Organization and the World Meteorological Organization. | DIVERSITAS, IHDP, IGBP, WCRP |
| Partnerships | Partnerships are in-formal arrangements established by the GEC research programs to exchange ideas, synthesize and communicate integrative GEC research findings and conduct interdisciplinary research. | ESSP |
| ESSP joint projects | Joint Projects are sponsored by at least three GEC research programs, promoting interdisciplinary research across disciplinary boundaries (natural and social science). The ESSP Joint Projects are designed to directly address the two-way interaction between GEC and global and regional sustainability issues. The Joint Projects also benefit from the expertise and synthesized knowledge of the Core Projects and the GEC research community. | GCP, GECAFS, GWSP & GECHH |
| Core projects | Core projects are disciplinary enterprises sponsored by one GEC research program, designed to research one specific field/scientific challenge. | For example, bioGENESIS (DIVERSITAS); Integrated Land Ecosystem-Atmosphere Processes Study (IGBP); Urbanization and Global Environmental Change (IHDP); Stratospheric Processes And their Role in Climate (WCRP). |
| Regional networks | Regional networks provide opportunities to enhance GEC research and networking capacity, particularly in developing countries. | Asia-Pacific Network for Global Change Research (APN), Inter-American Institute for Global Change Research (IAI), and global change SyTem for Analysis, Research, and Training (START). |

should be led by an independent chair, appointed by ICSU. In this way the ESSP governance structure resembles more closely that of the sponsor programs.

### Partnership or program?

At the same meeting, the possibility of all four programs and the ESSP moving toward a unified, well-structured integrated GEC research program was considered. The motivation for transforming the ESSP from a loose scientific partnership into a legally recognized integrated program was simple: to increase visibility for this scientific enterprise, attract more resources and contribute to the advancement of interdisciplinary Earth system science. As part of this long-term vision, it was agreed that the ESSP would become a program. This decision was also supported by ICSU. However, some of the partners stated that considering the sheer magnitude of this change, there should be a community-wide consultation process and this decision was not implemented. Several advantages and disadvantages of ESSP becoming a program were noted by various partners. The advantages, for example, included:

- an ESS program would complement the four GEC programs by having its own intellectual agenda and mechanism (activities) to address cross-cutting topics that the Joint Projects, START, integrated regional studies and the GEC programs cannot cover alone. It would therefore not overlay the four GEC programs as a superprogram, it would become a fifth endeavor of a highly integrative nature, closely linked to policy and other stakeholder interests;
- the ESSP would evolve as a coherent program through which all common scientific and advisory endeavors would operate in a consistent and strategic mode; and
- the new program structure would not lead to any diminishing engagement from any of the GEC programs — quite the contrary, it should help either to avoid or more easily deal with the kinds of conflicts of interest among the GEC programs that made the partnership difficult to manage at times.

The disadvantages, for example, included:

- although there was strong support for strengthening, and improving the governance and management of ESSP, and, most importantly, for advancing and further integrating Earth system science, this could also be achieved if the ESSP remained just a partnership; and
- the ESSP was not ready yet to become a program because operational funds were limited. IGBP and WCRP already had a strong interest and investment in Earth system science and a new program focusing on

the Earth system could become a competing program regarding agenda setting, involvement of scientists and funding.

### The ESSP Scientific Committee: a new voice for interdisciplinary research

The chair and director's meeting at the ESSP Open Science Conference in Beijing confirmed that ESSP would remain a partnership but now with the establishment of a SC. The next step was to establish the ESSP SC. The SC finally involved two ICSU-appointed members and the chair, GEC research programs chairs and directors, an ICSU representative, representatives of each Joint Project, integrated regional studies and START. There was a community-wide search for a Chair, who should be a well-respected scientist with interdisciplinary experience, who could advance ESSP by connecting existing activities of the GEC programs and ESSP, and who would enable new collaborative research opportunities with international organizations. Professor Rik Leemans (Wageningen University, The Netherlands) was nominated by the GEC programs and appointed by ICSU as the first Chair of the ESSP Scientific Committee. The inaugural ESSP SC meeting convened in 2007 in Paris. The chair participated in all governing meetings of the GEC programs, stimulated the development of several common activities between joint and core projects (e.g., the Climate-Convention Dialogue), and established a GEC synthesis/review journal [9].

### Review of ESSP

In 2008, an ICSU–IGFA review of the Earth System Science Partnership was completed [10]. The motivation for this review was to assist the further development of the ESSP. More specifically, despite scientific advances by the Joint Projects, there was concern that ESSP had not advanced as much as anticipated. The analysis of the review panel was based on a dialogue with the chairs and directors, ESSP and input from ICSU, IGFA and the wider community through questionnaires and interviews. The review provided guidance on options for the future. The panel elucidated that the ESSP was now more relevant than when it was established in 2001: There was a need for a robust ESSP. Key improvement areas were identified: firstly, ESSP must develop a stronger scientific focus; secondly, ESSP's structure should be driven by its scientific mandate with input from users; thirdly, ESSP must critically engage with the wider community; and finally, ESSP should continue its strategic and comprehensive approach to capacity building. Additionally the panel noted that current funding was insufficient to fulfill ESSP's mandate. The Panel was convinced that 'the status quo will inevitably result in a progressive decline of the partnership,' and thus, it recommended that 'the ESSP formulate as soon as possible a long-term vision of where it wants to be in 10 years time' (p. 8 in [10]).

In response to the review, the ESSP developed a common strategy for integrative global environmental change research and outreach [3••]. This strategy describes an internationally coordinated and holistic approach to Earth system science. The basic premise of this 'holistic' approach is to further enable interdisciplinary research — at the global and regional level — to integrate and synthesize knowledge from the natural and social sciences. This is important because no single discipline, program or nation alone can respond effectively to the increasing pressures by human transformations of the Earth system. The ESSP started to implement its integrative research and outreach strategy by developing new services that included knowledge products, Earth-system science dialogues, a synthesis journal for interdisciplinary collaborative research, and tighten its cooperation with policy makers. These activities have helped elevate ESSP's profile.

### ESSP concept revisited

Institutionally, the ESSP still remains a loose partnership of four GEC programs with no legal status. The programs and their core projects have contributed considerably to the ESSP scientific enterprise. However, programs and ESSP competed for resources at times but this did not limit interdisciplinary interactions and the creation of a more holistic strategy for integrated global environmental change research and outreach. Most of the ESSP's scientific activities rely on voluntary contributions of many researchers, who have demanding jobs at research institutes and universities throughout the world. There are ample opportunities for scientists to become involved in interdisciplinary research [11]. Education, career and funding opportunities could, however, better reflect the importance of such an integrated research approach, which contributes to the understanding of major societal challenges.

## Facilitation of global environmental change research

The research core of the ESSP is its set of Joint Projects. Their results are based on independent, participatory (both bottom up and top down approaches) and state-of-the-art science and coordinated international research initiatives. One of the main strengths of the Joint Projects is that they help assemble social and natural scientists to integrate different disciplinary concepts, tools, data and methods. Over the past decade, these Joint Projects have developed their own methodologies and approaches to build the scientific infrastructure that allows for a more integrated approach [3••]. Schmidt and Moyer [12], for example, describe the ESSP Joint Projects as an outlet for a new generation of interdisciplinary researchers.

ESSP and the four GEC programs organized the first ESSP Open Science Conference in Beijing, China, in November 2006 with the focus on 'Global Environmental Change: Regional Challenges.' Conference highlights included the launch of the first ESSP integrated regional study (Monsoon Asia Integrated Regional Study, MAIRS [13], which was coordinated by START with support from particularly the Asia-Pacific Network for Global Change Research (APN)), the publication of the science plan of GECHH and the presentation of the first annual global carbon budget and trends by GCP. However, while the conference sessions presented advances in GEC research from many disciplinary perspectives, collaborative research results between social and natural scientists remained limited.

To synthesize emerging GEC and sustainability research, the ESSP SC established a new journal 'Current Opinion in Environmental Sustainability' (COSUST), where advances in earth system and sustainability science, and science plans can be published in timely review and synthesis papers [9]. The interdisciplinary journal addresses all the environmental, economic, social, technological and institutional aspects of the sustainability challenges by integrating scientific insights and societal practices and processes. The almost immediate inclusion of COSUST in the Web-of-Science ISI journal database attested the success of this endeavor.

A crucial element of ESSP activities is its continuing dialogue with policy makers. Two pathways emerged by which the ESSP community contributes to decision-making processes and actively engages itself with both informing and shaping international policy agendas. First, numerous researchers who are closely involved in ESSP activities are also involved in various global science-policy assessments [14]. Examples include the Millennium Ecosystem Assessment, the IPCC Assessment Reports, UNEP's Global Environmental Outlook series, the triennial World Water Development Reports and various reports for international organizations, which draw knowledge from ESSP networks [15]. In recognition of its credible scientific achievements, ESSP recently signed an agreement to coordinate UNEP's scientific review of the next Global Environmental Outlook series. GEC research results are also communicated to policy communities (e.g., through the UNFCCC-Subsidiary Body for Scientific and Technological Advice dialogue) and other stakeholders. These dialogues also help to further focus research agendas on policy-relevant and timely societal issues and lay foundations for the future co-design of policy relevant projects that need an integrated approach to tackle the complex nature of global environmental change.

The ESSP, particularly through its Joint Projects, has promoted collaborative efforts with international organizations. For example, joint collaboration with the Scientific Committee on Problems of the Environment (SCOPE), UNESCO and UNEP resulted in policy briefs with GCP on the carbon cycle and GECAFS on food systems and environmental change. A major legacy of GECAFS (which ended by synthesizing its findings in 2011 [16]) was the link with the Consultative Group of International Agricultural Research (CGIAR) that led to the development of long-term ESSP-CGIAR collaborative research on Climate Change, Agriculture and Food Security (CCAFS [17]). CCAFS unites the complementary strengths of the CGIAR system and the ESSP to mitigate and adapt to climate change, which is one of the most pressing and complex challenges to food security in the 21st century.

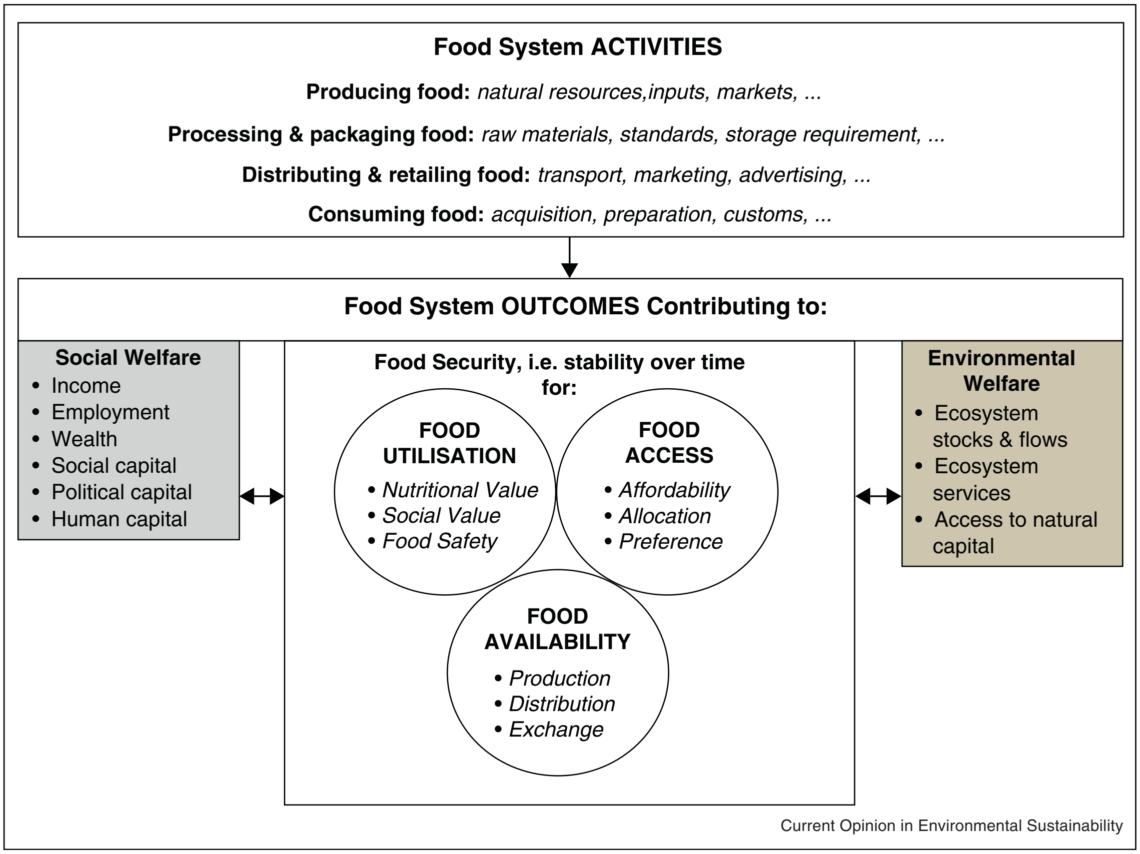
## Scientific achievements and lessons learnt

The Joint Projects are operated by officers with professional research and coordination experience, supported by a major host institution and often with several regional offices. They integrate the disciplinary perspectives and scientific advances of the GEC programs and enable new interdisciplinary research, under the leadership of the ESSP's SC and the Joint Projects' Scientific Steering Committees. Many lessons can be learnt from ESSP's experiences. The accomplishments of the Joint Projects to a large extent reflect the number of years they have operated to date.

GECAFS was established as a 10-year joint project and concluded in March 2011. In addition to substantial scientific and other outputs (see below) GECAFS identified many lessons on how to establish and deliver an interdisciplinary agenda on food security [22], aimed at assisting policy formulation and resource management, and at regional level — the three main 'charges' from the C&Ds. The first step was to establish formal, strategic partnerships with key international bodies: FAO, CGAIR and WMO. This helped increase visibility on international stage, bridge science and development agendas, the way for uptake of results and provided fundamental inputs to early planning and throughout the project.

GECAFS's objective was 'to determine strategies to cope with the impacts of GEC on food systems and to assess the environmental and socioeconomic consequences of adaptive responses aimed at improving food security.' This was derived at following many discussions with a range of stakeholders, and culminated in clear wording targeting policy and management, that stresses adaptation, and that emphasizes both socioeconomic and environmental consequences (i.e., trade-offs and synergies). GECAFS outputs included both formal science products and also improved approaches to deliver societal-relevant research. Drawing on the extensive (yet distinct) literatures built up by the food-chain and food-security communities, a key science innovation was the GECAFS food system concept [18,22] (Figure 1). By linking these two literatures, the concept systematically

**Figure 1**




Food system activities and outcomes.
Adapted from [18] and Ingram JSI: **From food production to food security. Developing interdisciplinary, regional-level research**, PhD thesis, Wageningen University, Wageningen, 2011.

integrated the 'what we do' (the *Activities*) with the 'what we get' (the *Outcomes*), and allows for a systematic analysis of the consequences of adaptation ('doing the Activities differently') for the suite of all nine elements (bullet points in Figure 1) that collectively define food security. The concept has now been adopted by major agencies including the FAO and CGIAR (via CCAFS).

Further outputs included improved scenarios methods [19,20] and approaches for improved stakeholder engagement, and particularly at the regional level [21]. A major synthesis of GECAFS outputs has also been published [16]. This helped to identify and integrate the links between several food system activities 'from plough to plate,' and the consequences of these activities for the well-established food security components of food (availability, access to food and food utilization). There were several main messages. *Systems approaches can help improve our understanding* of the interactions between global environmental change and food security, and thus of the range of policy options available to address them. Systems approaches connect the activities of food producers, processors, distributors, retailers and consumers to food security and environmental outcomes. This frames these activities as dynamic and interacting processes embedded in social, political, economic, historical and environmental contexts. Food systems operate across multiple scales and on a range of levels within all their different dimensions. Food systems can be conceptualized as coupled social-ecological systems, in which vulnerability arises from multiple stressors operating across different dimensions (e.g., temporal, spatial, and institutional) and scale levels on them (e.g., micro to macro). As the nonspatial dimensions are very relevant to food security/GEC interactions, research has to recognize, and engage with, a wide range of stakeholders. Stakeholder dialogue plays a particularly important role in agenda setting and a range of methods including consultancies, workshops and informal approaches may need to be employed. Most researchers and organizations in the 'food security' domain only consider agricultural issues; a new cadre of researchers and policy makers is needed on the broader food security agenda. Setting such an agenda that is relevant to regional (as opposed to global and/or generic) issues needs a highly consultative and inclusive approach. The utility of the GECAFS food system concept in framing and delivering research work was further refined by Ingram [22].

Another key aspect that GECAFS highlighted is that interdisciplinary research is best established from 'neutral' territory, that is its development should not be led by any given discipline but collaboratively from the outset. This is because — however open a discussion is intended — if the initial thinking is from a given discipline, the agenda is already 'flavored.' Initially GECAFS started from a crop-science viewpoint and considered what needed to be added to approach food security. It thereby reached out to social and human security scientists. But it was quickly realized that a fresh approach was needed: '*you can't just 'bolt on' social science!*' The best approach was to draft a question which would attract the necessary disciplines but without disciplinary 'spin.' This necessarily needed very simple language: '*How will GEC affect our ability to feed ourselves?*,' rather than a more-disciplinary question such as '*How will GEC affect food production?*' Many early drafts were therefore discarded in favor of a 'clean page' headed by this 'simple' question, and this page was then populated with increasing detail leading to researchable questions which maintained disciplinary balance at every step. Each research question required an active interaction between disciplines. Determining the 'final' interdisciplinary research agenda took some years. This was essentially due to the highly iterative way in which conceptual and regional research was planned and developed iteratively over time. While time consuming, it both established conceptual and methodological research on generic topics (e.g., food systems, vulnerability, scenario and decision support) based on science and policy issues identified in regional projects, and policy-relevant research at the regional-level on impacts, adaptation and feedbacks (based on improved conceptual understanding and methods). This both advanced science and addressed regional information needs, and helped link the international GEC science agenda with regional issues.

A related lesson was that *disciplines have differing viewpoints* on 'food security.' For instance, social scientists may think in terms of entitlement to food, economists in terms of food affordability, the humanities in terms of the social function of food, and biophysical scientists in terms of crop growth. None alone address food security but all are equally valid aspects and all have an important contribution to make. Varied views need to be considered for all highly integrated, societal-level questions of this type; research on food security (as with research on other societal-level 'securities' such as water security and energy security) requires balanced interdisciplinarity. The early years of GECAFS involved constant learning on *how* to address the charge, and the formal GECAFS science plan was not published until year five of the project.

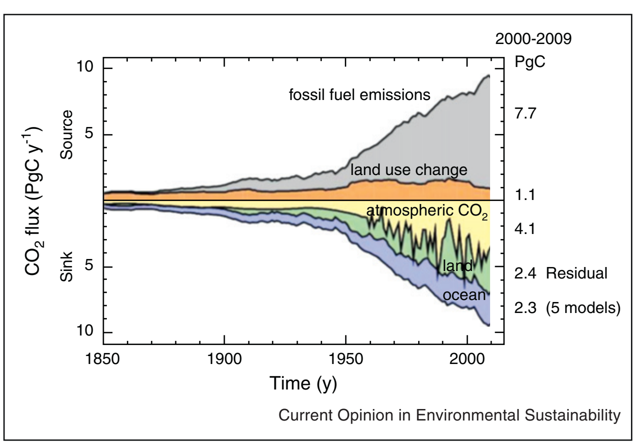
GEC research at the *regional-level had not been as prominent as at global and local levels*, yet is an important spatial level for food security, food system research and GEC considerations [22]. Similarly, food 'security' research (in fact, usually food 'production' research) has been more prominent at local and global levels. But a range of jurisdictional issues also arise when working at regional level. Food security research planning and delivery therefore has to encompass the notion of a range of spatial, temporal, jurisdictional scales, and multiple levels on each.

Further, effective implementation of food security research at regional level necessarily involves *complex interactions between multiple stakeholders*, all of whom have their own objectives and motives. It is therefore important to identify who the stakeholders are in the GEC-food security debate at the regional level, when to engage them in research planning, and how. Participatory research methods such as consultations, surveys and scenario exercises are effective ways to achieve this. It is important also to engage stakeholders in the co-production of knowledge, as far as possible. This means engagement in the research process itself, although it must be remembered that stakeholders are heterogeneous groups representing multiple interests in GEC science; and they choose to participate in various stages of the scientific process, seldom participating in all [23].

In addition to innovative science planning and delivery approaches, addressing this charge required innovative project governance and funding approaches. *The governance* of research to address the charge needed to learn from the programs' Core Project experience, but be modified to allow the stronger input from nonresearch stakeholders. GECAFS governance was therefore designed to foster the necessary interactions between a wider stakeholders community: international agencies, donors as well as researchers. A Scientific Advisory Committee was established comprising representatives from such groups; and an Executive Committee charged with implementation comprised representatives from the sponsoring program secretariats. This avoided an approach based on a single Scientific Steering Committee, which had to deal with both strategy and detail. It also helped ensure uptake of research results by leading collaborating agencies (e.g., FAO and CGIAR). GECAFS *funding strategy* was dependent on developing a research agenda that would appeal to both science and development donor communities. The continual core funding (from the Natural Environment Research Council of UK) was instrumental in levering research funds from some 25 different science and development agencies.

The GCP focused largely on the development of value-added integrated products which built upon more disciplinary research. These products include from the establishment of annual updates of the global $CO_2$ and $CH_4$ budgets to the assessment of the size of carbon pools and their vulnerabilities to changes in climate, land use, and resource extraction [24,25]. Although with a strong focus on global science, the GCP develop strategies to bridge seamlessly global and regional agendas through the engagement of scientists from all over the world to work on one common objective: the establishment of $CO_2$, $CH_4$ and $N_2O$ regional budgets and their attribution to the main underlying processes (see Figure 2 and [26]). The power of this approach is that regional budgets can be further constrained with the knowledge of the neighboring regions and global budgets, while global budgets can be disaggregated and attributed to regions which will help to identify the processes driving carbon sources and sinks. Thus, all contributors have something to gain regardless of their primary interest. Vastly different approaches that include top-down and bottom-up methods to estimate fluxes bring some of the most interesting interdisciplinary sciences together. The global analyses have critical links to international climate change negotiations and scenario development, while the regional budgets bring more connections with national interest in climate policies and mitigation strategies, and therefore to broader user and policy communities. This development began with the establishment and communication of the annual state of Global Carbon Budget [27–29] and expanded with the regional focus by the REgional Carbon Cycle Assessment and Processes (RECCAP; [30,31]) aiming to establish the mean and variability of regional carbon budgets at subcontinental and ocean basin level. This is an ongoing assessment with major milestones and specific set of research products in the form of 14 regional carbon balances and 10 global analyses and datasets supporting the regional analyses. The focus on key research products keep the assessment in check and the engagement of the research communities, while an expanded assessment can work on longer time scales to support and develop capacity building in regions with least capacity to undertake complex model simulations and data analyses [32].

**Figure 2**



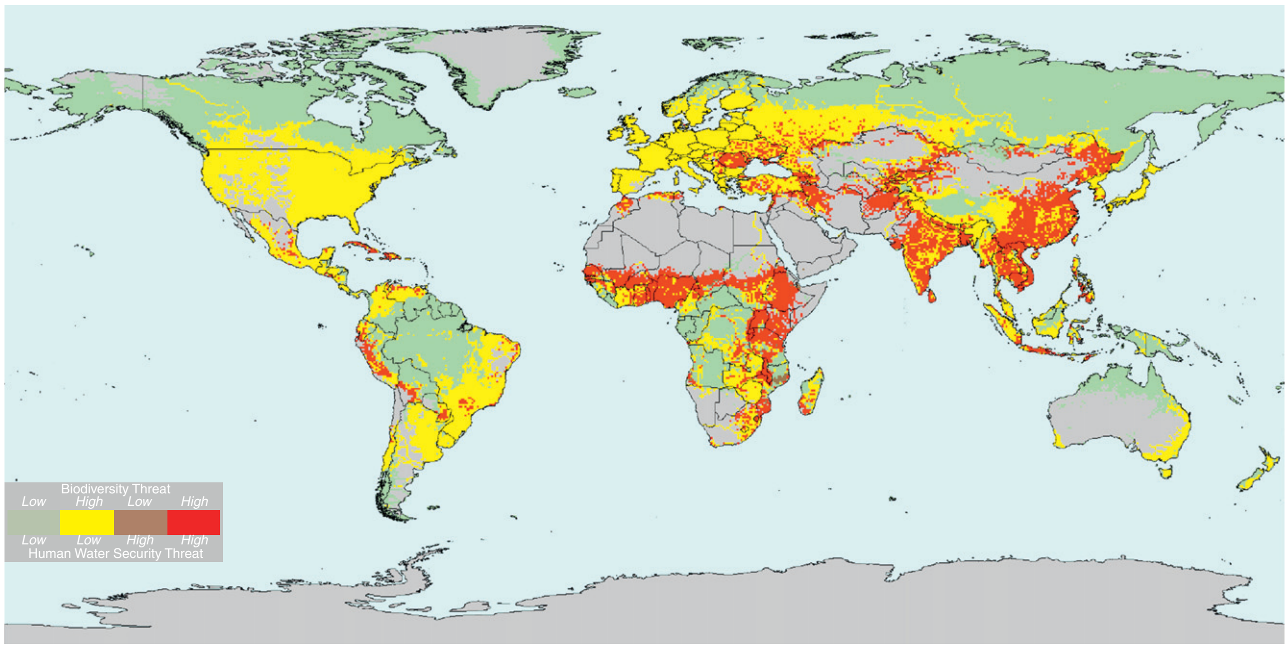

The evolution of the anthropogenic perturbation of the global $CO_2$ budget since 1850. Right column shows the average flux values for the decade 2000–2009 [28].

Other key lessons learned through a diverse portfolio of GCP activities is the importance and need of playing the dual role of a broker for community consensus and an explorer of novel science likely to become important but not yet embraced by the broader community. Examples in the first category include global synthesis on the size and distribution of the permafrost carbon pools [33] and the role of global forests as carbon sources and sinks [34,35]. Examples of the second category are exploring the links between the kaya identity and anthropogenic emissions and carbon sinks [36,37], the role of climate and resource extraction from methane hydrates [38], human interactions and emissions from drained tropical peatlands [39], and the role of the southern ocean as a carbon sink [40]. Timely contributions to influence specific policy outcomes are important and require a 'SWAT' approach to bring together a team of experts willing to contributing in shorter time scales than the ones usually driving more standard research contributions. Examples are the role of the tropical forests in climate policies [41] and the ability of science to separate out the direct from the indirect human influences on carbon sources and sinks [42]. Breaking new ground to bring concepts of carbon management to the city level has led to the development of a new network of scientists to advance urban carbon, energy, and water analyses and modeling [43].

The third ESSP Joint Project is the GWSP. One of the main products of this project is the Digital Water Atlas, a public depository of maps and datasets indicating the state of freshwater at a global scale. GWSP develops strategic partnership within the ESSP network. One of the recent collaboration projects with researchers from freshwater project of DIVERSITAS yield in a well-recognized publication where the potential for conflicts between 'human water security' versus that of biodiversity were exposed [44]. The global analysis, including 23 threat factors which may stress water for humans and nature, shows that most of the places where human water security is currently maintained are also those where freshwater biodiversity faces the greatest threat (Figure 3).

GECHH, as the newest Joint Project with a science plan [8] that was agreed upon in 2006 by DIVERSITAS, IGBP and WCRP and only later by IHDP faced several additional challenges in its early stages. First and foremost, GECHH had to integrate researchers from the health community with researchers from the more traditional GEC communities in the natural and social

**Figure 3**




Prevailing patterns of threat to human water security and biodiversity [44].

sciences. Secondly, starting a new Joint Project at a time when ICSU, the ISSC and other sponsors were starting to consider the future of the GEC programs and ESSP made it difficult to secure its own funding. A third challenge for GECHH has been to develop simultaneously an international profile within three science communities (natural sciences, social sciences, and health sciences) and products of wider public interest in a manner similar to the Carbon and Water Projects. Partly, this is a function of the time that GECHH has been effectively running (less than two years).

In contrast to the GECAFS approach, the GEC programs and ESSP decided to write a science plan before the opening of the project office. This had two unforeseen consequences. First, no one anticipated the complexities of drafting a science plan which needed to take into account not only the traditional science communities of the GEC programs, but also required greater input from the social science and health science communities. Finding a consensus among the various groups represented in the writing team and then gaining acceptance by the four GEC programs took longer than anyone anticipated. For example, at the launch of the GECHH science plan at the ESSP Open Science Conference in Beijing in 2006, IHDP had still not agreed to the science plan because of concerns about the lack of social science input. As a result, the final agreed science plan was not accepted by IHDP until 2008. Clearly, the contrasting experience of GECHH and the other Joint Projects suggests that more thought needs to be put into both what is required in a science plan and the processes required to launch Joint Projects. Despite these different implementation approaches, the Joint Projects have advanced to achieve considerable scientific success, as described in this paper. The programs and their core projects have also contributed considerably to the ESSP scientific enterprise.

## Opportunities and challenges

Increased recognition of an integrated Earth system under rapid anthropogenic change prompted the GEC programs to articulate the need for integrated research of the Earth's environment in order to understand why and how it is changing, and to explore the implications of these changes for global and regional sustainability. This also led to the Visioning Process sponsored by ICSU and ISSC aimed at setting new priorities for an international research for global sustainability [45]. On the basis of a series of consultations (with ESSP, the GEC programs and others), the five Grand Challenges (Box 1) in Global Sustainability Research were developed to provide a framework of future research direction [4,45]. This process is likely to initiate a change of the institutional structure of GEC research. It is, however, essential that the ESSP Joint Projects, START, MAIRS and other existing GEC research activities should become integral

**Box 1 The five Grand Challenges**

1. Forecasting — Improve the usefulness of forecasts of future environmental conditions and their consequences for people.
2. Observing — Develop, enhance and integrate the observation systems needed to manage global and regional environmental change.
3. Confining — Determine how to anticipate, recognize, avoid and manage disruptive global environmental change.
4. Responding — Determine what institutional, economic and behavioral changes can enable effective steps toward global sustainability.
5. Innovating — Encourage innovation (coupled with sound mechanisms for evaluation) in developing technological, policy and social responses to achieve global sustainability.

to any new effort to tackle the five grand challenges of Earth System and Sustainability Research.

Considerable scientific achievements have been accomplished within the ESSP, such as the design and implementation of an innovative food systems conceptual framework; an annual carbon budget trends and analysis; and a global analysis on human water security and biodiversity conservation. Understanding regional environmental change and its implications for local sustainability have been a critical area for the ESSP, as illustrated by the establishment of an integrated study on Monsoon Asia in MAIRS, the GCP's RECCAP and GECAFS regional science plans in the Caribbean, Indo-Gangetic Plain and Southern Africa.

There are many opportunities and challenges related to interdisciplinary GEC research to which the Future Earth initiative can contribute. Any future enterprise needs to stimulate broad inclusion of researchers across the globe and across different disciplines (see Ref. [4]). As depicted by the Joint Projects, the ESSP has involved researchers from the social and natural sciences but many continue to believe researchers from the humanities and social sciences are under-represented in ESS research. The humanities are the least represented and yet their involvement is important [46]. For example, organizational and behavioral scientists can advance our understanding of the history, philosophy, social, behavioral, and management changes required to move society toward more sustainable pathways [47]. A global survey to assess engagement of social sciences scholars [48] identified the following priority research areas: firstly, equity/equality and wealth/resource distribution; secondly, policy, political systems/governance, and political economy; thirdly, economic systems, economic costs and incentives; and finally, globalization, social and cultural transitions. There are also many other scientists working on global environmental change issues who are not active within the network.

The new initiative should continue to contribute to the central tenet of interdisciplinary research: integration of knowledge. There still is a need for an improved understanding of the practice of 'integration' and how to better position knowledge from the scientific community (and other stakeholders) to help decision makers and society cope with emerging challenges in order to optimize opportunities for a more sustainable future. ESSP will continue to stimulate truly integrative research within the new design of the Earth System Sustainability Initiative (Future Earth). To achieve this, the inclusion of the user community and funders to co-design research questions and stimulate wider discussions on possible solutions is important. This requires a willingness to participate and become involved in a collective learning process to establish a common language and better integrate different epistemologies and timeframes. The pursuit of integrated research in the field of GEC will require a shift in our language and a fundamental reframing of the field itself. New integrated research should be supported by well-designed funding schemes that allow collaboration across disciplines and sectors, stimulating an integrated approach. The Belmont Forum promises increased integration and an opportunity to restructure funding practices [49].

One of the challenges in designing a new integrative research structure is to give it enough flexibility to allow the researchers to easily (re-)organize themselves to tackle emerging scientific questions and at the same time to provide a stable institutional home where they would find support for their scientific activities. Those structures should enable rapid and accurate responses to emerging opportunities and challenges on one hand, and on the other should create possibilities to foster strategic alliances to tackle complex societal challenges. For example, to ensure international participation in research projects, close collaboration with regional research centers on environmental change should be enhanced. Regional nodes have in-depth information about specific challenges unique to their respective region. Regional research networks, such as the APN, START, and the intergovernmental Inter-American Institute for global change research (IAI) contribute to environmental knowledge at the regional and global levels.

Paraphrasing Bogardi [50], without understanding social and political dynamics, aspirations, beliefs and values, and their impact on our own behavior, we only describe the world's physical, biological and chemical phenomena, observe and document their changes at different scales, and apply technology to secure access to resources but would ultimately fail to ensure sustainability. Interdisciplinary research that bridges disciplines and involves stakeholders can contribute to solutions for a sustainable world. There is no other viable way forward. The sustainability challenges must be met and the Earth system science community will have an important role.

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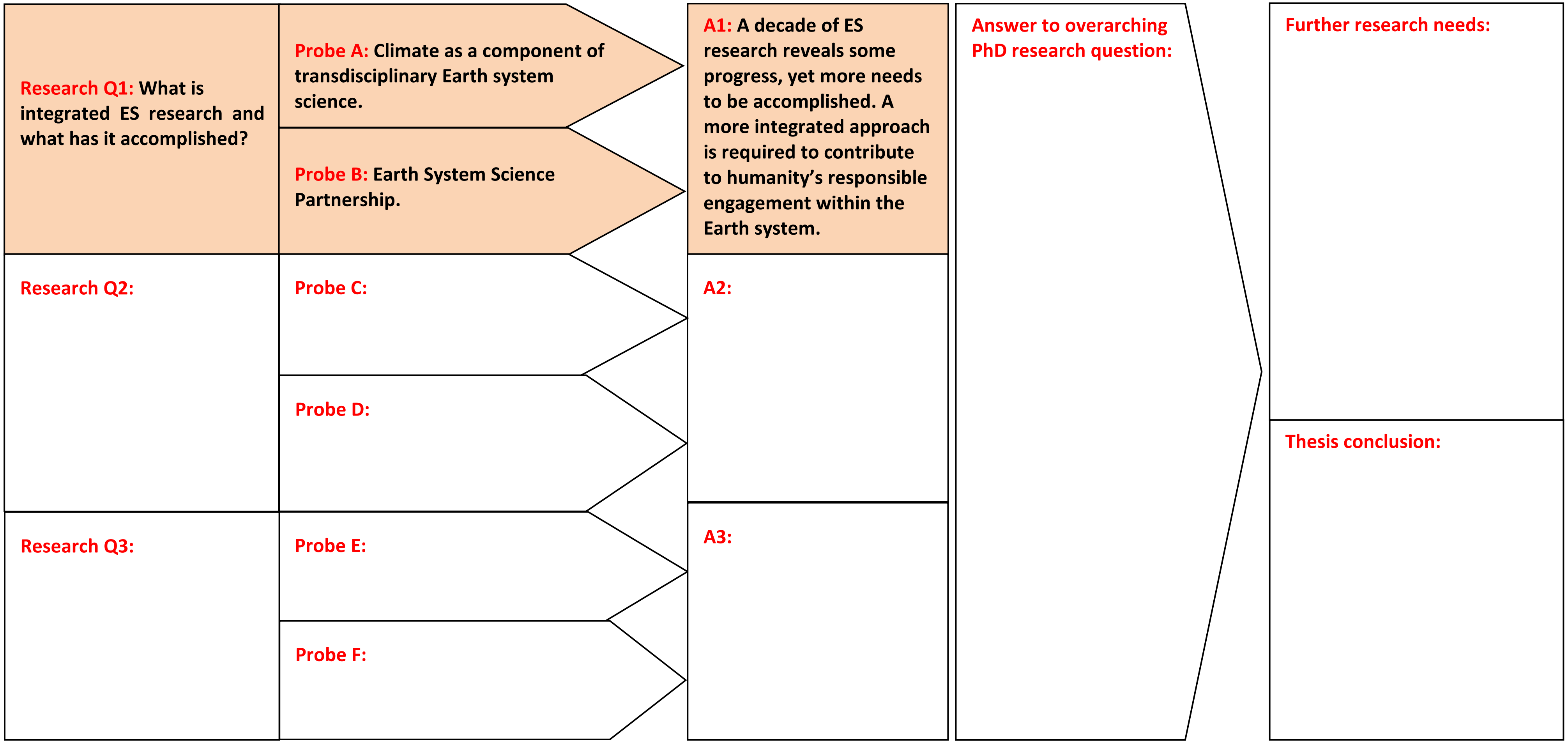
## 2.4. Response to research question one

**PhD research topic:** Integrated Earth System Science: Research Practice and Communication for Solutions to Twenty-First Century Sustainability Challenges



## 2.5. Conclusion

Chapter Two (Papers A and B) addressed the first research question of my thesis, "What is integrated ES research and what has it accomplished?". To try to answer this question, I present two contrasting reviews of Earth system research. Paper A views the ES from the perspective of climate change research and finds the latter to be incomplete in its view of an holistic Earth. Building on recognition of an integrated ES and the need to bring together natural and social sciences to tackle complex societal challenges, Paper B reviews a decade of the international Earth System Science Partnership (ESSP) and how it has evolved to support interdisciplinary research and the development of, for example, a food systems conceptual framework, an annual carbon budget trends and analysis and a global analysis on human water security and biodiversity conservation.

Paper A underlined that climate change is too narrow a framing of the challenges facing the Earth. Increased recognition of the Earth as an integrated system has helped advance understanding of the emergence of the geo-modifying human transformation of the Earth system. The outcomes of the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP)15 in Copenhagen and the COP16 in Cancun indicate limitations of the existing global governance structures, arguably exacerbated when mass media reporting of climate change passed social tipping points to create virtuous and vicious reinforcement. In response to the recognition that people are a geological force, the cause of the Anthropocene, big picture Earth system thinkers have helped identify what we, people, must consider as the necessary steps to become more than system modifiers. Paper A (future climate &

transdisciplinary ESS) concludes that a transdisciplinary Earth systems approach is required to contribute to holistic planetary management.

Paper B (ESSP & interdisciplinary research) shows that integrated research that bridges disciplines and involves stakeholders can contribute to solutions for a sustainable world. Specifically, neglecting social and political dynamics, aspirations, beliefs and values, and their impact on our own behaviour, researchers can describe only the world's physical, biological and chemical phenomena. From this standpoint research consists of observing and documenting ES changes at different scales and applies technology to secure access to resources, yet a more integrated, transdisciplinary approach is necessary to develop options to transition towards humanity's responsible engagement within the ES. Paper B concludes that the sustainability challenges must be met and transdisciplinary Earth system research will have an important role to support responses to global environmental challenges.

Chapter Two highlights some advances in integrated ES research, yet ES research is currently not integrated enough. The complexities and unprecedented scale of the ES-derived sustainability challenges require more integrated research that brings together natural, social and human sciences to contribute to solutions to the profound challenges humanity is facing.

The next chapter in this thesis examines how scientists' increasing recognition of an integrated ES and the need for humanity's responsible engagement within the Earth system has led to calls for inter- and transdisciplinary research. Yet, despite these continued calls for more integrated ES research, Chapter Three illuminates how advances in science integration remains limited because of persistent barriers that need to be overcome if ES research is to contribute to solutions to global sustainability crises.

# 3. Integrated Research: Conceptualisation, Practice and Publication

## 3.1. Introduction

In the context of this thesis, Chapter 3 examines how and if integrated research can help quantify, analyse and communicate increasingly complex Earth system-derived challenges. The chapter is based on Paper C '*Spanning Disciplinary, Sectoral and International Boundaries: A Sea Change towards Transdisciplinary Global Environmental Change Research?*' and Paper D '*Interdisciplinarity in Environmental Journals: What's in a Name?*'. Although there are many institutions and organisations dedicated to integrated environmental research, Paper C describes how four global environmental change research programmes and their scientific partnership (ESSP) attempted to provide a more holistic institutional and scientific framework to conduct interdisciplinary research. These research programmes were selected because of (i) their role as 'interdisciplinary bodies' of the International Council of Science (ICSU) and (ii) their interdisciplinary experience spanning three decades. Despite advances in ES research, Paper C describes some persistent barriers to science integration, such as how 'structural' (e.g. disciplinary) bias can influence the level of opportunities to publish interdisciplinary research (see, for example, Fry, 2001). Advancing this discussion, Paper D examines the disciplinary reach of environmental journals that self describe as interdisciplinary.

This chapter illuminates the evolution of global environmental change (GEC) research from an exclusive scientific enterprise focused on narrow (natural science) interdisciplinary research in the 1980s to recently more inclusive transdisciplinary research involving science and the users of scientific information. Definitions of key concepts (multidisciplinary, interdisciplinary and transdisciplinary) are provided and matched with existing GEC research practices. Multidisciplinary research involves two or more disciplines addressing a common problem. Yet, this approach remains siloed because only the tools and methods of a researcher's disciplinary 'home' are used and there is no integration of knowledge and research outputs from different disciplines. A central tenet of interdisciplinary and transdisciplinary research is an integration of knowledge. Interdisciplinary research crosses disciplines to address a complex challenge, while transdisciplinary research involves transcending disciplines and engaging with non-academics, such as the users of scientific information from the outset and throughout the research process. Despite calls for integrated research over the past three decades, persistent barriers to natural and social science integration are revealed, specifically issues of communication, and attitudinal and structural (including evaluation) bias (Paper C). This paper, therefore, illuminates some of the challenges of practising integrated Earth system research, among which is the difficulty of finding rewarding publication outlets to deliver the results. Paper D takes up this aspect of delivery by exploring opportunities to publish interdisciplinary research in peer-reviewed environmental journals.

Chapter Three reports findings of a study I developed to examine the 'breadth' of the disciplinary enquiry (i.e. knowledge integration) in environmental journals that describe themselves as interdisciplinary, and their processes for evaluating the quality of the articles submitted to them (Paper D). Study findings imply that there is no difference in breadth of disciplinary engagement between journals that self-describe as interdisciplinary and those that do not. Furthermore, the journals that self-describe as interdisciplinary pursue interdisciplinary reviews to varying degrees of intensity.

## 3.2. Paper C: 'Spanning Disciplinary, Sectoral and International Boundaries: A Sea Change towards Transdisciplinary Global Environmental Change Research?'

Rice M. (2013). Spanning disciplinary, sectoral and international boundaries: a sea change towards transdisciplinary global environmental change research?, *Current Opinion in Environmental Sustainability*, 5 (3-4): 409-419,

http://dx.doi.org/10.1016/j.cosust.2013.06.007.

Available online at www.sciencedirect.com

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Current Opinion in Environmental Sustainability

# Spanning disciplinary, sectoral and international boundaries: a sea change towards transdisciplinary global environmental change research?

Martin Rice

Scientists' increasing recognition of an interconnected Earth system and the need to pursue global sustainability has led to repeated calls, over the past three decades, for interdisciplinary and more recently transdisciplinary research into global environmental change (GEC). Interdisciplinary and transdisciplinary research are similar to the extent that they entail varied degrees of science integration. Transdisciplinary research involves transcending disciplines and engaging with non-academics throughout the research process, while broad interdisciplinary research happens when researchers across the natural and social sciences collaborate to tackle societal problems and produce new and insightful knowledge and possible solutions. This would have been impossible had they remained within single disciplinary confines. Such science integration raises awareness of the required focus on the nexus between human and environmental systems in order to achieve sustainability. Yet progress in science integration has only been incremental and remains limited. This paper elucidates an evolving conceptualisation of integration, identifies barriers and describes opportunities to dismantle persistent impediments to integration. Contemporary understanding of integration entails three dimensions: (i) scientific integration, involving integration across academic (natural, social and human science) disciplines, (ii) international integration, involving integration from local to global and across nations and cultures, and (iii) sectoral integration, involving integration across science and society. Persistent barriers must, however, be overcome and experiences documented and shared in order to enable transdisciplinary GEC research for sustainability to cross disciplinary, sectoral and international boundaries.

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**Current Opinion in Environmental Sustainability** 2013, **5**:xx–yy

This review comes from a themed issue on **Open issue 2013**

Edited by **Rik Leemans** and **William D Solecki**



**http://dx.doi.org/10.1016/j.cosust.2013.06.007**

## Introduction

The scientific community has increasingly recognised the paradigm that James Lovelock and Lynn Margulis put forward in 1973 of understanding the Earth as an integrated system [1,2]. Concurrent with this shift in thinking, scientists have become aware of the need for global sustainability and this has been coupled with repeated calls for multidisciplinary, interdisciplinary and more recently transdisciplinary global environmental change[a] research [4•,5,6,7,8].

There is a significant body of academic literature providing definitions for the three concepts of multidisciplinary, interdisciplinary and transdisciplinary research (see, e.g. [13–17]). However, these concepts are inconsistently understood resulting in different expectations of how to plan, evaluate, implement and conduct interdisciplinary and transdisciplinary research. For example, Klein observed that 'ask three scientists what interdisciplinary means, and they will likely give three answers' ([18••], pp. 3–4). Table 1 provides working definitions for this paper and examples of multidisciplinary, interdisciplinary and transdisciplinary global environmental change (GEC) research in practice.

A central tenet of interdisciplinary and transdisciplinary research is an integration of knowledge to tackle societally relevant problems [9,10•]. Societally relevant problems in GEC research include, for example, biodiversity loss and emerging infectious diseases; water resources; energy security; human health; ocean acidification and food security. Interdisciplinary research is primarily a scientific enterprise crossing disciplines, while transdisciplinary research involves transcending disciplines and engaging with non-researchers, such as users of scientific information from the outset and throughout the research process [11]. This paper considers advanced interdisciplinary GEC research broadly defined as an integrated scientific approach whereby natural and social scientists produce new and insightful knowledge through genuine collaboration to tackle societally relevant problems, while

[a] Global environmental change includes changes in the physical and biogeochemical environment, either caused naturally or influenced by human activities such as deforestation, fossil fuel use, urbanisation, land reclamation, agricultural intensification, freshwater extraction, fisheries over-exploitation and waste production [3, p. 5].

**Table 1**

**Definitions and GEC research examples.**

| Typology | Definition | GEC research example |
|---|---|---|
| Multidisciplinary | Multidisciplinary research involves two or more disciplines addressing a common problem. There may be an exchange of information and ideas between different disciplinary partners, but participants generally frame their research goals and outputs in terms of their 'home' disciplines ([92], p. 210) | Climatologists, environmental economists, oceanographers and political scientists publish separate journal papers in a special edition on climate change. |
| Interdisciplinary | Interdisciplinary approaches integrate separate [natural and social science] disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of a complex issue, question or problem ([93], p. 16). | Climate modellers, hydrologists, ecologists, and environmental economists develop a global synthesis to jointly consider human and biodiversity perspectives on water security (e.g. [94]). Atmospheric scientists, climate scientists, oceanographers, ecologists, and economists conduct a global synthesis of the carbon budget (e.g. [53]). |
| Transdisciplinary | Transdisciplinary research integrates academic researchers from different disciplines and non-academic participants to research real world problems and create new knowledge and theory. Transdisciplinarity combines interdisciplinarity with a participatory approach [involving engagement of scientists and non-academic stakeholders throughout the research process] ([95], pp. 4–5). | The engagement of GEC scientists, urban planners and officials, and representatives of disaster management and development agencies to review scientific findings and projections regarding climate-related risks to coastal megacities (see: 'Cities at Risk' programme: http://start.org/programs/cities-at-risk). Climate Change, Agriculture and Food Security (CCAFS) provides an analytical and diagnostic framework, that is grounded in the policy environment, incorporates biophysical effects, quantifies uncertainty where possible, and ensures effective engagement of rural communities and institutional and policy stakeholders (see: http://ccafs.cgiar.org/our-work/research-themes/integration-decision-making). |

traditional interdisciplinary research defined narrowly involves the integration of proximate disciplines within, for example, the natural sciences (e.g. biology, chemistry and physics). Broad science integration of the natural and social sciences plays a pivotal role in raising awareness to focus on the needed nexus between human and environmental systems (see, e.g. [12–15]).

## Genesis and evolution of integrated GEC research

The first proposal for an interdisciplinary research programme on global changes in the terrestrial environment and its living systems, based on an understanding of a holistic Earth system, was put forward in 1983 [16]. The US Academy of Sciences justified this narrow interdisciplinary (natural sciences only) approach in this new programme because it can illuminate the early onset of global change and support planetary stewardship for sustainability better than single disciplines alone [4•]. This effort culminated later in the launch of the International Geosphere-Biosphere Programme in 1986. Social sciences were, however, largely excluded from this new endeavour [16,17]. This was mainly because of the perceived difficulties of integrating natural and social sciences with differing data, tools, methods, theories, concepts and language [18••]. The GEC research enterprise was a narrow interdisciplinary (mainly natural sciences) enterprise throughout the 1980s and early 1990s [16]. Advances in interdisciplinary natural science research included, for example, the identification of the Antarctic ozone hole which required international collaboration among chemists and meteorologists and understanding the causes and consequences of acid rain involved joint research between atmospheric scientists and terrestrial ecologists [19,20]. Natural science collaboration remains a vital part of the scientific enterprise, yet increasingly complex Earth system-derived sustainability challenges require a more integrated approach involving broader interdisciplinary research with natural and social sciences. Furthermore, there is a need to engage with other communities involved in sustainability issues, such as engineering, health and technological sciences. Examples of integrated research from these communities are described in the 'Integration is not unique to GEC research' section.

In a recent review paper, Mooney *et al.* [18••] observe that in the 1990s, scholars from certain disciplines at the interface of the natural and social sciences called for more integration based on the premise of an integrated Earth system and its response to GEC. Initially geography (see, e.g. Henderson-Sellers [5] and Liverman [21]) was already well positioned and well equipped as a more integrative discipline with an inherent focus on both human and physical systems to advance interdisciplinary GEC research. Progress in understanding land-use and land-cover change processes and their societal implications is indicative of how geography contributed to the interdisciplinary GEC research enterprise [22]. For example, human and physical geographers have jointly



Please cite this article in press as: Rice M. Spanning disciplinary, sectoral and international boundaries: a sea change towards transdisciplinary global environmental change research?, Curr Opin Environ Sustain (2013), http://dx.doi.org/10.1016/j.cosust.2013.06.007

measured and observed people and environment interactions by taking advantage of their geographical expertise in spatial technologies (for instance, geographical information systems and remote sensing techniques) [23,24]. Later, ecological economics also established an impressive track record in enabling integrated (natural and social) research [18••]. Ecological economics has supported significant advances in, for example, biodiversity science and our understanding of the various values of ecosystem services [25–29]. Furthermore, ecological economics contributes to the integrated study of an environmental paradox concerning the fact that human well-being is improving while ecosystem services are declining [30]. This led to the publication of the Inclusive Wealth Report in 2012, which is a new United Nations effort to measure progress (beyond Gross National Product) towards sustainability [31]. The United Nations has a history of making recommendations for interdisciplinary research.

World leaders at the United Nations Conference on Environment and Development (the Rio Earth Summit) in 1992 affirmed the need for interdisciplinary research to inform options for sustainable development [22]. These international global initiatives thereby urge for science integration, yet in the 1990s and early 2000s, 'achieving a sufficiently intensive interdisciplinary collaboration, on a large enough canvas to meet the needs of sustainability, remain[ed] the central challenge' ([23], p. 1920).

With increasing awareness of the need to study an integrated Earth system and its response to global environmental change, in 2001 the international GEC research community articulated in the Amsterdam Declaration [32] the requirement for natural and social sciences to coalesce under a framework for Earth system science[b] [7]. This new framework for interdisciplinary research motivated four GEC research programmes (DIVERSITAS: an international programme of biodiversity science, IGBP: the International Geosphere-Biosphere Programme, IHDP: the International Human Dimensions Programme on Global Environmental Change Research (IHDP) and the WCRP: World Climate Research Programme) to establish the Earth System Science Partnership (ESSP). From 2001, the ESSP facilitated the study of the Earth's environment as an integrated system in order to understand how and why it is changing, and to explore these changes for global and regional sustainability [3]. Central to this scientific endeavour, the ESSP facilitated a diverse range of interdisciplinary joint projects on carbon, food, water, and health [33]. These projects are considered 'joint' because they were co-sponsored by three or four GEC research programmes and they aspired to involve the collaboration and integration of insights from the natural and social sciences.

Between 2007 and 2009, the International Council for Science (ICSU) performed reviews of the GEC research programmes and the ESSP. The reviews observed that the IGBP mission has become more oriented towards integrated Earth system research, that is, increasingly similar to the ESSP. This resulted in the recommendation for 'an overarching set of solution-focused and integrated research priorities for these institutions [programmes and partnerships]' ([34], p. 916). This, in turn, motivated ICSU and the International Social Science Council (ISSC) to establish a consultative visioning process, ultimately leading to the closure of the ESSP in 2013 and the creation of a new initiative for integrated GEC research for global sustainability, 'Future Earth'. Meanwhile, the GEC research programmes continue close collaboration with each other (including the fostering of ESSP Joint Projects) as the Future Earth initiative is anticipated to develop over the next few years. Unlike past GEC research endeavours, Future Earth has ambitions as a transdisciplinary initiative, bringing natural and social scientists closer together with members of society to inform sustainability solutions [18••,34].

This review paper focuses primarily on the activities of four GEC research programmes and their ESSP. Furthermore, by grounding this paper in existing literature, two major issues are revealed. First, the conceptualisation and practice of integrated GEC research has progressed from one dimension involving traditional interdisciplinary (natural sciences) research to two dimensions of integration. These two dimensions involve international as well as natural and social science (broad interdisciplinary) collaboration. Second, a 2020 vision for transdisciplinary GEC research involving science with society to tackle sustainability challenges is underway with the creation of 'Future Earth'. This new initiative was launched at the time that the United Nations was calling for transdisciplinary research to inform sustainability options (see, [35]). Furthermore, Future Earth builds on advances in interdisciplinary GEC research.

## Advances in interdisciplinary GEC research

One of the first integrated efforts to synthesise GEC research were the science-policy assessments by the Intergovernmental Panel on Climate Change (IPCC). These assessments are critical evaluations of the state-of-the-art scientific understanding of climate change to guide policy decisions [36]. The first assessment [37], which was largely structured by natural scientists, was a collection of disciplinary chapters integrated in the summary for policy makers. The integration gradually improved over the next assessment reports epitomised by the third synthesis report [38], where many scientists

[b] Earth System Science is the study of the Earth system, with an emphasis on observing, understanding and predicting global environmental changes involving interactions between land, atmosphere, water, ice, biosphere, societies, technologies and economies [3, p. 5].



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from natural and social science backgrounds addressed the ten most demanding questions posed by policy makers (i.e. the IPCC plenary assembly). The fourth assessment report was somewhat less integrated but focused on many natural science aspects (WG1), adaptation and vulnerability of systems, sectors and regions (WG2), and mitigation (WG3). The latter two working groups were much more interdisciplinary than WG1. Its synthesis report [39] was merely a multidisciplinary summary. Fully integrated models were used only for determining plausible scenarios for future trends and policies. The comprehensive assessments by the IPCC have been influential [40]. They helped frame the objective of the climate convention, its scenarios and the resulting vulnerabilities illuminated the urgency of this grand societal challenge, while the mitigation analyses illustrated that society could solve the climate change problem through international collaboration.

Complex societal challenges are now clearly articulated in other international scientific assessments, such as the Millennium Ecosystem Assessment (MA) [41] and the International Assessment of Agricultural Knowledge, Science and Technology for Development [42]. The interdisciplinary GEC research community has enriched these science-policy assessments [3,18••,28,40,43]. However, in all such assessments, the context of disciplinary and interdisciplinary knowledge needs to become more explicit. This could be achieved by convening scoping workshops to develop a comprehensive conceptual framework and glossary. However, this does not effectively deal with the divergent paradigms, values, framings and perspectives, which all need to be considered from the outset during assessment design [44]. Although these assessments differ in procedures and structure [45], their link to and impact on policy makers and users remains essential.

The last decade has seen tremendous advances in interdisciplinary GEC research and assessments, generating new data and providing robust analyses of intertwined sustainability crises [15,34,41,46], such as anthropogenic climate change [47], increasing biodiversity loss [45,48], ocean acidification [49,50], food and water insecurity [51]. The development of the global carbon budget and the regional carbon, methane and nitrous oxide budgets [52], coordinated by the Global Carbon Project, exemplifies such interdisciplinary research. The 2012 global carbon budget [53] entails sharing and integrating knowledge from atmospheric science, climate science, ecology, economics, and oceanography using different methods to estimate and elucidate carbon fluxes. Furthermore, both the global and regional budgets are international in scope. The global analysis underpins international climate negotiations and scenario development, while the regional budgets serve national interests in climate policies and mitigating strategies. The global and regional budgets are, therefore, of use for a broad range of research and policy communities [33]. The latest Global Carbon Budget illuminates how political impasse (for instance, the recent United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties) and the challenge for individual nations to transition to low carbon social and economic systems [54] may well consign Earth and its inhabitants to temperature rises between 4.0 and 6.1 °C by 2100 [53].

The annual global carbon budgets and other advances in integrated GEC research illustrate the urgent need for more effective Earth system governance and planetary stewardship [55–58], yet ‘Never before has humanity had to devise and implement governance structures at a planetary scale’ ([55], p. 295). In response, the GEC research community, under the auspices of the IHDP, established the Earth System Governance (ESG) project in 2008. This interdisciplinary project aims to bring together natural and social scientists to integrate knowledge from, for example, the earth system science, sustainability science and governance theory communities in order to study the governance dimensions of global environmental change [58,59]. A recent comprehensive assessment by the ESG project urged for a major overhaul of existing global governance structures and described the need for governments to improve the integration of sustainable development policies [60]. One of the most challenging sustainable development goals is attaining food security [57,61,62].

A major output of the ESSP Joint Project on Global Environmental Change and Food Systems (GECAFS) was its innovative food systems concept [33,63]. This helped identify where opportunities for broad interdisciplinary research involving the natural and social sciences (for instance, agricultural scientists, climate scientists, human geographers, economists, and policy scientists) would be most important for studying the two-way interactions between GEC and attaining food security. The articulation of the GECAFS research approach started with a blank page rather than an assumption it should start from an agricultural ‘world view’. This was an important first step because it ensured that GECAFS research was not biased by one particular discipline. The research questions were, therefore, elucidated with input from natural and social scientists together with the users of GECAFS science during Project planning meetings [33].

The GECAFS food system concept has since been used in a number of ways including helping to identify vulnerability points for district level food systems in the Indo-Gangetic Plain that are prone to GEC, and hence adaptation options [62]. In this example, it was found that the Ludhiana District of the Indian Punjab suffers from extreme ground water extraction, which limits irrigation



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supply and hence food production. The situation is further complicated by projected changes in rain and glacier melt because of climate change, leading to vulnerable food systems. In contrast, in the Ruhani Basin District in Nepal's Terai region, food insecurity arises because of food distribution infrastructure, such as footpaths and bridges being subject to flooding during extreme weather events. Regional natural and social scientists and local decision makers used the food systems concept to identify the principal vulnerability points of the food system in these two Districts. For the Nepali case, policy options included establishing strategic grain reserves and improving regional infrastructure to ensure the timely transit of food in times of crisis, whereas in the Indian case, improving institutions governing water extraction (including water pricing) were more appropriate. By seeking ways to reduce the vulnerability of the whole food system (rather than just the production system) to GEC, the GECAFS integrated framework helps remind interdisciplinary researchers and decision-makers of a multitude of possible interventions that need to be considered [62].

These examples are indicative of how interdisciplinary research can play a pivotal role in illuminating GEC challenges. Yet, broad science integration, that is, the engagement of the natural and social sciences has generally been slower than anticipated [9,18••,64•]. This is largely attributed to persistent barriers that future research for sustainability will need to overcome.

## Barriers for interdisciplinary GEC research

Numerous barriers undermine attempts to integrate natural and social sciences [9,65], many of which are described in the academic literature (see, e.g. [66–74]). Barriers include entrenched disciplinary-based institutions; disciplinary language and jargon; limited funding opportunities; restricted career opportunities; discipline-oriented review processes and hence 'double jeopardy'; the time, effort and investment required for integrated research being greater than working within the confines of single disciplines; the natural and social sciences having different cultures and frames of reference; and a deficiency in skills for managing integration processes. Table 2 synthesises the literature (see, e.g. [5,17,57–59,62,64•,65]) and identifies the most common barriers to integrated research over the past three decades relating to communication, attitudinal and structural (including evaluation) bias (shown in Table 2 in bold).

**Table 2**

**Barriers to interdisciplinary research (adapted from Franks *et al.*, [70], with permission of Taylor & Francis Ltd.).**

| Author | Barriers to interdisciplinary research |
|---|---|
| [17] Kates, 1985, pp. 491–493 | • **Attitudinal:** lack of mutual respect across disciplines.<br>• **Structural bias:** different reward systems. |
| [5] Henderson-Sellers, 1992, p. 31 | • **Attitudinal:** Urge to bridge disciplines outweighed by a fear of the unknown and ridicule of experts safe in their own disciplines.<br>• **Communication:** Striving to achieve expertise in one discipline and effective communication with other disciplines can become overwhelming.<br>• **Structural bias:** Funding preference for single-disciplinary research over interdisciplinary research. |
| [66] Braddock *et al.*, 1994, p. 39 | • **Attitudinal:** Interpersonal or informal barriers.<br>• **Structural bias:** External resistance from professional associations, employers, universities and government agencies who may not be sympathetic to the broad approach. |
| [96] Bradbeer, 1999, pp. 392–394 | • **Communication:** Differences in disciplinary epistemologies. |
| [67] Brewer, 1999, p. 335 | • Different cultures and frames of reference.<br>• **Communication:** Different languages between disciplines.<br>• **Attitudinal:** Personal challenges — gaining trust and respect of colleagues from other disciplines.<br>• **Evaluation:** Institutional impediments (e.g. funding).<br>• **Structural bias:** Professional impediments (e.g. hiring, promotion, status and recognition). |
| [68] Fry, 2001, pp. 162–163 | • **Communication:** 'Sociology' of academia (e.g. specialised language, insular disciplines).<br>• Quantitative versus qualitative approaches.<br>• **Structural bias:** Merit system and peer review biased against interdisciplinarity make, for example, publishing difficult. |
| [71] Phelan *et al.*, 2013, p. 57 | • **Structural bias:** Institutional structures and reward systems favour disciplinary research.<br>• **Communication:** Communicating across natural and social science disciplines can be challenging.<br>• **Attitudinal:** Difficulty to open minds and transcend disciplines.<br>• **Structural bias:** Lack of appropriate support and management structures. |
| [75] Mauser *et al.*, 2013, this volume | • **Evaluation:** Deficiency in skills for managing integration processes, including the necessary reward structures, and adjustments to funding mechanisms, including selection and evaluation procedures. |



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This next section describes advanced notions of integration, some emerging opportunities for integrated research, as well as describing the need to dismantle persistent barriers in order for transdisciplinary GEC research for sustainability to become a common activity.

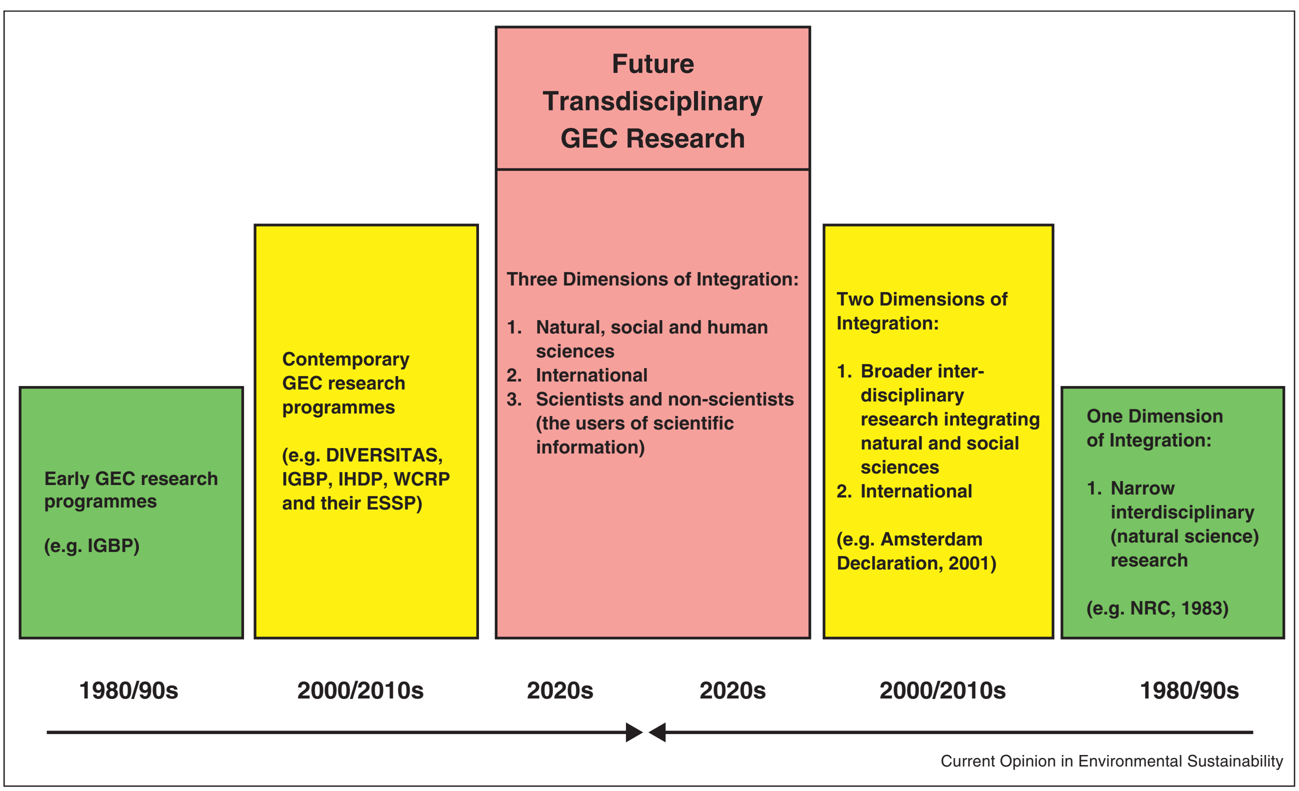
## A 2020 vision for transdisciplinary GEC research

The past three decades have witnessed an increasingly sophisticated conceptualisation of integration. Figure 1 depicts the evolution of how scientists have conceptualised integration. This has moved from one dimension (mostly natural interdisciplinary science) in the 1980s (green boxes), to two dimensions (broader interdisciplinary (natural and social science) engagement and international collaboration) in the 2000s (yellow boxes), to the contemporary understanding of three dimensions of integration (natural, social and human science engagement, international and sectoral) (pink box). The left hand boxes show the institutional platform for integration for each time period. These correlate to the mirrored right hand boxes for the same time period, illustrating their corresponding dimensions of integration and examples of fora which provided the foundations for each dimension. The Future Transdisciplinary GEC Research (pink) box depicts a 2020 vision for the three dimensions of integration to become common practice. The three dimensions include: (i) scientific integration involving crossing academic (natural, social and human science) disciplines, (ii) international integration involving the incorporation of regional, national and local cultures, and (iii) sectoral integration involving sciences and stakeholders in society (the users of science). This 2020 vision of international science working with society is solutions-oriented, motivated by contexts of application, and the framing, execution and delivery of research involves all stakeholders throughout the process [75••].

### Supporting interdisciplinary GEC research

In order for these three dimensions of integration to evolve from concept to activity, it is necessary to design and implement appropriate support and management structures and develop a range of skills for supporting and conducting integrated research. This includes providing suitable reward structures, generating new funding opportunities, and establishing selection and evaluation

**Figure 1**




Conceptual evolution of integration for GEC research. Advancing from one dimension of integration indicative of narrow interdisciplinary (natural science) research in the 1980s to a 2020 vision for the three dimensions of integration to become common practice. The three dimensions of integration is a transdisciplinary research approach driven by stakeholder requirements, integrating (i) the natural, social and human sciences and engineering, (ii) local, regional and global perspectives, and (iii) scientists, civil society, governments and other stakeholder's needs in order to develop response options to sustainability challenges.



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procedures conducive to integrated research proposals and peer-reviewed manuscripts [75••].

There have been positive developments concerning efforts to overcome barriers and provide opportunities for broad interdisciplinary research. For example, the International Social Science Council and the Swedish development cooperation agency (SIDA) proposed to establish and fund a ten-year programme to help further integrate the social sciences (including behavioural and economic sciences) into GEC research (see, [76]). Pahl-Wostl *et al.* [64•] identified the need for the (i) funding of long-term (decadal) research networks that analyse and enhance the capacity of regions to cope with environmental changes; (ii) development and testing of integrated methodologies; and (iii) establishment of standards of 'excellence' for future integrated GEC research for sustainability. Training is a vital aspect of realising future integrated GEC research for sustainability. Graduate programmes such as 'The Dissertations Initiative for the Advancement of Climate Change Research' (see: www.disccrs.org) provide examples of how the next generation of interdisciplinary and transdisciplinary researchers are receiving training on integration skills such as team building and cross-disciplinary communication [71]. For example, students learn that it is vital to establish a common language at the beginning of the research process. In academia, the creation of incubators (such as meeting spaces where interdisciplinary teams can come together to define problems and write grant proposals) could help facilitate science integration. When establishing research projects, it is important to include all the relevant stakeholders (academic and non-academic) from the beginning. Furthermore, as exemplified by the GECAFS experience, it is important to start any collaborative process on a clean slate where ideas can be exchanged and research questions and appropriate methods are identified by all the stakeholders. Establishing clear rules of engagement is important in order to avoid any misunderstandings concerning responsibilities and expectations of everyone involved.

Another crucial area is funding, which can be illustrated in a number of examples. The US National Science Foundation supports interdisciplinary research through various mechanisms[c] and the UK's Economic and Social Research Council and the Natural Research Council jointly offer interdisciplinary PhD scholarships.[d] Furthermore, approximately 13 billion Euros of the European Commission's Sixth Framework Programme budget was channelled into 'Integrating and Strengthening the European Research Area' [77]. Indicative of this commitment is an integrated project involving the joint collaboration of 54 European coastal management institutions to study the ecological, social and economic dimensions of the coastal zone [9]. Private foundations are supporting integrated research. For instance, the National Academies' Keck Futures Initiative, is a 15-year (2003–2018), US$ 15 million initiative by the WM Keck Foundation to promote integrated research, including communication across science, funders, universities and the general public [78]. Major funders of GEC research recently established the 'Belmont Forum' to strengthen engagement between the research funding agencies and the GEC research community in order to improve co-design, co-alignment and co-funding of integrated research for sustainability [79]. This initiative runs parallel with the development of Future Earth.

Although it is not possible to measure the success of these mechanisms because they are currently active, they can provide an indication of funding structures required to support transdisciplinary GEC research, similar to what is described in the next section.

### Transdisciplinary GEC research underway

Some exciting and innovative transdisciplinary GEC research initiatives are already underway that resonate with the three dimensions of integrating scientific, sectoral and international perspectives. An example is an international programme on 'Cities at Risk: Developing Adaptive Capacity for Climate Change in Asia's Coastal Mega Cities' which was launched in 2008 and is partnered by the GEC research community, including the Asia-Pacific Network for Global Change Research (APN), the global change SysTem for Analysis, Research, and Training (START) and the WCRP. The goal of this programme is to augment efforts on risk and vulnerability assessment, awareness raising, and the integration of science into planning and policy for precarious areas under threat [80]. This transdisciplinary programme involves science integration (e.g. the engagement of climate scientists and urban planners), the participation of scientific programmes, development agencies and local governments and it is international in scope, embedding perspectives from across Asia. The programme is grounded in the fact that Asia is undergoing rapid population and economic growth in coastal megacities and is prone to sea-level rise and other climate change-induced extremes [81,82]. Despite these urgent threats, local governments and the international development community have yet to take account of the implications of climate change and sea-level rise on rapidly growing coastal populations and infrastructure. In part, this is due to the difficulty of forecasting future extreme weather events. Recent findings of the Cities at Risk programme include (i) the need to overcome divergent geographies and timescales employed by the scientific and planning/policy communities and (ii) the importance of implementing

[c] See, http://www.nsf.gov/od/oia/additional_resources/interdisciplinary_research/.

[d] See, http://www.nerc.ac.uk/funding/available/postgrad/schemes/jointesrc.asp.



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effective governance in order to situate adaptation strategies at the centre of the science-policy interface [80].

Another example of the GEC research community instilling the three dimensions of integration (science, international and sectoral) into research practice is the Climate Change, Agriculture and Food Security (CCAFS) project on 'Integration for Decision Makers'. Food security is one of the most prominent societal challenges of our time [83]. Food security not only just connects to food production, but to whole food systems, to water and energy availability, to trade and to other environmental challenges such as climate change and biodiversity decline [84]. A commission appointed by CCAFS synthesised all these issues and successfully put them on the agenda of international UN conventions [85]. Recognising that both the development and GEC research communities can contribute to the quantification, illumination and communication of climate change and food security, CCAFS was established by the Consultative Group of International Agricultural Research (CGIAR) in partnership with the ESSP. The CCAFS project on 'Integration for Decision Makers' aims to engage scientists, local communities and decision-makers in Africa and Asia to (i) enhance the assessment of the likely impacts of climate change on agricultural systems and (ii) improve methodologies used to evaluate the likely impacts of various policy and programme interventions in order to inform adaptation and mitigation strategies aiming to alleviate poverty and enhance food security and environmental health. The project website[e] implies that this 'Integration for Decision Makers' initiative encompasses the three dimensions of integration. First, the project involves the engagement of, for example, agricultural and climate scientists, development researchers, economists, and policy scientists. Second, it includes the international dimension of integration because the project aims to 'Explore and jointly apply approaches and methods that enhance knowledge-to-action linkages with a wide range of partners at local, regional and global levels'. Third, the project attempts to provide 'an integrative function for CCAFS stakeholder engagement from local to global levels, both in terms of setting research agendas and providing forums for discussing emerging results and options for action'. Although in its embryonic stage, this project and the Cities at Risk programme could provide useful lessons for future integrated GEC research for sustainability. Experience can be gained from other problem driven science that seek sustainability solutions, such as health and engineering.

### Integration is not unique to GEC research

The challenge of practising genuine integrated (interdisciplinary and transdisciplinary) research is not unique to GEC research. Integrated health research has already experienced success at incorporating the three dimensions of integration. For example, the discovery that tobacco use was associated with high rates of lung disease required science integration (for instance, medical research and behavioural sciences) and an international, cross-sectoral response from, for example, governments and the World Health Organisation (WHO) to inform and issue health warnings of smoking tobacco [86,87]. Furthermore, the need for integrated health research is described in a forthcoming major review and synthesis for the WHO's Tropical Diseases Research Programme. This initiative aims to embody the three dimensions of integration with calls for interdisciplinary research, as well as sectoral and international collaboration, to prevent and control infectious diseases. This integrated approach is informed by the complexities of ecological relationships, among the domains of environmental change (including climate change), agricultural production, nutritional health and the influence on emergence, spread and severity of infectious diseases, especially in situations of poverty and deprivation [88]. Another important research field that seeks to tackle sustainability challenges is engineering.

Engineering is perhaps one of the most solutions oriented scientific enterprises, yet Mihelcic *et al.* [89] observe the need for engineering to better integrate societal and economic issues with environmental science. Traditionally, an engineer was trained to undertake technological problem solving by examining problems locally or from one dimension. The quality of a project was measured by engineering specific standards, such as robustness against physical stress. Whereas, contemporary engineering recognises that, for example, major infrastructure projects (for instance, bridges, roads and dam construction) have social, economic, and environmental impacts. Engineering now requires scientific collaboration across disciplines and a transdisciplinary approach of mutual learning and joint problem solving with practitioners to solve sustainability problems [90,91].

## Conclusions

Persistent barriers to science integration have prevailed for too long. It is vital that they are overcome. Furthermore, lessons learned from attempts to tackle intertwined sustainability challenges need to be synthesised and embedded in future transdisciplinary global environmental change research. The humanities and non-scientific knowledge, such as expert, lay and indigenous, remain to be integrated regularly in GEC research. Yet these knowledges should be considered in order for science with society to produce options to overcome sustainability challenges. A key finding from the ESSP review was that, despite the need for a partnership to study an integrated Earth system and its response to global environmental changes, the ESSP was under resourced to meet this

[e] http://ccafs.cgiar.org/our-work/research-themes/integration-decision-making.



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mandate. An important lesson from this experience is that financial and human resources and a commitment commensurate to the task are required for the necessary sea change to span, and so integrate, the disciplinary, sectoral and international elements of transdisciplinary GEC research.

## Acknowledgements

The author acknowledges valuable comments and suggestions to the draft manuscript from Colin Butler, Pep Canadell, Michelle Carnegie, Ann El Khoury, Leah Goldfarb, Andy Haines, Ann Henderson-Sellers, John Ingram, Anne Larigauderie, Rik Leemans, Tony McMichael, Harold Mooney, Howard Moore, Liam Phelan, Ross MacKenzie, and Greg Walkerden. I would also like to thank two reviewers and the journal editors for their insightful reviews and extremely useful comments on early drafts.

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## 3.3. Paper D: 'Interdisciplinarity in Environmental Journals: What's in a Name?'

Manuscript submitted for peer-review on 1 August 2013 to Climatic Change

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**Interdisciplinarity in Environmental Journals: What's in a Name?**

**Abstract**

Interdisciplinary research plays a pivotal role in increasing the focus on the nexus between human and environmental systems. Yet, there have been few studies on the performance of one conduit of interdisciplinary research: environmental journals. The aim of this research is to examine the 'breadth' of the disciplinary enquiry in environmental journals that describe themselves as interdisciplinary, and their processes for evaluating the quality of the articles submitted to them. To pursue this research aim, data are derived from the Web of Science electronic database, journal websites and survey interviews of journal editorial offices. The characteristics of thirty-three journals that self-describe in their title or website as being interdisciplinary are examined and compared with the same attributes drawn from a randomly selected group of thirty-three journals that do not describe themselves as interdisciplinary. Increasingly challenging bibliometric measures are applied to gauge disciplinary breadth using the subject categories in which related journals are grouped. Study findings imply that self-described interdisciplinary journals are not demonstrably broader in their disciplinary reach than other environmental journals. Furthermore, our findings suggest a weak connection between (self-described) interdisciplinary environmental research and research in a wide variety of practical areas (e.g. business and transportation) where substantial policy shifts are needed to respond to anthropogenic climate change. The responses from the editorial offices of the thirty-three self-described interdisciplinary environmental journals, reveal that the professional practices of interdisciplinary reviewing differ widely and could benefit from sharing values.

**Keywords:** Interdisciplinary; Environmental Journals; Climate Change; Practical Research; Bibliometrics; Editorial Office Survey.

## 1. Environmental Journals: A conduit of interdisciplinary research

The scientific community has increasingly recognised the paradigm that James Lovelock and Lynn Margulis put forward in 1973 of understanding the Earth as an integrated system (Lawton, 2001; Pitman, 2005). Concurrent with this shift in thinking, scientists have become aware of the need for global sustainability and this has been coupled with repeated calls for interdisciplinary environmental research (Schneider, 1977a; Schneider, 1977b; Lubchenco, 1998; Steffen et al., 2004; Leemans et al., 2009). Interdisciplinary research plays a pivotal role in increasing the focus on the nexus between human and environmental systems (see, for example, Clark & Dickson, 2003; Ehrlich et al., 2012; Griggs et al., 2013).

Academic journals provide opportunities to add to an existing body of knowledge and for scholars and an issue to gain prominence (Hargens, 1988). Yet, there have been few studies on the performance of one conduit of interdisciplinary research: environmental journals. This study examines (i) the 'breadth' of the disciplinary enquiry in journals that describe themselves as vehicles for interdisciplinary research, and (ii) their processes for evaluating the quality of the articles submitted to them.

The Oxford English Dictionary defines 'interdisciplinary' as, "Of or pertaining to two or more disciplines or branches of learning; contributing to or benefiting from two or more disciplines" (Oxford English Dictionary Online, 2013). The terms "pertaining to" or "contributing to" and "benefitting from two or more disciplines" are central because they indicate an integration of knowledge, which is a central tenet of interdisciplinary research (Klein, 2000; Newell, 2001; Porter et al., 2006; Szostak, 2007; Youngblood, 2007). The notion of integration is further advanced by (Wagner et al., 2011) who contend that, "Interdisciplinary approaches integrate separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of a complex issue, question or problem" (Wagner et al., 2011, p. 16).

Recognising that it is the integration of different disciplinary approaches and knowledge to address a complex problem that separates interdisciplinary from multidisciplinary (see, for example, Morillo et al., 2001; Szostak, 2007; Raasch et al., 2013), this research evaluates the disciplinary breadth of environmental journals that self-describe as interdisciplinary. We gauge breadth using the subject categories in which related journals are grouped - taking inclusion of a journal in multiple subject categories as a rough measure of greater breadth. We test the hypothesis that environmental journals that describe themselves as interdisciplinary demonstrate greater breadth than environmental journals that do not, and reflect on the implications for 'disciplinary breadth' of the subject areas which are and are not pulled into interdisciplinary environmental research practice. The bibliometric analysis is complemented by an e-mail survey interview sent to the editorial offices of the thirty-three self-described interdisciplinary environmental journals, designed to support interpretation of the bibliometric data.

## 2. Research Methods

### *2.1 Selection of a journals database with which to analyse disciplinary breadth*

To compare the disciplinary breadth of journals using subject categories, a journals database is needed as a platform. Various databases (e.g. Thomson Reuters' Web of Science (WoS), Scopus, Google Scholar, PubMed/Medline, and the Network for

Transdisciplinary Research) are used in bibliometric studies. Each use different classification systems to categorise journals. For example, WoS assigns journals to 250 categories within sciences, social sciences, arts and humanities, while Scopus assigns journals from life sciences, physical sciences, health sciences, and social sciences and humanities into 27 major subjects (Abrizah et al., 2013). Thomson Reuters' Journal Citation Reports (JCR) environmental subject categories are more finely categorised than the Scopus environmental subject area which includes disciplines which JCR differentiates out with stand-alone subject categories (e.g. Ecology, Geography, Law and Toxicology). Journal Citation Reports is a resource to evaluate and compare journals using citation data drawn from scholarly and technical journals (see: http://wokinfo.com/products_tools/analytical/jcr/). The most widely used unit of analysis to examine the interdisciplinarity of research are the Thomson Reuters' subject categories (Porter et al., 2008). We therefore used Thomson Reuters' WoS journals database and their Journal Citation Reports as the foundation for our analysis.

*2.2 Identification of interdisciplinary environmental journals*

We identified environmental journals that self-describe as interdisciplinary by starting from journals listed in WoS as environmental and for each journal looking to see whether it self-described as interdisciplinary in one or more of the following three ways: (i) the word 'interdisciplinary' was in its title; (ii) the journal claims that it is a source of interdisciplinary information; and / or (iii) the word 'interdisciplinary' is on the homepage description of the journal (e.g. aims, approach, coverage, scope).

*2.3 Analysis of breadth of integration*

We analysed breadth of integration by applying a series of increasingly stringent bibliometric tests, and to identify whether environmental journals that describe themselves as interdisciplinary were significantly broader in their disciplinary reach than environmental journals that do not, we applied these methods to a random sample of environmental journals that do not identify themselves as interdisciplinary. The tests we applied, to focus in on the relative breadth of interdisciplinarity were as follows.

i) We identified how many subject categories a journal was associated with. To a first approximation, if a journal is associated with multiple subject categories it possesses relatively broad interdisciplinarity. If it is listed in only one subject category, it may well only be interdisciplinary in a relatively narrow sense (acknowledging that the breadth of individual JCR subject categories varies).

ii) We then examined the disciplinary breadth of 'related journals'. The second breadth threshold was whether three or more out of five of a journal's top-five 'related' journals were associated with two or more subject categories. The 'Related Journals' page on the JCR database identifies journals which have a subject relationship with the journal being studied based on citations either given or received. They are ranked by their degree of relatedness (Thomson Reuters, 2010).

iii) The third breadth threshold was whether at least two of the top-five 'related' journals had three subject categories, two of which must be different to the journal under examination.

By applying these tests sequentially, on each of the environmental journals that self-describe as interdisciplinary, and a random sample of environmental journals that do not, we get profiles of relative breadth in the two populations that can be contrasted with each other.

In addition, we reviewed the subject categories that this examination of related journals revealed with the overall set of subject categories used by JCR, to explore the reach of the environmental journals' disciplinary engagements.

*2.4. Survey of editorial practices*

To assist with interpretation of the bibliometric data, and to more closely examine publication processes for interdisciplinary environmental research, we surveyed the editorial offices of the self-described interdisciplinary environmental journals to obtain information about how these journals identify and publish interdisciplinary papers. We conducted the survey by e-mail between 21 September 2012 – 15 October 2012, 19 December 2012 – 18 January 2013 and 18 February – 11 March 2013.

The survey consisted of eight questions asking the editorial offices about: (i) the total number of manuscripts received in 2010; (ii) the number of manuscripts rejected by the editor before undergoing peer review; (iii) the number of reviewers assigned to each manuscript; (iv) the duration of the manuscript review; (v) the number of manuscripts accepted for publication; (vi) the way that a journal seeks to pursue integrative writing, reviewing and editorial assessment; and (vii) whether or not an editorial office has a strategy concerning the journal's impact factor, specifically if (a) they think about papers that might increase its impact factor and (b) if very interdisciplinary papers increase the journal's impact factor.

## 3. Results

JCR categorises 263 journals as environmental. Of these, thirty-three self-describe as interdisciplinary, using the criteria listed above (Table 1).

**[Table 1 about here.]**

### *3.1. Analysis of breadth of integration*

The disciplinary breadth profiles of the 33 environmental journals that self-describe as interdisciplinary, and the random sample of 33 other environmental journals from the JCR database were surprisingly close (Figure 1). Inspection demonstrates that there is no significant difference between them. By this measure, self-described interdisciplinary journals are not demonstrably broader in their disciplinary reach than other environmental journals.

Comparing the complete list of subject categories found in the JCR database with the set of subject categories applied to the interdisciplinary environmental journals and their related journals, revealed a low level of connection between (self-described) interdisciplinary environmental research and research in a wide variety of practical disciplines that, in principle, one would hope to see well-linked to environmental research, e.g. business and finance, education, energy and fuels, planning and development, and transportation.

**[Figure 1 about here.]**

### *3.2. Survey of editorial practices*

Twenty-one percent of the editorial offices (seven of the thirty-three self-described interdisciplinary environmental journals) responded to the survey. Several other editorial offices/publishers declined to participate: one on the grounds of the confidentiality of its review process, another because of "commercial strategic" reasons, while the management of a major publisher of eight of our sample of thirty-three journals advised some of its editorial managers not to engage in this survey and offered "no comment" as their fixed response to our investigations. Recognising that journal editorial offices, editors and editorial board members have to deal with constant demands and pressures, we are grateful for the responses received (completed surveys or emails explaining why a journal was unable to participate in our survey).

The following section describes the major findings of the survey and resulting issues, while taking care to preserve the anonymity of individuals and journals.

*i) Rejection Rates*

Peer review is a well-established aspect of academia (van Raan, 2001; Jefferson et al., 2002; Cassey & Blackburn, 2004; Rushby, 2010), where manuscript rejection or acceptance is part of the bitter-sweet life of an academic. Yet, there are only a limited number of studies on journal rejection rates (see, for example, Zuckerman & Merton, 1971; Miller & Serzan, 1984; Weller, 2001; Aarssen et al., 2008; Schultz, 2010a). Moreover, to our knowledge, none have investigated the rejection rates of interdisciplinary environmental journals. One aim of our survey was, therefore, to measure the success rate of interdisciplinary manuscripts surviving the rigours of academic peer-review.

The first hurdle for many manuscripts to overcome is an initial screening by the editor to determine if it is on-topic and scientifically robust (see, for example, Weller, 2001;

Croll, 2007). Additionally, interdisciplinary journal editors need to check that a manuscript is not too specialised or narrow in focus. We asked editorial office respondents, “How many manuscripts were rejected by the editor before undergoing peer review?”. The rejection rate ranged from ten percent to as high as forty-two percent. The average rejection rate of twenty-six percent seems high. Although, we could not find any similar studies in the literature to provide a comparison.

The next stage in the review process usually involves the editor or an editorial board member assigning a manuscript to external experts for peer review (Weller, 2001). Here we can compare the rejection rates of manuscripts that underwent peer-review because (Schultz, 2010a) provides an excellent study on the rejection rates of journals publishing in the discipline of atmospheric sciences.

The approximate rejection rate was calculated from the data received from editorial offices by dividing the total number of accepted papers by the total number of submissions in 2010. We defined rejection rate as 100 minus the acceptance rate and expressed the value as a percentage (Table 2). Our data has limitations because the rejection rates are approximate values because in some cases the editorial office provided a rough estimate or added the caveat that the number of manuscripts accepted may also include manuscripts from the previous year and not just the year being studied. Next, we compared our results with (Schultz, 2010a), excluding from our sample the outlier journal B, which primarily publishes solicited papers. Our sample of survey respondent interdisciplinary environmental journal rejection rates range between forty-eight percent and eighty percent, while Shultz’s sample of atmospheric sciences journals rejection rates (excluding an outlier) range between twenty-five percent and sixty percent.

**[Table 2 about here.]**

Although the difference in rejection rates might be attributed to the fact that Shultz's dataset is from 2006 and 2007, while our dataset is from 2010 (when some journals switched to electronic manuscript submission systems). The possibility of an increased number of manuscripts received as a result of switching to an electronic submission system is reflected in one editorial office response, observing that "the number of submissions changed from about 180 prior to the electronic submission system to 370 last year (2012)."

The rejection rates in humanities and social science journals are higher (approximately seventy percent) than those in physical science journals (about thirty percent) because of the difficulty in reaching consensus in the social sciences (Schultz, 2010a). Supporting this finding, a survey of ninety-five political science journals reported an average rejection rate of eighty percent in 2011 (ReviewMyReview, 2013), while twenty-eight American Psychological Association (APA) journals had an average rejection rate of seventy-seven percent in 2009 (American Psychology Association, 2009). Although limited to a small sample of environmental journals, one possible explanation of our findings could be that deciding to accept or reject a manuscript during an interdisciplinary review is challenging because of the need to communicate and consider the integration of different disciplinary perspectives.

*ii) Accept or Reject: Reaching a decision*

Consensus is reached when reviewers and, ultimately, the editor agree to accept or reject a manuscript. The criteria applied to help reach a decision include, for example, consideration of appropriate research problems, theoretical approaches or research techniques (Hargens, 1988; Schultz, 2010a). Our sample of journals tended to assign two or three reviewers per manuscript, although one editorial office commented, “If an interdisciplinary issue is controversial for a specific disciplinary view, additional reviewers can be sought”. Concerning the number of reviewers assigned to review a manuscript, a study on the Monthly Weather Review concludes that there is no difference in the Editor’s final decision if a manuscript is reviewed by two or three reviewers (Schultz, 2010b). An additional consideration is the time spent on reviews. Golden & Schultz (2012) observe that, “Apart from anecdotal evidence, however, quantitative measurement of the time spent on the peer-review process is largely unknown” (Golden & Schultz, 2012, p. 337). We suspect that it takes longer to reach a decision with interdisciplinary manuscripts, yet we cannot substantiate this from our survey of interdisciplinary environmental journals. These range from one month to up to six months to decide to accept or reject a manuscript. Furthermore, to our knowledge, there is limited literature or data available to compare the duration of interdisciplinary versus disciplinary manuscript reviews.

The editorial offices of the thirty-three self-described interdisciplinary environmental journals were asked to consider, “In what way does the journal seek to pursue integrative writing, reviewing and editorial assessment?”. The purpose of this question was to determine how integrative the review process is in practice because “Individual [disciplinary] standards must be calibrated and tensions among different approaches carefully managed in balancing acts that require negotiation and compromise” (Klein, 2008, p. S116). Responses include:

*Journal A: "One of our primary criteria for submission review is its interdisciplinary content, which is emphasized in our reviewer guidelines. All our editors are very conversant with interdisciplinary research, and we encourage them to consult with one another on interdisciplinary topics. We commonly ask authors to revise their submission to be accessible in terms of context, content, and method for the broad, interdisciplinary audience of the journal. Submissions that are narrowly focused without broader insights are routinely rejected, often before external review, and authors are generally directed to more specialized journals."*

*Journal B: "The editor in chief is very interested in interdisciplinarity and actively pursues integrative papers. It is extremely important for sustainability science, not only to publish findings but also procedures and research strategies."*

*Journal C: "The whole review and assessment process is set up to be efficient, fair but rigorous, and the quality of the content is a reflection on this."*

*Journal D: "It [the journal] seeks out a diverse Editorial Board with broad qualifications".*

These responses, albeit from a small sample, suggest that integrative reviews are pursued to varying degrees of intensity. Some journals have rigorous policies and procedures in place (e.g. Journal A), while others do not.

## 4. Discussion

The absence of a difference in disciplinary breadth between formally interdisciplinary environmental journals, and other environmental journals, was surprising. This suggests that an explicit commitment to interdisciplinarity does not lead to a broader disciplinary reach as we expected. Although the comparisons with other areas of research are tentative, the rejection rates amongst the sample of journals analysed in the survey support Lynch's (2006) observation that it is not easy being interdisciplinary. Given the importance of improving integration to address practical problems, notably at the global and regional scales that Earth system science focuses on, Paper D findings imply that linkages between interdisciplinary environmental journals and journals from areas of practice where substantial policy shifts are needed are weak - for example, business and finance, education, energy and fuels, planning and development, and transportation - is an especially concerning aspect of this lack of breadth.

Kammen (2013), in a recent Environmental Research Letters editorial, emphasises the importance of focusing research on the nexus of science and action. An exemplar is the recently established journal - "Solutions: For a sustainable and desirable future" - which provides opportunities for academics and non-academics to publish practical, solutions-oriented research on integrated ecological, social, and economic problems (see: http://thesolutionsjournal.anu.edu.au/). The absence of distinctive disciplinary breadth in journals setting out to support and promote interdisciplinary research is clearly an area for their journal editorial boards to consider.

There is a need for a more 'open' knowledge system that includes both academics and non-academics engaged in transdisciplinary research for Earth system sustainability (see, for example, Scholz, 2011; Cornell et al., 2013; Tàbara & Chabay, 2013). Potentially, a way for editorial boards to foster greater breadth is to increase their support for explicitly transdisciplinary research. Future research could study if there is a trend towards interdisciplinary environmental journals broadening their horizons to integrate knowledge from more 'practically' oriented disciplines and to examine if journals are publishing integrated research at the nexus of science and action that can help contribute to solutions to grand societal challenges, such as anthropogenic climate change.

It also appears that the professional practices of interdisciplinary reviewing could benefit from strengthening, potentially by more sharing of best practices. Journal A, for example, appears to exemplify excellence.

## 5. Conclusion

Self-described interdisciplinary journals are not demonstrably broader in their disciplinary reach than other environmental journals. Nor are the links to practical disciplines, like business and transportation, well-developed. If there is a need for a marked broadening of interdisciplinary research to address the major societal challenges, and specifically those like anthropogenic climate change that have driven dramatic expansions in Earth system science, then strengthening practices for reviewing interdisciplinary research would be an important element of this.

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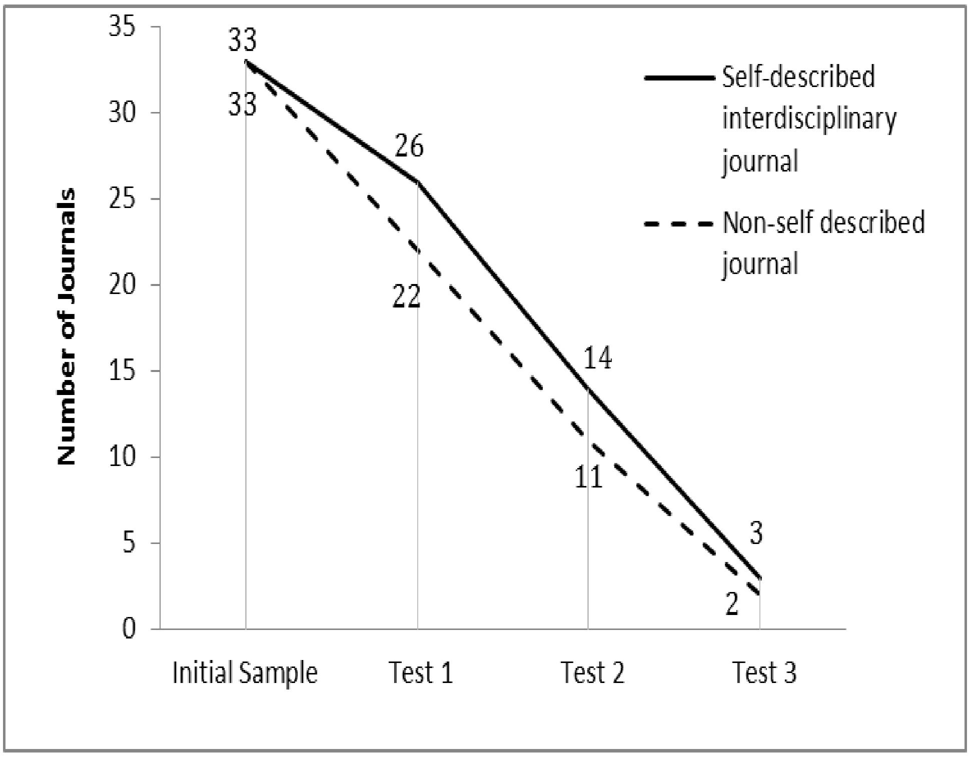
**Figure 1: Results of Bibliometric Measures.**




Results of Bibliometric Measures. Increasingly difficult bibliometric measures (tests one to three) are applied to environmental journals (self-described interdisciplinary (solid line) and non self-described (dashed line)). Forty-eight out of sixty-six journals pass test one, while only five journals survive test three. The relative interdisciplinary breadth is almost identical in the two populations.

**Table 1: Sample of Sixty-Six Web of Science Listed Environmental Journals.** The complete set of thirty-three self-described interdisciplinary journals and the random sample of thirty-three non self-described interdisciplinary environmental journals from the Web of Science database.

| All Self-Described Interdisciplinary Environmental Journals | Random Sample of Non Self-Described |
|---|---|
| Aerobiologia | Aerosol Science and Technology |
| CLEAN-Soil Air Water | Annual Review of Environment and Resources |
| Climatic Change | Aquatic Conservation – Marine and Freshwater Ecosystems |
| Computers Environment and Urban Systems | Australasian Journal of Environmental Management |
| Current Opinion in Environmental Sustainability | BioEnergy Research |
| Environment and Behavior | Biomedical and Environmental Sciences |
| Environmental Conservation | Chemistry and Ecology |
| Environmental Engineering Science | Cultural Geographies |
| Environmental Ethics | EcoHealth |
| Environmental Fluid Mechanics | Ecological Engineering |
| Environmental Impact Assessment Review | Energy and Environmental Science |
| Environment and Planning A | Energy Journal |
| Environmental Research Letters | Environment and Planning D – Society and Space |
| Environmental Science and Pollution Research | Environment International |
| Environmental Toxicology and Pollution | Environmental Forensics |
| Frontiers in Ecology and the Environment | Environmental Health |
| Global Environmental Change – Human and Policy Dimensions | Environmental Modelling and Software |

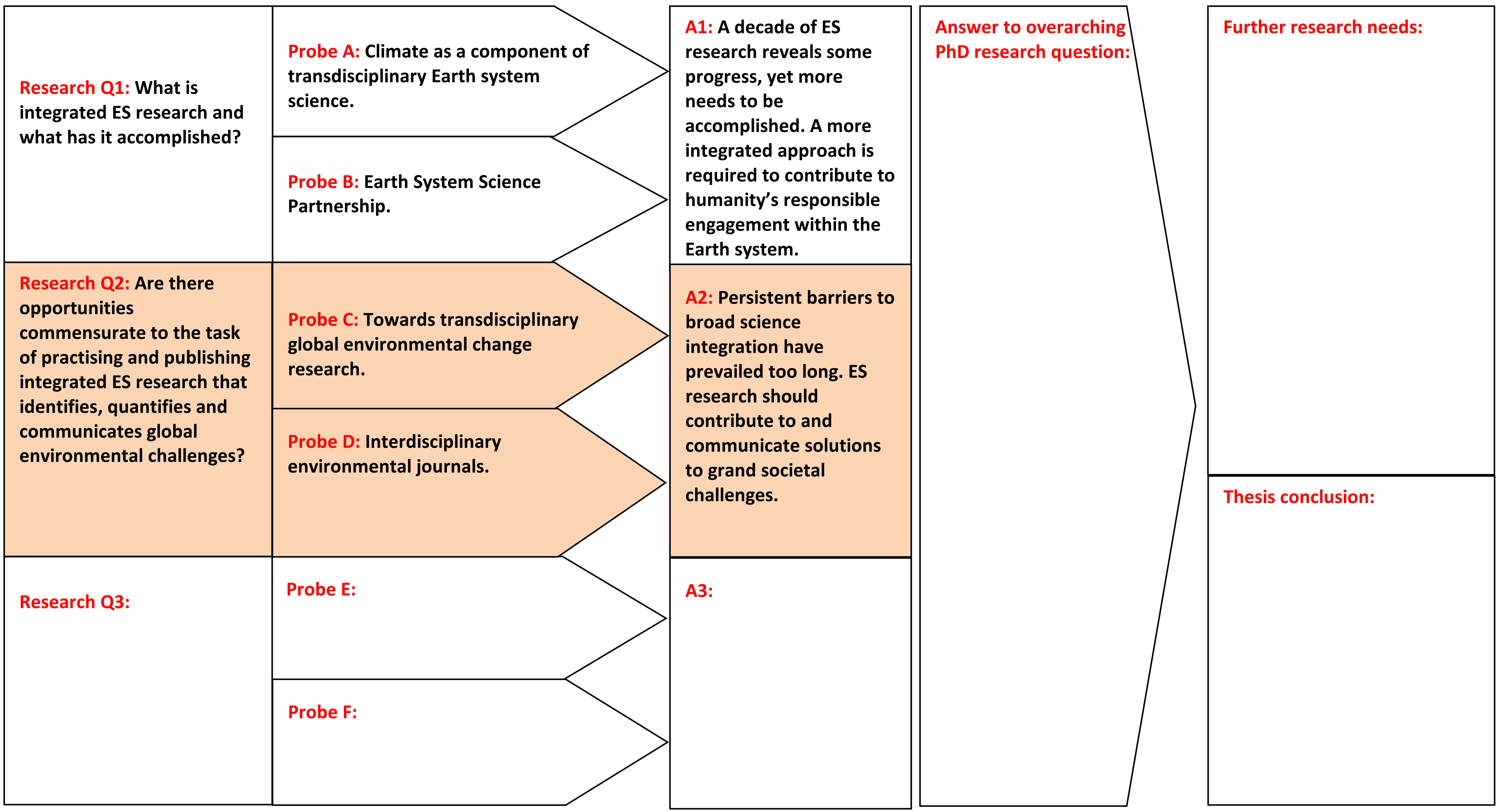
| All Self-Described Interdisciplinary Environmental Journals | Random Sample of Non Self-Described |
|---|---|
| Human Ecology | Environmental Technology |
| Human Ecology Review | Environmental Values |
| International Journal of Environmental Analytical Chemistry | Fresenius Environmental Bulletin |
| Journal of Architectural and Planning Research | GAIA-Ecological Perspectives for Science and Society |
| Journal of Cleaner Production | Industrial Health |
| Journal of Environmental Engineering - ASCE | International Journal of Environmental Health Research |
| Journal of Environmental Informatics | International Journal of Life Cycle Assessment |
| Land Use Policy | Journal of Contaminant Hydrology |
| Natural Resources Journal | Journal of Environmental Economics and Management |
| Organization and Environment | Journal of Environmental Health |
| Population and Environment | Journal of Environmental Monitoring |
| Remote Sensing of Environment | Journal of Environmental Planning and Management |
| Stochastic Environmental Research and Risk Assessment | Journal of Health Population and Nutrition |
| Tourism Management | Journal of Industrial Ecology |
| Water Air and Soil Pollution | Journal of Regional Science |
| Water Resources Research | Regional Science |

**Table 2: Rejection Rates of Interdisciplinary Environmental Journals.** The number of submissions is a 12-month value from 2010, except Journal A which is from 2011. The numbers of manuscripts accepted are from 2010, except for journals A and E, which added the caveat that this figure could include manuscripts from previous years. The rejection rates are therefore approximate values. The actual names of the journals are not shown to preserve their anonymity.

| Journal | Number of submissions | Number of manuscripts accepted | Approximate Rejection Rate |
|---|---|---|---|
| A | 538 | 111 | 80% |
| B | ~ 120 | ~ 100 | ~ 20% |
| C | ~ 180 | ~ 42 | ~ 80% |
| D | ~ 240 | ~ 50 | ~ 80% |
| E | 566 | 143 | ~ 80% |
| F | 250 | 96 | 62% |
| G | 61 | 32 | 48% |

## 3.4. Response to research question two

**PhD research topic:** Integrated Earth System Science: Research Practice and Communication for Solutions to Twenty-First Century Sustainability Challenges



### 3.5. Conclusion

Chapter Three addressed the thesis research question, "Are there opportunities commensurate to the task of practising and publishing integrated ES research that identifies, quantifies and communicates global environmental challenges?". This question is difficult to answer because doing so requires selection of one or more platforms of existing ES research for evaluation. Any such selection itself impacts the findings. Here I select two contrasting modes of ES research: the Earth System Science Partnership (ESSP) and a cadre of self-identified journals purporting to publish 'integrated Earth system science'. The former is selected because it provides an example of an interdisciplinary scientific partnership created to bring together natural and social scientists to study changes to an integrated ES and the implications for global sustainability. The latter examines environmental journals as major channels of interdisciplinary ES knowledge. These two examples, therefore, reflect opportunities for the research community to practise and publish integrated ES research.

Paper C synthesised the conceptual evolution and practice of integration for GEC research, advancing from one dimension (narrow, natural science interdisciplinary research) to more recent transdisciplinary research driven by stakeholder needs. Paper C underlined the key finding from the ESSP review that, despite the need for a partnership to study an integrated Earth system and its response to global environmental changes, the Earth System Science Partnership was under-resourced as compared to the magnitude of its mandate. An important conclusion is that financial and human resources and a commitment commensurate to the task are required for the necessary sea change to span, and so integrate, the disciplinary, sectoral and international elements of transdisciplinary Earth system research. Obstinate obstacles to science integration have prevailed for too long. Paper C underlined why it is vital that they be overcome. Lessons learned from attempts to tackle intertwined sustainability challenges need to be synthesised and embedded in future transdisciplinary global environmental change research. Furthermore, non-scientific knowledge ought to be integrated more regularly into transdisciplinary ES research in order to contribute to options to overcome sustainability challenges.

Paper D presented results of a study to determine the breadth that journals integrate knowledge from different disciplines and factors that contribute to the publication of interdisciplinary papers based on analysis and survey enquiry around thirty-three self-described interdisciplinary environmental journals. Paper D found that self-described interdisciplinary journals are not demonstrably broader in their disciplinary reach than other environmental journals. Findings also suggest a weak connection between (self-described) interdisciplinary environmental research and research in a wide variety of practical areas (e.g. business and transportation) where substantial policy shifts are needed to respond to Earth system derived sustainability challenges. Paper D underlines that self-described interdisciplinary journals have a responsibility to conduct integrative reviews and finds (only) one excellent exemplar journal rigorously pursuing such a process. The professional practises of interdisciplinary reviewing could, and Paper D argues should benefit from sharing values. Furthermore, more opportunities to publish practical, policy-oriented and user engaged research could contribute to solutions to grand societal challenges.

# 4. Surviving Growing Pains to Help Society Respond to Global Environmental Challenges

## 4.1. Introduction

Chapter Two describes the need for more integrated ES research to tackle complex societal challenges, while Chapter Three describes some promising advances in integrated research on global environmental changes. Yet, despite some progress persistent barriers to science integration remain. Chapter Four considers opportunities to overcome these barriers based on Paper E *'Surviving the growing pains of the inter-to-disciplinary lifecycle'* and Paper F '*Overcoming A Diabolical Challenge: Comparing journalists' and researchers' views on the performance of the media as a channel of climate change information*'. Appendix Two *'Transdisciplinary global change research: the co-creation of knowledge for sustainability'* and Appendix Three '*Survival of the fittest is not always the best option'* provide further insights. In the context of this thesis, Chapter Four considers how ES research can become more integrated and better positioned in order to contribute to responses to global environmental challenges.

This chapter contends that the set-backs of emerging integrated science can be seen as a positive part of the process of evolution (Paper E). Furthermore, integrated ES research has contributed to the articulation of the planetary boundaries concept, which aims to help society set parametres to responsibly engage within the Earth system. However, as Chapter Two has revealed, the outcomes of the UNFCCC COP15 in Copenhagen illuminates some of the limitations of global governance and the challenges of mass media reporting of climate change. There is a need to devise new and innovative methods of improving public communications, particularly in an often crowded and noisy public policy space. Chapter Four considers how it is vital that an evidence-based approach is used when the mass media reports on ES-derived challenges (e.g. climate change). Yet, the literature describes tensions between science and the mass media.

Such tensions and media coverage of alleged climate research misconduct formed the basis of a survey I developed for an interface group of researchers and scientifically knowledgeable journalists who have a vested interest in climate science and evidence-based journalism. Survey findings described in this chapter reveal a mutual intelligibility and general trust between this core group of journalists and researchers. Chapter Four proposes that this interface group can help influence mainstream journalists to better inform the public about the urgency to overcome the diabolical climate challenge by using evidence-based science.

## 4.2. Paper E: 'Surviving the growing pains of the inter-to-disciplinary life cycle'

Published PNAS Letter (29 May 2013): Rice M. and Henderson-Sellers A. (2013). Surviving the growing pains of the inter-to-disciplinary lifecycle. *Proceedings of the National Academy of Sciences*, USA. Early edition,

www.pnas.org/cgi/doi/10.1073/pnas.1306270110.

LETTER

# Surviving the growing pains of the inter-to-disciplinary lifecycle

In PNAS, Shaman et al. (1) introduces a collection of articles from the Arthur M. Sackler Colloquium of the National Academy of Sciences "Fostering Advances in Interdisciplinary Climate Science." The papers provided an informative account of progress in interdisciplinary climate science, examples of emerging research, and some of the challenges that can impede interdisciplinary research (e.g., planning, funding, execution, and dissemination). However, when one reviews the literature, a pattern emerges where these same challenges relating to attitudinal (planning), communication (planning, execution, and dissemination), and structural bias (funding) have persisted over the past three decades (see, for example, refs. 2, 3, 4, and 5). Are these obstacles too massive to overcome? Or are the "growing pains" of maturing from an adolescent (emerging interdisciplinary field) into an adult (an established discipline) part of the inter-to-disciplinary lifecycle?

We agree with Shaman et al. (1) that emerging interdisciplinary research fields struggle to gain recognition and that some fail, but we propose that such selection is both "natural" and perhaps beneficial. Researchers accept that if a species is washed ashore on the Galápagos Islands, then it must adapt or perish and that a new business must quickly become competitive or will fail. In the same way, emerging interdisciplinary research fields must demonstrate their added value. Interdisciplinary climate science provides an excellent example. It has endured growing pains to mature into an established discipline. Globally, there are scientists, research institutes, journals, and training courses dedicated to interdisciplinary climate science. How did this happen? Pioneers, such as Jim Hansen and Stephen Schneider, championed the interdisciplinary climate science cause. They articulated exciting and novel research questions, raised funds for projects and research institutes, attracted the brightest scientists, engaged with different disciplines, and communicated the science via the mass media or assessment processes (e.g., the Intergovernmental Panel on Climate Change). Climate change is now recognized as one of the most urgent societal challenges of our time, demanding the integration of the natural, social, and human sciences and the engagement of science and society to provide options for the responsible management of the world's climate.

A decade ago, the seminal National Academies report *Facilitating Interdisciplinary Research* (4) concluded that complex challenges motivate interdisciplinarity and the emergence of new disciplines, attracting researchers toward exciting questions and the interface of disciplines. However, 10 y on, the same challenge remains to provide the institutional and funding support required for interdisciplinary research. Rather than repeatedly identify the same barriers, we propose researchers, funding agencies, and academies might better devise methods to penetrate barriers and tools to identify interdisciplinary efforts not yet strong enough to stand alone.

The barriers to interdisciplinary research are not insurmountable, as demonstrated by the new interdiscipline of climate. On the contrary, the growing difficulties are healthy evidence of the inter-to-disciplinary lifecycle, where "natural selection" enables the most worthy scientific enterprise to flourish and leaves weaker species time to adapt.

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**4** National Academy of Sciences; National Academy of Engineering; Institute of Medicine of the National Academies (2004) *Facilitating Interdisciplinary Research* (National Academies Press, Washington, DC).
**5** Phelan L, Jones H, Marlon JR (2013) Bringing new PhDs together for interdisciplinary climate change research. *Eos Trans AGU* 94(5):57.

Author contributions: M.R. and A.H.-S. wrote the paper.

The authors declare no conflict of interest.

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Rice, M., & Henderson-Sellers, A. (2013). Surviving the growing pains of the inter-to-disciplinary lifecycle. Proceedings of the National Academy of Sciences of the United States of America, 110(29), 1. https://doi.org/10.1073/pnas.1306270110.

## 4.3. Paper F: 'Overcoming A Diabolical Challenge: Comparing journalists' and researchers' views on the performance of the media as a channel of climate change information'

Article in press (accepted on 9 July 2013). Rice M., Henderson-Sellers A., Walkerden G. (2013). Overcoming A Diabolical Challenge: Comparing journalists' and researchers' views on the performance of the media as a channel of climate change information. International Journal of Science Education, Part B. Communication and Public Engagement. http://dx.doi.org/10.1080/21548455.2013.824131.

*International Journal of Science Education, Part B*, 2013
http://dx.doi.org/10.1080/21548455.2013.824131

# Overcoming a Diabolical Challenge: Comparing journalists' and researchers' views on the performance of the media as a channel of climate change information

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The mass media has a fundamental role to sustain an informed citizenry as a prerequisite for democratic politics. It is, therefore, vital that an evidence-based approach is used when reporting on climate change. Yet, multiple and arguably irreconcilable tensions exist between science and mass media. For example, as media workers are trained to provide a 'balanced' approach, this can result in bias in climate change reporting. Additionally, various industry-related pressures mean that mainstream journalists often have limited resources and time to check the accuracy of their climate news stories with researchers. Such tensions and media coverage of alleged climate research misconduct formed the basis of a survey we have developed for an interface group of researchers and journalists who have a vested interest in climate science. The aim of this survey is to compare their attitudes on the performance of the media as a channel of climate change information. The survey was conducted in mid-2010, with responses from journalists and researchers who attended international fora for science–media interface and research integrity discussions, or accessed the survey via an international climate research programme website. Survey findings reveal, contrary to tensions described in the existing literature, a mutual intelligibility and general trust between this core group of journalists and researchers, who have a vested interest in evidence-based climate science reporting. We argue that scientifically informed interface journalists, by collaborating with scientists, can help influence mainstream journalists to better inform the public about the urgency for society to overcome the diabolical climate challenge.

Keywords: *Climate change; Mass media; Diabolical challenge; Mutual intelligibility; Trust*

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## 1. The 'Diabolical Challenge'

Wicked problems are extremely challenging; and the term is well established in the literature (e.g. Brown, Harris, & Russell, 2010; O'Neill, Hulme, Turnpenny, & Screen, 2010; Rittel & Webber, 1973; Turnpenny, Lorenzoni, & Jones, 2009). For the most extreme wicked problems, a more intense term is appropriate. Following Ross Garnaut, a way to signal these extremes is to call them diabolical problems. Climate change is a 'diabolical policy problem'—it is 'harder than any other issue of high importance that has come before our polity in living memory', and 'any effective remedies lie beyond any act of national will, requiring international cooperation of unprecedented dimension and complexity' (Garnaut, 2008, p. xviii). Climate change requires an international response, but existing global environmental governance structures (e.g. the United Nations Framework Convention on Climate Change) are ill-equipped for grand sustainability challenges, such as anthropogenic climate change (Biermann et al., 2012). Nations have to implement their own policies to tackle climate change and their willingness to do so depends on public opinion (Pietsch & McAllister, 2010). Yet, the public (particularly in western, Anglophone countries) relies mostly on a politically motivated, commercial media to convey highly complex climate research fairly and judiciously (Clarke, 2008; Schechter, 2005). Section 2 describes how this situation is further complicated by (perceived) tensions between scientists and mass media.

Trumbo (1996) depicts the media as a channel of communication between 'social agencies' (e.g. government, scientific organisations and the media) where claims (e.g. climate change) that become news are those that have 'entered one very important arena in the struggle for legitimacy' (p. 270). The relationships between these 'social agencies' are complex (Wilson, 2000a) including trade-offs associated with gaining societal prominence. For instance, Carvalho (2007) describes how, as societies forge stronger connections between citizens, scientists, politicians and media professionals, 'the embeddedness of science and politics' elevates science into the public domain which, in turn, makes it more susceptible to 'criticism, contestation and deconstruction' (p. 224). Building on existing academic literature that describes the intricate inter-connectedness of governments, society and science (e.g. Anderson, 2009; Feng, 2005; Smith, 2005), we assume that (a) the public derives research findings largely from mass media and this public view then influences policy; and (b) policy-makers receive research directly, via assessments, or in mass media reports of findings and through changes in public opinion (Figure 1, Landscape for communicating climate science). A well-informed public is a prerequisite for democratic politics to work effectively (Durant, 1999) and the media has an important role to serve the interests of the public (Carey, 1993). Furthermore, because climate change is such a critical societal problem, it is essential that the media acts in the public interest to accurately inform the public about climate change.

The media plays a pivotal role as a 'gatekeeper' of knowledge about the climate system, where climate change information is infused with social and cultural perspectives. Such perspectives (or assumptions) also shape the reception of information

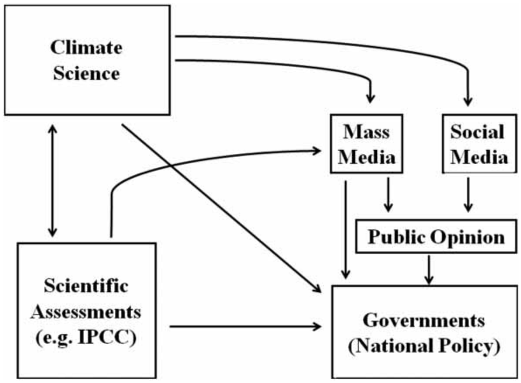


Figure 1. Landscape for communicating climate science. This flow diagram shows how climate science findings are transmitted (arrowheads indicate directional influence). Governments receive information both directly from scientists and via assessments (synthesis of the scientific literature, for example, the Intergovernmental Panel on Climate Change (IPCC) and the Millennium Ecosystem Assessment), and via media reports of findings. Public climate science information derives largely from mass and social media and this view then influences policy

(Billett, 2010). This paper examines data derived from an online questionnaire survey comparing the attitudes of a core group of journalists and researchers at the centre of the science–media nexus, specifically to ascertain what they think about mass media as conduits of climate information and how this interface group of journalists and scientists can better inform the public about the need for urgent action on climate change. ‘Interface journalists’ are strongly engaged with science, devoting a major effort into understanding the science in order to facilitate its translation in lay terms to help the public understand climate change. With their scientific knowledge and understanding, interface journalists have the ability to criticise, synthesise and analyse complex science. Unlike mainstream journalists who lack any specialist knowledge in science, interface journalists have an important role as ‘science critics and civic interpreters’ (Fahy & Nisbet, 2011, p. 790). The design of this survey and our model (Figure 1) is situated in a body of literature (Section 2) which describes how informing the public about climate change has become a diabolical challenge because of the tension between science and media.

## 2. The Fourth Estate and Tension Between Science and the Media

The fourth estate (news media) was established in the 1800s, at a time of increasing public literacy and has become one of the most prominent industries worldwide (Schultz, 1998). Since its creation, a central tenet of the fourth estate has been freedom of speech, as a ‘feedback mechanism’ for democracy (Kunczik, 1989). Schultz (1998) contends that the media has evolved into a profit-oriented, politically aligned enterprise. In other words, the mass media has become a ‘bastard estate’ (Schultz, 1998) that has

> created itself as an institution of political life designed to act on behalf of people and report on and give voice to those in positions of political, corporate, economic and social power. In the intervening decades the news media has itself become a source of real and significant power and influence, an industry prepared to exercise and pursue self-interested, political and cultural agendas. (Schultz, 1998, p. 1)

The mass media as a commercial enterprise is depicted by a *New York Times* advertisement, 'from Fourth Estate to Real Estate' (Schultz, 1998, p. 5). Sadly, humanity is 'running the planet like a subprime loan' (Rockström, 2008) at a time when 'mainstream media devolves into a mudstream' (Schechter, 2005, p. 25). McChesney (1999) contests that the Fourth Estate has become a 'poison pill' for democracy (p. 2). Other commentators (e.g. Lewis, Cushion, & Thomas, 2005) raise the notion of a 'compromised' fourth estate, especially when one considers that commercially motivated and politically aligned Public Relations (PR) professions are becoming an important form of news gathering. The situation is further exacerbated as journalists (who are often under-resourced and under pressure) are, according to Lewis, Williams, and Franklin (2008), relying on 'pre-packed' news from the PR industry. The mass media are important conduits of climate science (Figure 1) and yet there exists tension between media and their suppliers of science: the research community (Bell, 1994).

One of the reasons for this tension is that mass media operate on an hourly to daily timeframe, while scientific research (and the scientific method of hypothesising, testing and validating) can take years. Both groups seek the truth to confirm legitimacy, but the practice is fraught because the media and the scientific community have a different understanding of its meaning and how the truth is substantiated. Journalists and scientists attach importance to accuracy and both are in competitive publication environments (Bell, 1994). Peters et al. (2008a) describe the ongoing tension between scientists and journalists, some of the reasons for which are described by social theory and empirical research. For instance, 'science and journalism construct knowledge about the world to different principles. It is, therefore, not a random malfunction but a systemic feature that the meanings of scientific messages change when they are reconstructed by journalism for the public sphere' (Peters et al., 2008a, p. 269).

When one considers accuracy, the issue of 'check back' can become a source of friction. Journalists have deadlines to meet, the pressures of which can become exacerbated by a failure to locate sources or if the scientist raises (considerable) objections to the reporting of their research findings. All of which, journalists fear, might lead to a lost story. Scientists, on the other hand, can become exasperated if there is no check back to ensure that their research is reported accurately (Bell, 1994). Smith (1999) examines the competitive nature of the commercial mass media, which can lead to reporters publishing before accuracy has been checked.

There have been numerous studies on the reporting of climate change (e.g. Antilla, 2010; Boykoff & Boykoff, 2007; Brossard, Shanahan, & McComas, 2004; Hulme, 2009; Lyytimäki, 2011; Painter & Ashe, 2012; Schneider, 2010; Trumbo, 1996; Weingart, Engels, & Pansegrau, 2000). Some studies conclude that journalists in the 1990s and 2000s found it difficult to accurately report climate research findings (e.g. Corbett & Durfee, 2004; Henderson-Sellers, 1998). Other studies have examined how journalistic norms (e.g. 'fairness') can influence the representation of climate science (Chubb, 2010). For example, Boykoff and Boykoff (2004) contend that journalistic 'balance' (fairness) lends 'equal weight' to both scientific consensus (e.g. IPCC) and the 'sceptical' view (Schneider, 2010). Furthermore, journalists and scientists 'come to the issue [climate change] with their own preconceptions, mental models, and agendas' (Schneider, 2010, p. 174). The literature described in this section illuminates the issue of objectivity, which can influence relationships between researchers and media.

Despite the 'objectivity' of journalism modelled on the scientific method (Nelkin, 1995), Antilla (2010) asserts that 'the norm of balance [fairness] isn't relevant to understanding our natural world and doesn't provide enough guidance to the audience as the relative significance of opposing views' (p. 242). This is a significant contestation when one considers that existing research suggests that the general public absorbs most of its climate change information from mainstream media (television, radio, newspapers). The mass media are important sources of climate science (and other prominent societal issues); they can shape public opinion and influence policy (Figure 1). The public rely on the media to enhance their knowledge about the natural world beyond their 'lived experience' (Smith, 2005; Weber & Stern, 2011).

The media can have a helpful influence as a 'validator' of science (Carvalho, 2007; Gamson, 1999), yet the industry is facing difficult challenges. For instance, mainstream media are under pressure as a consequence of the global financial crisis and competition from the emerging 'social media'[1] (Ward, 2009). The challenge is further complicated when bias supersedes scientific consensus as media editors attempt to provide equal 'air time' to a small, but vocal, minority as is given to the overwhelming majority (Boykoff, 2008a; Hansen, 2009). There is scientific understanding on anthropogenic climate change and, yet, inaccurate and so-called fair reporting by mass media can lead to public misconceptions about scientific consensus because of this 'false balance' (Mooney, 2004). Boykoff's (2007) research on newspaper[2] coverage of climate science between 2003 and 2006 in the UK and the USA concludes that 'balanced' reporting on anthropogenic climate change research in 'quality' or 'prestige' press is no longer evident, suggesting that communication researchers may be 'flogging a dead norm' (p. 479). This finding, albeit limited to prestige newspaper coverage in two countries, offers hope that the media can better inform the public about the need for action on climate change. Yet, in a period of around four months, mass media coverage of real and vexatiously claimed errors in the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) and other issues of alleged research misconduct[3] were continually raised in the media (Painter & Ashe, 2012).

Schneider (2005) commented on his web blog 'Mediarology' that

> We live in complex and confusing times, and rationality (that is knowing enough about what might happen and how likely it is, and being willing to change our current beliefs

> given challenging new evidence) is the only way to clearly define our values when it is time to make policy—and that is the job of *all* citizens, including journalists and scientists. (last para)

Changing values (e.g. beliefs and lifestyles) in order for humanity to transition to low carbon social and economic systems is not the only diabolical problem. The mass media, as major sources of climate information for the public, have a responsibility to provide evidence-based reporting. Yet, media reporting of anthropogenic climate change, we contend, has itself become a diabolical challenge as a result of multiple and arguably irreconcilable tensions. This section has described how the media's 'fair' approach lends itself to bias and that fierce competition from social media places mainstream journalists under pressure, compounding economic imperatives and the effects of the global financial crisis (e.g. Ward, 2009). These, albeit limited, examples provide some insight into why tension can erupt between scientists and journalists.

## 3. Research Method

Given the aforementioned tensions, we developed a questionnaire-based survey that aimed to (i) compare the attitudes of journalists and researchers at the heart of the science–media nexus concerning the performance of the media as a channel of climate change information and (ii) obtain their views on the opportunities for this core interface group to better inform the public about climate change. The survey was devised as a result of the tensions described in Section 2 and mass media coverage of the claims of errors in the IPCC AR4 and other issues of alleged research misconduct between late 2009 and early 2010.

The survey was conducted between 4 June 2010 and 24 August 2010 with the questionnaire posted online and links sent to the conference organisers of the Global Media Forum on Climate Change and the Media (Bonn, Germany, 21–23 June 2010, www.dw-gmf.de) and the World Conference on Research Integrity (Singapore, 21–24 July 2010, www.wcri2010.org). The questionnaire was also posted on the Earth System Science Partnership (ESSP at www.essp.org) and partner global environmental change (GEC) research programme websites and their social networking sites. The conferences were specifically selected for this survey because they were fora for science–media interface and research integrity discussions. The ESSP represents an international network of GEC researchers, many of whom contribute to the IPCC.

Two hundred and twenty-one people responded to the survey: 134 from the Global Media Forum, 60 from the World Conference on Research Integrity and 27 from the ESSP. Not all respondents completed all of the questions. This is common for web-based surveys where respondents can choose not to answer every question. Because we wanted to understand the views of a core group of respondents at the interface of communicating climate science, findings in this paper describe the views of respondents from university or research institutions (33.5%, $N = 74$) and mass media

(22.6%, $N = 50$) who are professionally committed to quality science communication.

Studies imply that most people absorb their climate information from media (e.g. Boykoff & Boykoff, 2004; Rahmstorf, 2012; Wilson, 1995), while politicians receive climate science information directly from scientists (e.g. Lahsen, 2005; Oreskes, 2004; Trumbo, 1996) or indirectly via media (Nelkin, 1995) (Figure 1). The research method for this paper uses a questionnaire survey to compare the attitudes of a specialist sample of scientifically knowledgeable interface journalists and researchers closely involved in the climate change debate. Findings provide a window on some key linkages between media and science and an opportunity for journalists and scientists in this core interface group to commit to joint and effective communication of climate science information.

The statistical analysis of the questionnaire responses was directed at examining differences of opinion between journalist and researcher respondent groups, so unpacking possible tensions between these two professions at the centre of communicating climate science. The chi-square test was used to examine differences in responses to items with categorical responses. For items with rating scale response formats, the *t*-test was used, or the non-parametric Mann–Whitney test for items whose distribution was non-normal (absolute value of skewness greater than 1). A type-I error rate of 0.05 was adopted to determine the statistical significance of differences between the groups, which are all described in Section 4 when the *p*-value is less than 0.05. All analyses were carried out with the statistical software program IBM SPSS Statistics 20.

## 4. Results

### *4.1 Mutual Intelligibility: Shared sources of climate science*

Boykoff (2007) contends that 'without some scientific knowledge to provide a foundation of understanding to follow ongoing issues, more journalism will not help' (p. 479). Journalistic coverage can even be detrimental when media 'framing' blurs rather than illuminates scientific understanding, which, in turn, 'create spaces for policy actors to defray responsibilities and delay action' (Boykoff, 2007, p. 471). Not surprisingly considering the respondents' professions, Table 1 (Sources of respondents' climate change knowledge where respondents could answer more than one option) reveals significant statistical differences where media workers were more likely than researchers to have studied climate change via newspapers, radio, TV and films (80.9% versus 59.5%, $p = 0.017$), while researchers were more likely to have studied climate change at university or at a research institution (37.8% versus 8.5%, $p \leq 0.001$). Table 2 (Sources of climate change information) highlights that the majority of journalists use the mass media for climate information, newspapers (88.0%) and television (78.0%) being the most popular media source. There was also significant statistical difference ($p = 0.024$) where 78.0% of journalists absorbed climate change information from the television, compared to 56.1% of

Table 1. Sources of respondents' climate change knowledge

| | Respondent group | | |
|---|---|---|---|
| | Journalists $N = 50$ | Researchers $N = 57$ | Chi-square ($p$) |
| High school only | 3 (6.4%) | 8 (10.8%) | 0.68 (0.526) |
| Newspapers, radio, TV, films | 38 (80.9%) | 44 (59.5%) | **6.02 (0.017)** |
| University or other research institution | 4 (8.5%) | 28 (37.8%) | **12.71 (<0.001)** |
| Conducted own research | 8 (17.0%) | 23 (31.1%) | 2.98 (0.093) |
| Studied IPCC reports in detail | 9 (19.1%) | 25 (33.8%) | 3.05 (0.099) |

Notes: Respondents were asked to select all that apply to the question of, 'to what extent have you studied the science of climate change? (i.e. high school science; mass media; tertiary qualifications in science; conducted research; studied IPCC reports in detail; other)'. The chi-square test reveals any differences of opinion between journalist and researcher respondent groups, which are shown in bold type when $p < 0.05$.

Table 2. Sources of respondents' climate change information

| | Respondent group | | |
|---|---|---|---|
| | Journalists $N = 50$ | Researchers $N = 57$ | Chi-square ($p$) |
| TV | 39 (78.0%) | 32 (56.1%) | **5.70 (0.024)** |
| Newspapers | 44 (88.0%) | 41 (71.9%) | 4.21 (0.055) |
| Magazines | 40 (80.0%) | 25 (43.9%) | **14.59 (<0.001)** |
| Radio | 25 (50.0%) | 22 (38.6%) | 1.41 (0.249) |
| Scientific publications | 31 (62.0%) | 50 (87.7%) | **9.78 (0.003)** |
| Blogs | 25 (50.0%) | 19 (33.3%) | 3.06 (0.115) |
| Other | 12 (24.0%) | 12 (21.1%) | 0.12 (0.817) |

Notes: Respondents were asked to choose as many options as they wished when answering, 'where do you get information about climate change from?'. The chi-square test reveals any differences of opinion between journalist and researcher respondent groups, which are shown in bold type when $p < 0.05$.

researchers. An additional statistical difference ($p = 0.001$) reveals that 80.0% of journalists and 43.9% of researchers included magazines as a source of climate change information.

Despite statistical differences between the two groups ($p = 0.003$), where 87.7% of researchers and 62.0% of journalists obtain climate information from scientific publications, results reveal that the scientific literature influences the sampled journalists, who are professionally committed to quality science communication. This finding demonstrates that we are dealing with a distinct group, who share a mutual intelligibility because, in addition to receiving information from mass media, scientific publications are a significant source of climate change information for both researcher and journalist respondents. Wilson (2000b) contends the notion of 'mutual intelligibility' (i.e. journalists deriving information about climate change directly from science) lends itself to more accurate reporting of climate science and a better informed public. This research, therefore, aims to explore if, despite the tensions described in Section 2, there is a core interface group of media professionals knowledgeable in climate science who, by sharing a mutual intelligibility, can cross boundaries and work with the scientific community to better inform the public about climate change. To further assess their compatibility, and consequent ability, to better inform the public about climate change, the next section compares attitudes of respondents' opinion of media content during the IPCC AR4 errors and alleged climate research misconduct spanning the time of the fifteenth session of the Conference of the Parties (COP-15) to the United Nations Framework Convention on Climate Change (UNFCCC) in Copenhagen (between late 2009 and early 2010).

### *4.2 Testing Times*

Although more difficult to measure, this section attempts to analyse if respondents thought that recent media reporting of climate change had any bearing on policy discourse (Figure 2, Media influence on policy). The majority of respondents (84.0% of researchers and 78.0% of journalists) consider that media influences policy indirectly through public opinion, while only a minority of researchers (9.0%) and only slightly more journalists (14.0%) thought that media informs policy-makers directly. There were no statistically significant differences between the opinions of journalists and researchers. Similar to our model (Figure 1, Landscape for communicating climate science) and our survey results (Figure 2), Billett's (2010) review of the literature

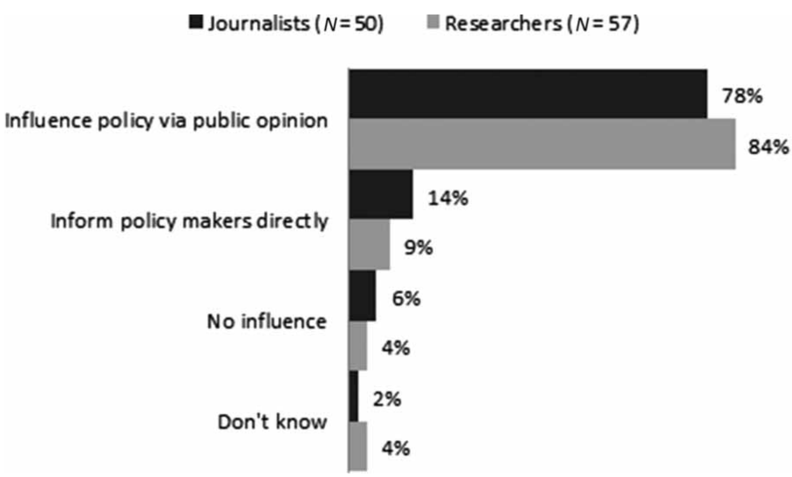


Figure 2. Respondents' views of the media's influence on policy. In relation to the question, 'in your opinion, in which way is climate change policy most shaped by the mass media?', respondents were asked to choose one response from the following: influencing politicians through public opinion; informing policy-makers directly; no influence; do not know

says that 'Different mass media, and different groups within those media, communicate climate science through a set of culturally specific frames, which have a major influence on public perception and, by extension in a voting democracy, on subsequent public policy' (p. 2).

Journalistic coverage of the claims of errors in IPCC AR4 and other issues of alleged research misconduct pervaded the mass media between late 2009 and early 2010 (Painter & Ashe, 2012). In our survey (Table 3, Media coverage of IPCC errors), some of the journalists' responses to the question about the purpose of media coverage reflect journalistic notions of the 'fourth estate' as a 'feedback mechanism' for democracy (e.g. Kunczik, 1989) where the media informs public debate and gives voice to 'whistleblowers' (i.e. 30% of journalists thought that the main purpose of media reports was to inform public debate), while the 35.7% of researchers who thought that media coverage of IPCC errors served to sell newspapers/attract viewers support observations of an increasingly commercially driven mass media (e.g. Schechter, 2005). These results suggest that the journalists, as a group, consider their profession more principled than researcher respondents think it is. Only 2% of journalists and 12.5% of researchers thought that the media coverage served to influence national policies brought to COP-15 in Copenhagen, which suggests that both journalist and researcher respondents thought that the media content on IPCC AR4 errors was not aimed directly at influencing policy (Table 3).

The media coverage did, however, have an impact on government policy. For instance, the reaction of the Dutch government, as a result of media coverage of alleged IPCC errors, was to instruct its Environment Minister to commission the national Environmental Assessment Agency to review the findings of the regional chapters of IPCC

Table 3. Respondents' views of media coverage of IPCC errors and alleged climate research misconduct

| | Respondent group | |
|---|---|---|
| | Journalists $N = 50$ | Researchers $N = 56$ |
| Inform public debate | 15 (30.0%) | 9 (16.1%) |
| Sell papers/attract viewers | 12 (24.0%) | 20 (35.7%) |
| Act as whistle blowers | 7 (14.0%) | 5 (8.9%) |
| Influence national policies brought to COP-15 | 1 (2.0%) | 7 (12.5%) |
| Tried to support scientists by failing to reveal information | 2 (4.0%) | 3 (5.4%) |
| Influence views about IPCC | 10 (20.0%) | 5 (8.9%) |
| Other (e.g. misinform public, support climate contrarians) | 3 (6.0%) | 7 (12.5%) |

Notes: Respondents' views of the reasons behind the media reporting of alleged IPCC errors. Respondents were asked to consider the following statement,

> the media played a large role in late 2009 in discovering and disseminating the content of emails about climate change processes and about errors in IPCC AR4. In your view, did the journalists reporting on the content of these emails ... (choose the one that best describes your view).

AR4 on climate change impacts, adaptation and vulnerability (The Netherlands Environmental Assessment Agency, 2010). The Dutch Agency found no errors in the IPCC AR4 that would discredit key findings. It did, however, recommend that IPCC should improve 'quality control'. The InterAcademy Council (2010) also conducted a review of the IPCC. The review panel Chair, Harold T. Shapiro, concluded that

> In my judgment IPCC can continue to remain a very valuable resource, provided it can continue to highlight both what we believe we know and what we believe is still unknown and to adapt its processes and procedures in a manner that reflects both the dynamics of climate science and the needs of public policy for the best possible understanding of changing global climate, its impacts, and possible mitigation initiatives. (p. viii)

The University of East Anglia CRU has also been cleared of any research misconduct by three independent reviews (House of Commons Science Technology Committee, 2010; Oxburgh, 2010; The Independent Climate Change E-mails Review, 2010). These reviews also 'raise important issues about how to do science in such an argumentative area under new levels of scrutiny, especially from a largely hostile and sometimes expert blogosphere' (The Economist, 2010, p. 76). Despite these demands for scrutiny of, and integrity in, climate research, we contend that the 'diabolical challenge' is further exacerbated because calls for investigations of accuracy of the mass media's reporting of climate change have received less publicity than alleged climate research misconduct.

We also sought respondents' views on the UNFCCC Copenhagen Accord. Both researchers and journalists consider the 'Accord' to be weak (Table 4, Commitment to action on climate change). On a scale of 1 (=powerful) to 4 (=pointless), mean scores for journalists and researchers were 2.74 and 2.83, respectively, which are values close to the scale point of 3, labelled 'weak'. The difference between the two groups was not statistically significant ($t = 0.64$, $p = 0.525$).

Our study then focused on a small sub-set of respondents ($N = 23$) who claimed that, post-COP-15, they feel less committed to tackling climate change. The majority (54.5%) of media respondents felt less committed because of political inaction and failure at COP-15, while the researchers' responses were more varied (Table 4). However, differences between the two groups in the overall pattern of responses to this question were not statistically significant.

### *4.3 Quality of Media Coverage and Levels of Trust*

Recognising that the general public absorb most of their climate information from the mass media, respondents were asked to consider the perception of the quality of the mass media's dissemination of climate research. Respondents commented that there was a disparity in the quality of reporting through the western mass media industry. The *Guardian* newspaper (UK), the *New York Times* (USA) and the BBC website (UK) were considered to provide good coverage of climate change, while Fox News (USA), *Der Spiegel* (Germany), the *Daily Mail* (UK) and *The Australian* newspaper (Australia) were considered to provide poor coverage of the climate debate.

Table 4. Respondents' commitment to action on climate change after Copenhagen COP-15 (December 2009)

| | Respondent group | | | | |
|---|---|---|---|---|---|
| | Journalists | | Researchers | | |
| | *N* | | *N* | | Chi-square (*p*) |
| After Copenhagen, I feel less committed to the need for action on climate change | 47 | 10 (21.3%) | 74 | 8 (10.8%) | 2.49 (0.125) |
| If less committed to action after Copenhagen, why?[a] | 11 | | 12 | | 1.56 (0.788) |
| • Political inaction; failure at COP-15 | | 6 (54.5%) | | 4 (33.3%) | |
| • Inconclusive science | | 2 (18.2%) | | 2 (16.7%) | |
| • Hacked climate scientists' emails | | 1 (9.1%) | | 3 (25.0%) | |
| • Challenge is too overwhelming | | 2 (18.2%) | | 3 (25.0%) | |

Notes: Respondents were asked to consider the following statement, 'Anthropogenic climate change is a complex issue and one that has been greatly debated; after Copenhagen I feel less committed to the need for action on climate change' and then answer, 'If you answered "yes" to question above, please explain why (choose whichever best describes your view)'. The chi-square test reveals no difference of opinion between journalist and researcher respondent groups (i.e. $p > 0.05$).

[a]Additional respondents answered this question, hence the different total number of responses between the initial and follow-up questions.

Painter (2011) provides a comparative study of sceptical voices in the print media in Brazil, China, France, India, the UK and the USA. More than 3000 articles were analysed from two newspapers in each of the six countries, over two separate three-month periods in 2007 and then again in 2009/2010 (matching our study period). The aim of Painter's study was to determine any discernible increase over the two periods in the amount of coverage climate sceptics received in the print media, finding pronounced increases in the UK and USA (i.e. the Anglophone countries). Considering the influential role of Brazil, China, France, India, the UK and the USA in international climate negotiations (e.g. UNFCCC COPs), Painter's finding (although published after our survey was conducted) stimulated our interest in considering the question, 'Do countries where climate skeptical voices appear in greater numbers in newspaper coverage have less ambitious climate change policies?' (Table 5, Sceptical voices and national emissions reductions). Three out of the four (non-Anglophone) countries that have less sceptical voices in newspaper coverage (China, France and India) are more likely to meet their 2020 emissions reduction targets (while Brazil's chances are uncertain). The Anglophone countries (the UK and the USA) where climate sceptics have a more amplified voice in newspapers have mixed chances of attaining 2020 emission reduction targets. The UK (which, like France, is under the European Union umbrella) is likely to meet a 20% emissions reduction target by 2020, while the USA could undershoot its 2020 emission reductions pledge to the UNFCCC

Table 5. Comparison of national media portrayal of climate scepticism and capacity to deliver on pledges to reduce greenhouse gas emissions

| Country | Media sceptics | Climate policies of listed nations and their prospects of fulfilling their 2020 greenhouse gas emission reduction pledges | | |
|---|---|---|---|---|
| National attribute | Strong sceptical voice in newspapers | 2020 pledge (calculated resulting emissions) | Examples of climate policies | Expectations of meeting 2020 emission reduction targets pledged to UNFCCC |
| Brazil | No | • 36–39% below business as usual levels (2.0–2.1 $GtCO_2e$) | • Anchored pledge in national law, forestry policy | Uncertain whether pledge will be met |
| | | | • Grazing land management<br>• Expanding fossil fuels<br>• Renewable target | |
| China | No | • 40–45% decrease of $CO_2$ emissions per GDP below 2005 | • $CO_2$/energy intensity targets | Likely to meet pledge but rapid greenhouse gas increase up to 2020, due to higher than expected GDP growth in the last few years |
| | | • 15% share of non-fossil energy | • Non-fossil targets | |
| | | • Forestry target (13.3–15.5 $GtCO_2e$) | • Renewable energy capacity targets | |
| France | No | • 20% below 1990 levels (unconditional) | • Comprehensive policy portfolio including emission trading system, renewable energy targets and support, energy efficiency policy | Likely to meet unconditional pledge |
| | | • 30% below 1990 levels (conditional) | | |
| India | No | • 20–25% decrease of $CO_2$ emissions per GDP below 2005 (3.5 $GtCO_2e$) | • Renewable energy target | Likely to meet pledge, but huge uncertainty |
| | | | • Efficiency in industry | |

(*Continued*)

Table 5. Continued

| Country | Media sceptics | Climate policies of listed nations and their prospects of fulfilling their 2020 greenhouse gas emission reduction pledges | | |
|---|---|---|---|---|
| National attribute | Strong sceptical voice in newspapers | 2020 pledge (calculated resulting emissions) | Examples of climate policies | Expectations of meeting 2020 emission reduction targets pledged to UNFCCC |
| UK | Yes | • 20% below 1990 levels (unconditional)<br>• 30% below 1990 levels (conditional) | • Comprehensive policy portfolio including emission trading system, renewable energy targets and support, energy efficiency policy | Likely to meet unconditional pledge |
| USA | Yes | • 17% below 2005 levels (6 $GtCO_2e$) | • $CO_2$ standard for new fossil power plants<br>• Car standards<br>• State renewable portfolio standards<br>• California emission trading scheme | Emissions expected to be above pledge |

Notes: Sceptical voices in newspapers and emission reduction targets of Brazil, China, France, India, the UK and the USA. Column 2 indicates if climate sceptics became more vocal in the print media between 2007 and 2010 (adapted from Painter, 2011), while (Columns 3–5) list examples of the domestic climate policies of some of the major emitting countries in the world and their prospects of fulfilling their 2020 greenhouse gas emission reduction pledges to the UNFCCC are shown (adapted from Höhne et al., 2012, with permission from PBL Netherlands Environmental Assessment Agency).

(Höhne et al., 2012). This comparison has limitations because developed and developing countries have different UNFCCC obligations and, despite a gloomy federal-level prospect of the USA achieving 2020 emission reduction targets, some states (e.g. California) have progressive climate policies, such as emission trading schemes (Table 5).

Another examination of countries' commitment to tackling climate change (Schroeder, Boykoff, & Spiers, 2012) utilises changes of the size of national delegations to UNFCCC COPs (COP-1 in 1995 to COP-17 in 2011), with countries with fewer climate sceptics receiving newspaper coverage (Brazil, China, France and India) increasing their UNFCCC delegations, while (after withdrawing from the Kyoto Protocol) the US delegation size has diminished. Future research on a co-evolving system of countries' commitment to tackling climate change could involve studying if territories with poor media coverage of climate change, or with media that portrays the science as uncertain, have less ambitious climate change policies and, if not, then what other factors influence policy.

Our study findings of an interface group of researchers and journalists imply that, despite an overall higher level of journalist respondents' (vis-à-vis researcher respondents) trust in the media's role as a helpful channel of climate information (Mann–Whitney $U = 1288.5$, $p = 0.017$), there is a strong overlap where both journalists and researchers from this interface group consider the media's role as beneficial (Figure 3, Helpfulness of the media). Surprisingly, in the wake of intense mass media scrutiny of climate science, only a relatively minor proportion of researcher respondents (15.0%) considered the media's role as unhelpful. This finding implies that, despite tension between science and media (Section 2) and media content of climate science around the time of the UNFCCC COP-15 in Copenhagen, a degree of trust exists between a key, principled group of journalists and researchers at the interface between science and media. These data also support previous research (e.g. Peters et al., 2008b), where interactions between leading scientists and journalists in France, Germany, Japan, the UK and the USA are described as 'more frequent and smooth than previously thought' and 'the scientists most involved in these interactions tend to be scientifically productive, have leadership roles, and—although they consider concerns as well as perceived benefits—that

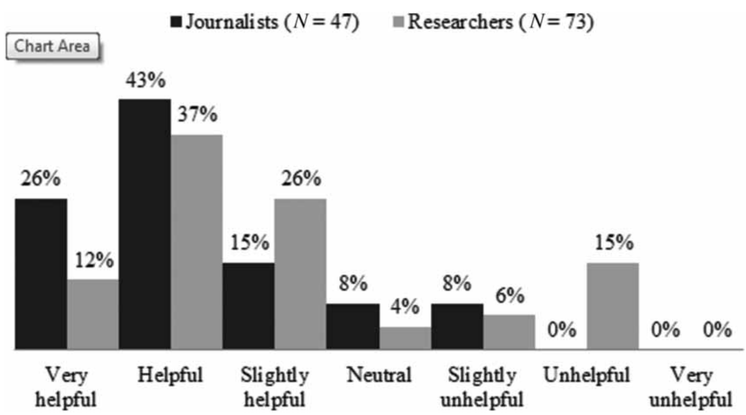


Figure 3. Respondents' views on the helpfulness of the media as a channel of climate information Respondents' were asked to consider,

> Some people feel that the mass media play a valuable role as disseminators of climate research in a format that can be understood by most people. Others feel that the mass media is an unhelpful influence on the process of sharing climate change research results. Using the scale below please indicate to what degree you believe mass media is generally helpful or unhelpful in communicating research from scientists to the general public and policy-makers. (Please choose one from: very helpful; helpful; slightly helpful; neutral; slightly unhelpful; unhelpful; very unhelpful)

they perceive the interactions to have more positive than negative outcomes' (Peters et al., 2008b, p. 205). Peters et al. (2008a) note that, by and large, communication researchers have sought out and identified communication barriers, asking 'Why are the relationships between science and the media so difficult?', instead of, 'Why are the interactions so smooth given the well-known and empirically confirmed differences in expectations, quality goals, and system logics?' (p. 270). Building on this notion of 'smooth interactions', despite the intensity of journalistic coverage of IPCC AR4 errors and alleged climate research misconduct, our survey findings imply that a group of specialists at the heart of the science–media nexus can, by sharing a mutual intelligibility and level of trust, cross boundaries and act as 'change makers' to better inform the public about climate change. The next section explores this idea.

### *4.4 Opportunities to Better Inform the Public about Climate Change*

Both communities shared the view that there were unrealistic expectations on researchers and journalists (Table 6, Expectations of media and science). There was, however, statistical significance ($p = 0.042$) where more researcher respondents (76.1%) tended to think that the media had unrealistic expectations about what the scientific community can produce. Respondents were then asked about their views on how the media transmission of science can be improved. As well as the obvious responses of clearer science and better journalistic understanding (Table 6), respondents noted a number of alternatives in response to an open-ended 'other, please specify' option, such as penalties for media misrepresentation of science; better use of science communicators (bridge between research community and the media); media differentiation of professional climate scientist and pseudo-scientist; abandoning the framework of 'fair' (false balance) reporting; quick and concise rebuttals of media misinformation; stopping the axing of dedicated science reporters; and that media proprietors should be regulated, assessed regularly for performance and made more accountable for the effects of their stories (e.g. Finkelstein, 2012; Leveson, 2012). There were no statistically significant differences between the researchers and journalists on these items regarding ways to improve the transmission of research findings.

According to Boykoff (2008b), journalists can improve the transmission of science findings by liaising better with editors to match headlines with the stories and improve fact checking. A recent independent review of the BBC's coverage of science by Professor Steve Jones (2011) and Imperial College London recommended that, while recognising 'Disagreement, scepticism and questioning are the life-blood both of science and serious journalism' (p. 59), mass media must make it clear to the audience the distinction between well-established fact and opinion in science, and the need to avoid providing unwarranted attention to marginal opinion (Jones, 2011). Interface journalists, therefore, have an important role to work with mainstream media colleagues to ensure that the audience is well aware of the distinctions between opinion and scientific evidence, while scientists could put their message more in

Table 6. Respondents' expectations of media and science and ideas to improve communication of science findings

| | Respondent group | | | | |
|---|---|---|---|---|---|
| | Journalists | | Researchers | | |
| | *N* | | *N* | | Chi-square (*p*) |
| The scientific community has unrealistic expectations on the way media reports climate science | 38 | 25 (65.9%) | 43 | 22 (51.2%) | 1.77 (0.259) |
| The media has unrealistic expectations on what the scientific community can produce | 41 | 22 (53.7%) | 46 | 35 (76.1%) | **4.83** (**0.042**) |
| How can the general transmission of science findings be improved? | | | | | |
| • Scientists to present results in plain and informative language | 50 | 34 (68.0%) | 57 | 42 (73.3%) | 0.42 (0.533) |
| • Journalists need to have greater scientific literacy | 50 | 35 (70.0%) | 57 | 36 (63.2%) | 0.56 (0.540) |
| • Joint workshops including scientists and the media | 50 | 31 (62.0%) | 57 | 38 (66.7%) | 0.25 (0.687) |
| • Editorial mechanisms to ensure accurate media reporting | 50 | 29 (58.0%) | 57 | 29 (50.9%) | 0.54 (0.560) |
| • Improve and simplify synthesis of research in assessments (e.g. IPCC) | 50 | 19 (38.0%) | 57 | 15 (26.3%) | 1.68 (0.217) |

Notes: Respondents' expectations of science and the media and respondents' views on improving transmission of science findings. Respondents were first asked (top two rows) to consider the following, 'in your opinion, does the scientific community have unrealistic expectations of the way the media reports climate science?' and 'in your opinion, does the media have unrealistic expectations of what the scientific community can produce?' Respondents were asked,

how can the general transmission of science findings be improved? (choose as many as you wish from: scientists need to present results in plain and informative language; journalists need to have greater scientific literacy; joint workshops including scientists and the media; editorial mechanisms to ensure accurate media reporting; improve and simplify synthesis of research in assessments (e.g. IPCC), Other)?

The chi-square test reveals any differences of opinion between journalist and researcher respondent groups, which are shown in bold type when $p < 0.05$.

context to avoid potential misinterpretation of research findings (Hassol, 2008). Smith's (2005) study of BBC news and television decision-makers, and environment and development specialists describes the desire of media professionals to receive ideas, advice and critical feedback from scientists to help improve climate change storytelling in the media. On ABC Radio in Australia, journalism academic Professor Jay Rosen has called for a 'branded explainer' role, that is, gathering data from the internet, using editors to synthesise this information and then employing artists and multimedia producers to tailor the package through the most appropriate medium, for example, video. The aim of this 'explainer' role is to help convey complex issues to the public (Colvin, 2010).

The scientific community is also starting to use the social media to communicate research findings and engage with a broader audience (Figure 1). The trans-disciplinary 'Planet Under Pressure conference' in London (26–29 March 2012) was streamed live globally on the internet and the use of social media during plenary sessions helped facilitate the inclusiveness of the conference. A Planet Under Pressure 'DebateGraph'[4] (http://debategraph.org/planet) was created, which is an open-access internet platform enabling collaboration to distil the main arguments, evidence, risks of Earth system changes and discuss sustainable policy options facing humanity. The 2012 Global Carbon Budget (Peters et al., 2012)—which highlighted that $CO_2$ emissions in 2011 were the highest in human history and 54.0% higher than in 1990 (the Kyoto Protocol reference year)—was released by the Global Carbon Project (GCP) in time for the UNFCCC COP-18 in Doha. Part of the GCP's 2012 Global Carbon Budget outreach effort included a combination of press releases circulated to international media outlets and a social media campaign. The social media is becoming a useful tool for communicating climate science. Survey findings in this paper also illuminate the continued importance of mass media (newspapers, radio, television) as channels of climate information. Rahmstorf (2012) argues that 'the media are the most important means by which lay people obtain their information about science. Good science journalism is therefore a decisive factor for the long-term success of modern society' (p. 1). Our results offer grounds for hope that an interface group of journalists exists that can work with colleagues from the scientific community and the mainstream media to inform the public about the need for urgent action on grand sustainability challenges (e.g. climate change).

## 5. Conclusion

This research provides a lens to focus on journalists and researchers at the forefront of communicating climate science. Although our sample of journalists is more involved in climate change issues than the majority of journalists (because of the way they were recruited), our survey results have revealed, contrary to tensions between scientists and journalists described in the existing literature, general trust and a mutual intelligibility in this core interface group. Furthermore, regardless of relatively recent media reporting of IPCC errors and alleged climate research misconduct, which could have inflamed tensions between researchers and the media, our results show that the majority, of a sample from this core group of researcher and journalist respondents, consider the mass media a valuable conduit of climate information. Despite a legacy of factors contributing to the diabolical challenge (e.g. 'balanced' reporting, the global financial crisis and competition from the social media), our findings imply that an opportunity exists for this influential group at the science–media interface to overcome these barriers. The mass media is a major artery in democracy, supplying the public and governments with information about climate change (Figure 1). Selected scientists (interface group) must have the courage to cross boundaries and clearly elucidate research findings to journalists at the core of the science–media nexus. By the same token, interface journalists, in partnership with scientists, can help influence mainstream journalists dismantle the diabolical challenge and better inform the public about the necessity for governments and society to embark on responsible management of the world's climate.

## Acknowledgements

The authors thank Ann El Khoury, Myanna Lahsen and Tim Flannery for valuable comments on the draft manuscript; John Crawford for assistance with statistical analysis and comments on the draft manuscript; Michelle Carnegie, Brian Henderson-Sellers, Kendal McGuffie, Catherine Simpson and Natasha Udu-gama for feedback on the survey design; and Rik Leemans for helping conceptualise the 'landscape for communicating climate science' figure. We would also like to thank two reviewers for their insightful reviews.

## Notes

1. 'Websites and applications used for social networking', online Oxford English Dictionary (www.oed.com).
2. The *Los Angeles Times*, the *New York Times*, *USA Today*, the *Wall Street Journal* and the *Washington Post in the USA*, and the *Independent* (and *Independent on Sunday*), *The Times* (and *The Sunday Times*) and the *Guardian* (and *Observer*) in the UK.
3. For example, the University of East Anglia Climatic Research Unit's (CRU) email content of climate change processes.
4. Debategraph was created because 'Conventional media reporting of public policy debates often struggles with the challenge of conveying nuanced, reasoned positions, when simple heated oppositions deliver a more dramatic and rewarding effect' (http://debategraph.org, retrieved 4 December 2012).

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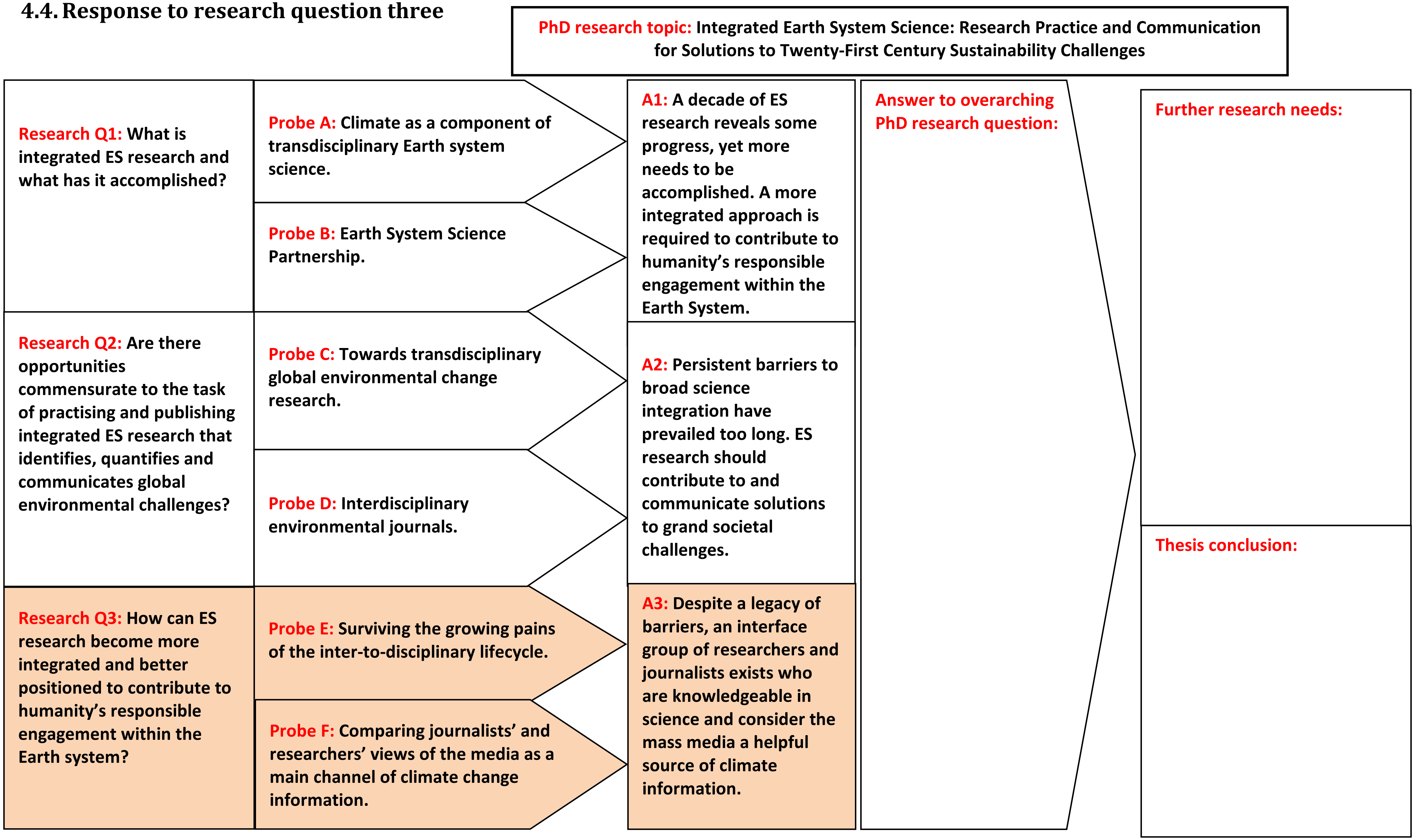
## 4.4. Response to research question three



### 4.5. Conclusion

Chapter Four tackled the third and final thesis research question, "How can ES research become more integrated and better positioned to contribute to humanity's responsible engagement within the Earth system?".

Paper E (inter-to-disciplinary lifecycle) points out a decade has passed since the seminal USA National Academies Report on 'Facilitating Interdisciplinary Research' concluded that complex challenges motivate interdisciplinarity and the emergence of new disciplines, attracting researchers towards exciting questions and the interface of disciplines. Ten years later, the same challenge - to provide the institutional and funding support required for interdisciplinary research - remains. However, the barriers to interdisciplinary research are not insurmountable as demonstrated by the new 'interdiscipline' of climate (see Paper A: future climate & transdisciplinary ESS). Paper E and Appendix Three conclude that the integrated ES scientific enterprise could benefit from researchers, funding agencies and academies devising new methods to penetrate barriers and tools to better support interdisciplinary efforts. A promising example is for scientists to work with the media to improve the public communication of Earth system research findings (Paper F).

Paper D (interdisciplinary environmental journals) concluded that (i) environmental journals possess narrow disciplinary breadth and (ii) journals pursue integrative reviews to varying degrees of intensity. Paper F (media & climate change) pushes research on the communication of ES-derived challenges further and suggests that an opportunity exists for an influential group at the science-media interface to better communicate integrated research findings on global environmental changes. The mass media is the major source of ES information to the public (Figure 1), and despite a legacy of factors and inherent barriers, survey findings suggest that an interface group of researchers and journalists knowledgeable in science consider the media a helpful source of ES science information. This finding implies that journalists and researchers at the nexus of the media and science can, in partnership, cross boundaries and clearly deliver research findings to mainstream journalists to help overcome the diabolical challenge by better informing the public about the necessity for governments and society to embark on responsible engagement within the Earth system.

# 5. Research Findings, Discussion and Directions for Further Research

## 5.1. Introduction

The aim of this PhD research is to examine if Earth system research is integrated enough to identify, quantify, communicate and support responses to twenty-first century global environmental problems. This aim is addressed through: (i) elucidating what integrated ES research entails and its achievements, (ii) examining opportunities to practise and publish integrated ES research, and (iii) discussing options to overcome persistent barriers to integration and consider ways to better communicate ES findings.

The analysis provided in this PhD thesis elucidates advances in integrated Earth system research, including an increasing awareness of humans as a vital component of this system. Unlike other species, humanity has a unique ability and an immense responsibility to engage responsibly within the Earth system. Integrated ES research has an important role to identify, quantify and communicate global environmental change risks. However, despite continued calls for integrated ES research on global environmental changes (Lubchenco, 1998; Clark & Dickson, 2003; Steffen et al., 2004; Schellnhuber et al., 2005) and advances in ES science, this study reveals gaps between calls for integrated ES research and wholesale opportunities to practise, publish and communicate integrated research that can support responses to global environmental challenges. In response to these findings, this study describes potential opportunities for ES research to better communicate findings and become more integrated in order to support transitions to responsible engagement within the Earth system.

This PhD began in pursuit of an overarching research aim, with three related research questions (Section 1.2). Section 5.2 summarises findings of this study in response to these research goals. Some discussion of the research's findings of the stand-alone papers is included in each of the chapter conclusions. Section 5.3 provides a more detailed discussion of the findings and the research process undertaken to achieve them. Section 5.4 considers possible future research directions.

## 5.2. Research findings

### *5.2.1. What is integrated ES research and what has it accomplished?*

The first research question addressed the evolution and genesis of integrated ES research, describing what it involves and examples of its major achievements. As discussed in Chapter Two, integrated ES research is the study of the Earth, its response to anthropogenic change and the implications of these changes for global sustainability. It goes beyond its geoscience origins to integrate knowledge from the natural and social sciences to help provide societally relevant information about global environmental changes. Landmarks in the development of ES science include the Gaia hypothesis and recognition of the Earth as a holistic system capable of self-regulation, through to the articulation of the Amsterdam Declaration and the need for interdisciplinary research to study changes to an integrated ES and the implications for global sustainability (Paper A: future climate & transdisciplinary ESS and Paper B: ESSP & interdisciplinary research).

Chapter Two describes significant achievements in integrated ES research including, for example, how advances in the science and observation of climate change are providing a more coherent understanding of the variability of Earth's climate system and its likely response to anthropogenic and natural influences (e.g. Moss et al., 2010). Another example is the development of a comprehensive global water assessment (e.g. Vörösmarty et al., 2010) (Paper A). Additionally, the scientific and institutional transformation of the Earth System Science Partnership resulted in considerable interdisciplinary ES research achievements such as the design and implementation of an innovative food systems conceptual framework; an annual carbon budget trends and analysis; and a global analysis of human water security and biodiversity conservation.

Chapter Two illuminates how integrated research projects on global environmental change and the carbon cycle, food and water systems and human health have developed their own methodologies and approaches to build the scientific infrastructure that allows for a more integrated approach to ES research (Paper B). Building on advances in integrated ES science, the 'planetary boundaries' concept proposes 'sustainability guardrails' within which humanity can operate safely. Similar to the evolution of the integrated ES science enterprise, the planetary boundaries concept recognises that climate is too narrow a framing (Paper A). There is a need for a global agreement for sustainable development that addresses all interacting planetary boundaries that influence the ES (Steffen & Stafford-Smith, 2013). This integrative thinking is indicative of the need to focus on the nexus between human and environmental systems in order to achieve sustainability, which is a central tenet of this thesis (Paper A: future climate & transdisciplinary ESS and Paper B: ESSP & interdisciplinary research).

Chapter Two elucidates how the holistic ES comprises a planet including the actions of humans, as a massive component of this system. However, by using the data and tools of integrated ES research, humans, unlike any other species on this planet, can consider the necessary steps to become responsible stewards. This chapter concludes that to move forwards, a more integrated, transdisciplinary ES approach is required that can contribute to holistic planetary management. This assumption provides a bridge between Chapters Two and Three and the next research focus of this PhD research, which studies opportunities to practise and publish integrated ES research that identifies, quantifies and communicates global environmental challenges.

*5.2.2. Are there opportunities commensurate to the task of practising and publishing integrated ES research that identifies, quantifies and communicates global environmental challenges?*

The second research question addressed two issues. First, it examined how integrated ES research has evolved in order to illuminate grand societal challenges. Second, the performance of scientific journals as channels of integrated ES findings is examined. The analysis provided in Chapter Three, reveals how scientists' increasing recognition of an interconnected Earth system and the need to pursue global sustainability has led to sustained calls for integrated research.

Indicative of this trend, Chapter Three reveals how the past three decades have witnessed an increasingly sophisticated conceptualisation of integration: advancing from one dimension (mostly natural interdisciplinary science) to transdisciplinarity and the contemporary understanding of three dimensions of integration. The three dimensions of transdisciplinary research include: (i) scientific integration involving crossing academic (natural, social and human science) disciplines, (ii) international integration involving the incorporation of regional, national and local cultures, and (iii) sectoral integration involving science and the users of science (paper C: evolution & practice of integrated ESS and Appendix Two).

This thesis describes advances in integrated ES research and scientific assessments (e.g. the IPCC and the MEA) which have generated new data and provided robust analyses of intertwined sustainability crises, such as anthropogenic climate change, increasing biodiversity loss, food and water insecurity. These examples typify how interdisciplinary research can play a pivotal role in identifying and quantifying GEC challenges. Yet, broad science integration, that is, the engagement of the natural and social sciences has generally been slower than anticipated (e.g. Pahl-Wostl et al., 2012; Mooney et al., 2013). By unpacking the literature, this study reveals a pattern of persistent barriers relating to attitudinal, and communication and structural (including evaluation) bias. Limited science integration is largely attributed to these obstacles that future integrated ES research for sustainability will need to overcome (Paper C: evolution & practice of integrated ESS).

Concerning the communication of integrated ES findings, Chapter Three describes an original study designed for this thesis that examines the disciplinary 'breadth' of environmental journals that describe themselves as interdisciplinary, and their processes for evaluating the quality of the articles submitted to them (Paper D: interdisciplinary environmental journals). Study findings imply that there is no difference in the disciplinary reach of journals that self-describe as interdisciplinary and those that do not. Furthermore, my findings reveal limited relatedness between self-described interdisciplinary environmental research and practical areas (e.g. business and transportation) where substantial policy shifts are needed to respond to global environmental challenges. Yet, interdisciplinary environmental journals, by integrating disciplinary approaches and knowledge more broadly and publishing practical, solutions-oriented and user engaged research, can communicate solutions to grand societal challenges.

The barriers to integration (Paper C: evolution & practice of integrated ESS) and the importance of integrating more knowledge from practical areas and publishing research at the nexus of science and action (Paper D: interdisciplinary environmental journals) underline the need for ES research to become more integrated and better positioned to contribute to humanity's responsible engagement within the Earth system. This is the research focus of Chapter Four. Furthermore, the recommendations of Chapter Three (Papers C and D) and the focus of Chapter Four (Paper E: inter-to-disciplinary lifecycle, Paper F: media & climate change and Annex 2: Transdisciplinary research) represent a shift in this PhD research from problem identification (ES-derived sustainability crises) to solution creation (opportunities to contribute to humanity's responsible engagement within the Earth system).

### *5.2.3. How can ES research become more integrated and better positioned to contribute to humanity's responsible engagement within the Earth system?*

The third research question addressed options for ES research to contribute to responsible planetary management. Chapter Four used climate science as an exemplar and the 'growing pains' metaphor to illustrate that it is possible to overcome the barriers to integrated research (Paper E: inter-to-disciplinary lifecycle). This chapter suggests that rather than repeatedly identifying the same barriers, researchers, funding agencies and academies could coalesce to create novel methods to deepen science integration of the natural, social and human sciences and develop new mechanisms to support integrated ES research.

Lastly, Chapter Four described a survey developed for this PhD research to study the attitudes of an interface group of researchers and scientifically informed journalists concerning the performance of the mass media as a major conduit of climate science information (Paper F). Despite tension between science and the media, survey results of an interface group reveal that the majority of researcher respondents considered the media's role as helpful and the journalist respondents derive information about ESS findings from scientific literature. This finding implies that an opportunity exists for this core group at the nexus of science and media to work together to help influence mainstream journalists to better inform the public about the necessity of humanity responsibly engaging within the Earth system.

## 5.3. Discussion of this research

This section discusses the important responses produced by this PhD thesis to the three research questions as originally defined. Additionally, recognising the need to devise new and innovative ways of communicating complex societal challenges (e.g. anthropogenic climate change), my research interests in the use of web 2.0 technologies to communicate ES research findings resulted in the Debategraph map for the transdisciplinary ES research conference on 'planet under pressure: new knowledge towards solutions' (Paper C: evolution & practice of integrated ESS). This map received media coverage in the New York Times[5]. During my candidature I was extensively involved in a transdisciplinary research project that analysed the relationship between scientific integration and transdisciplinarity. Major outcomes of this project included a published, peer-reviewed article and the proposal of an innovative framework for future ES research for sustainability which identifies useful processes of integration (Appendix Two: Transdisciplinary research).

Reflection on the course of the research process supports my (pre-PhD study) prior hypothesis that, despite advances in ES science, possessing the means and ability to actually do integrated research can be difficult. However, I was surprised by my literature review findings (Paper C: evolution & practice of integrated ESS) which reveals a pattern of persistent barriers to integration that have remained for over three decades (e.g. Kates, 1985; Henderson-Sellers, 1992; Brewer, 1999; Phelan et al., 2013). Furthermore, in response to Paper E (inter-to-disciplinary lifecycle) in this thesis which aims to discuss options to overcome barriers to integrated research, Shaman et al. (2013) (Appendix Three) disagree with my suggestion that emerging interdisciplinary research must prove its worth, that is, that natural selection is perhaps beneficial. Instead, they counter by suggesting that interdisciplinary research needs guidance to steer in the right direction in order to survive the growing pains of the inter-to-disciplinary lifecycle. Yet, this response raises the issue of control and who selects those

[5]See: http://dotearth.blogs.nytimes.com/2012/03/29/scientists-call-for-practical-steps-to-smooth-humanitys-journey/

responsible for guiding the advancement of the integrated ES research enterprise. Furthermore, for the purpose of this thesis, science is more than a mechanism to "advance a more complete understanding of the universe" (Shaman et al., 2013). Explanatory type research is important and basic science will continue to be the backbone of the scientific enterprise, yet more practical, solutions-oriented research is required to tackle ES-derived sustainability challenges. Additionally, as discussed in Chapter Three, interdisciplinary environmental journals will have an important role to broaden their horizons and integrate more knowledge from practical areas and create opportunities to publish research at the nexus of science and policy.

The public derives information about ES-derived challenges largely from the mass media and this view then influences policy. This is why Chapter Four (Paper F: media & climate change) emphasises the need for an interface group of researchers and journalists knowledgeable in science to work together to help mainstream journalists provide evidence-based reporting of climate change. Although, this is challenging when one considers that the public (particularly in western, Anglophone countries) relies mostly on a politically-motivated, commercial media to convey highly complex climate research fairly and judiciously (e.g. Schechter, 2005).

Chapter Two reflects that the challenge of anthropogenic climate change remains the inability of science to be clearly understood and the search for clarity in public understanding (Paper A: future climate & transdisciplinary ESS). This suggestion resonates with the findings of a recent a study on the Australian public's attitude to climate change, where thirty-six percent of respondents felt "concerned and confused"

(Ashworth et al., 2011, p. 25). Here, the media can play a vital role to communicate evidence-based information about climate change. This thesis has identified the potential for interface researchers and journalists knowledgeable in science to work with mainstream journalists to better inform the public about the urgency to move away from crossing critical planetary boundaries (Chapter Four).

By responding to the overarching aim of this thesis – to examine if ES research is integrated enough to contribute to solutions to twenty-first century sustainability challenges – my research found that (i) despite advances in ES science, natural and social science collaboration remains limited and barriers to science integration remain; (ii) there is no difference in breadth of disciplinary engagement between journals that self-describe as interdisciplinary and those that do not. Nor are links to practical areas (e.g. business and transportation) well developed; and (iii) contrary to tensions between scientists and the mass media described in existing literature, a mutual intelligibility (i.e. knowledge in science) and general trust (i.e. the media is a useful source of public climate information) exists between an interface group of researchers and journalists. This core group has an important role to provide evidence-based ESS findings to the mainstream media in order for them to better inform the public about the urgency of responding to ES-derived sustainability challenges.

This research illuminates opportunities for ES research to become more integrated, including (i) researchers, funding agencies and academies jointly devising new opportunities to overcome persistent barriers and providing the necessary institutional support for integrated ES research, (ii) strengthening interface journalists' and researchers' interactions, specifically by jointly providing evidence-based ES science findings to mainstream journalists in order to better inform the public about global environmental change risks, and (iii) interdisciplinary environmental journals sharing information on interdisciplinary review and publication practices, integrating more knowledge from practical areas and providing opportunities to publish solutions-oriented research at the nexus of science and action to support humanity's responsible engagement within the Earth system.

### 5.4. Directions for further research

This thesis has aspired to address the overarching research aim and three research questions articulated initially in Section 1.2. In so doing, the thesis has raised several promising and important options for future research. Firstly, as noted in Chapters Three and Four, persistent barriers have made broad science integration across the natural, social and human sciences difficult. Future integrated ES for sustainability requires novel collaboration between academics and non-academics. This effort could be supported by research on the development of new methods and tools for integrated research. Additionally, there is still a need for an improved understanding of the practice of integration and how to better position knowledge from the scientific community (and other stakeholders) to help decision makers and society cope with emerging global environmental problems. The challenge of integrated research is not unique to the ES science enterprise. Other critical societal fields (for example, education, engineering and health) require integrated research. Future research could synthesise, share and integrate knowledge and experiences from these communities.

Secondly, the research described in Chapter Three (Paper D: interdisciplinary environmental journals) illuminated a lack of breadth of knowledge integration and the need for more engagement with practical, solutions-oriented integrated research. Future research could involve the use of more sophisticated bibliometric techniques and in-depth interviews with publishers and journal editors to consider options to provide more opportunities to publish integrated ES research at the nexus of science and action and to share interdisciplinary reviewing and publishing experiences.

Thirdly, the more informed the public is about ES-derived challenges, the more useful they are in societal decision-making processes. As described in Chapter Four, the mass media is a major channel of climate information. Paper F, which compared the researchers views with those of an interface group of journalists knowledgeable in science, reveals that there is better communication and more goodwill than is generally assumed, leading to the conclusion that there is a capacity to inform the community about the nature and scale of the ES-derived challenges. Future research could devise ways for this interface group to get information past the gate-keepers in the commercial mass media. Concerning the co-evolving system of countries' commitment to tackling climate change, future research could involve studying if territories with poor media coverage of climate change, or with media that portray the science as uncertain, have less ambitious climate change policies and, if not, then what other factors influence policy. Future research could also examine in greater detail the role of editorial bias in media reporting of ESS findings. Furthermore, there needs to be more interface with ES scientists and the general public. The Climate Council (formerly the Climate Commission) provides authoritative, expert advice to the Australian public on climate change. Research on the experiences and impact of the Climate Commission/Council in Australia could help inform similar efforts in other countries.

An additional aim of this thesis is to help future scholars and research managers better understand what worked and what did not concerning attempts by four global environmental change research programmes and the ESSP to create opportunities for inter- and transdisciplinary research on global environmental changes (Papers A – C). Future research could, for example, provide additional historical context by looking at the role of other key institutions, such as the National Center for Atmospheric Research in the USA, the International Institute for Applied Systems Analysis in Austria, and the Earth System Science centres at universities like Penn State. Future research could also focus on the challenges of doing integrated Earth system science in the global south. Additionally, future research could provide more depth by drawing on social science theory and literature from, for example, the political economies of science to explain the funding and organisation of science and there could be more research on other networks that are supporting integrated ES research, such as the Energy Modelling Forum, the Resilience Alliance and European Union funding mechanisms.

Lastly, future research could be directed towards using web technologies to inform the public about emerging ES science findings and the need to transition to responsible engagement within the Earth system. Additionally, technology will no doubt play an important role in supporting transdisciplinary research. Research on the use of technology could be beneficial for the future ES research for sustainability enterprise.

## 5.5. Response to overarching research aim

**PhD research topic:** Integrated Earth System Science: Research Practice and Communication for Solutions to Twenty-First Century Sustainability Challenges

**Research Q1:** What is integrated ES research and what has it accomplished?

**Probe A:** Climate as a component of transdisciplinary Earth system science.

**Probe B:** Earth System Science Partnership.

**A1:** A decade of ES research reveals some progress, yet more needs to be accomplished. A more integrated approach is required to contribute to humanity's responsible engagement within the Earth system.

**Research Q2:** Are there opportunities commensurate to the task of practising and publishing integrated ES research that identifies, quantifies and communicates global environmental challenges?

**Probe C:** Towards transdisciplinary global environmental change research.

**Probe D:** Interdisciplinary environmental journals.

**A2:** Persistent barriers to broad science integration have prevailed too long. ES research should contribute to and communicate solutions to grand societal challenges.

**Research Q3:** How can ES research become more integrated and better positioned to contribute to humanity's responsible engagement within the Earth system?

**Probe E:** Surviving the growing pains of the inter-to-disciplinary lifecycle.

**Probe F:** Comparing journalists' and researchers' views of the media as a main channel of climate change information.

**A3:** Despite a legacy of barriers, an interface group of researchers and journalists exists who are knowledgeable in science and consider the mass media a helpful source of climate information.

**Answer to overarching PhD research aim:**

**i)** Despite advances in ESS, natural, social and human science collaboration is limited and barriers to science integration remain.

**ii)** Interdisciplinary environmental journals who might help communicate solutions to global environmental challenges tend not to broadly integrate knowledge from many disciplines and interdisciplinary reviews are pursued to varying degrees of intensity.

**iii)** General trust exists between an interface group of researchers and journalists knowledgeable in science. This core group has an important role to regularly provide evidence-based ESS findings to mainstream media colleagues in order to better inform the public about the urgency of responding to ES-derived sustainability challenges.

**Further research needs:**

**i)** Develop new methods and tools for integrated research.

**ii)** Research on the practice, publication and communication of integrated research.

**Thesis conclusion:**

# 6. Thesis Conclusion

This thesis provides a systematic study of how integrated Earth system research has contributed to identifying, quantifying, communicating and responding to global environmental challenges over the past decades. It has examined the ways in which ES science needs to continue to evolve in order to effectively tackle the enormity of human transformation of a holistic ES.

This thesis has revealed how, by using climate processes as illustrative examples, Earth system thinkers advanced the notion of the Earth as an integrated system. This big picture perspective supported the genesis and evolution of ES science, producing a wealth of knowledge pertaining to the world's environmental challenges. The generation of water system knowledge, global and regional carbon and methane budgets, a food system conceptual framework, and the articulation of the planetary boundaries concept and sustainability guardrails, for example, have been possible because of integrated ES science. Furthermore, recent advances in ES research include recognition that humans are both capable of, and responsible for, safeguarding planetary welfare.

There are, however, some limitations to this thesis. The following are, therefore, important considerations for further research on conducting international and integrated ESS in the global North and South. Firstly, the scope of the thesis could have incorporated more social science theories and ideas to help explain the difficulties of linking social and natural sciences, or in creating international and integrated ESS collaborations. This includes, for example, drawing on literature from research fields such as science, technology and society; political economies of science; and the history of science. Secondly, the thesis largely focused on research based at a limited number of global North institutions. For greater historical understanding of the origins of integrated research on environmental problems, the thesis could have included an analysis of science integration in institutions other than ICSU and their interdisciplinary programmes. For example, the Earth system science centres at US-based universities and the International Institute for Applied Systems Analysis in Europe. Thirdly, while the thesis did include research conducted in locations in the global South, this could have been expanded to include a more complete study on the challenges and opportunities of doing integrated ESS in the global South.

The ES research community will continue to reveal emerging global environmental challenges and track existing ones. However, this study illuminates persistent barriers to science integration. This includes limited breadth of knowledge integration and varying professional practices of interdisciplinary reviewing in the sample of environmental journals examined, and the challenge of the mass media accurately using scientific evidence to inform the public about climate risks and other ES-derived challenges. This analysis suggests that ES research is currently not integrated enough. Yet, there are opportunities for ESS to continue to evolve and become more integrated in order to support responses to global environmental problems.

This thesis elucidates some possibilities for ES research to become more integrated, by involving the users of scientific information. For example, researchers, funding agencies and academies (from both the global North and South) can work together to deepen science integration of the natural, social and human sciences and develop new ways to support integrated ES research. Interdisciplinary environmental journals can explore opportunities to integrate more practical knowledge and disciplinary insights and publish research at the nexus of science and action, and interface journalists and the media with a vested interest in evidence-based reporting of ESS findings can work together to better inform the public about the urgent need to respond to global environmental challenges. Furthermore, all relevant knowledge from epistemic communities across countries, regions, cultures and societies could be more regularly integrated into ES research. By so doing, transdisciplinary Earth system research can cross disciplinary, sectoral and international boundaries to become more integrated and better positioned to contribute to solutions to twenty-first century sustainability challenges.

## 6.1. Summary Schematic

**PhD research topic:** Integrated Earth System Science: Research Practice and Communication for Solutions to Twenty-First Century Sustainability Challenges

**Research Q1:** What is integrated ES research and what has it accomplished?

**Probe A:** Climate as a component of transdisciplinary Earth system science.

**Probe B:** The Earth System Science Partnership.

**A1:** A decade of ES research reveals some progress, yet more needs to be accomplished. A more integrated approach is required to contribute to humanity's responsible engagement within the Earth system.

**Research Q2:** Are there opportunities commensurate to the task of practising and publishing integrated ES research that identifies, quantifies and communicates global environmental challenges?

**Probe C:** Towards transdisciplinary global environmental change research.

**Probe D:** Interdisciplinary environmental journals.

**A2:** Persistent barriers to science integration have prevailed too long. ES research should contribute to and communicate solutions to grand societal challenges.

**Research Q3:** How can ES research become more integrated and better positioned to contribute to humanity's responsible engagement within the Earth system?

**Probe E:** Surviving the growing pains of the inter-to-disciplinary lifecycle.

**Probe F:** Comparing journalists' and researchers' views of the media as a main channel of climate change information.

**A3:** Despite a legacy of barriers, an interface group of researchers and journalists exists who are knowledgeable in science and consider the mass media a helpful source of climate information.

**Answer to overarching PhD research aim:**

**i)** Despite advances in ESS, natural, social and human science collaboration is limited and barriers to science integration remain.

**ii)** Interdisciplinary environmental journals who might help communicate solutions to global environmental challenges tend not to broadly integrate knowledge from many disciplines and interdisciplinary reviews are pursued to varying degrees of intensity.

**iii)** General trust exists between an interface group of researchers and journalists knowledgeable in science. This core group has an important role to regularly provide evidence-based ESS findings to mainstream media colleagues in order to better inform the public about the urgency of responding to ES-derived sustainability challenges.

**Further research needs:**

i) Develop new methods and tools for integrated research.

ii) Research on the practice, publication and communication of integrated research.

**Thesis conclusion:**

The ES research community has identified and analysed global environmental problems. Yet, broad science integration and the communication of ES research findings remain demanding. However, by creating and responding to novel opportunities to support deeper integration, transdisciplinary ES research can cross boundaries to support responses to twenty-first century sustainability challenges.

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# Appendix One: Candidate's contribution to Paper B

Martin Rice
PhD Candidate
Department of Environment and Geography
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22 May, 2013

Dear Martin

As lead author, I am writing to confirm your contributions to our peer-reviewed paper on "Responding to Complex Societal Challenges: A decade of Earth System Science Partnership", which was recently published in Current Opinion in Environmental Sustainability. Co-author contributions to this paper are as follows:

| Paper | Conceptualization | Data collection & research | Writing |
|---|---|---|---|
| Ignaciuk A., Rice M., Bogardi J., Canadell J.G., Dhakal S., Ingram J., Leemans R., Rosenberg M. Responding to Complex Societal Challenges: A decade of Earth System Science Partnership (ESSP) interdisciplinary research (2012) Current Opinion in Environmental Sustainability, 4 (1), pp. 147-158. | 40% Rice<br>50% Ignaciuk<br>10% Leemans | 40% Rice<br>40% Ignaciuk<br>5% Ingram<br>5% Bogardi<br>5% Canadell<br>5% Dhakal | 35% Rice<br>30% Ignaciuk<br>10% Ingram<br>5% Bogardi<br>5% Canadell<br>5% Dhakal<br>5% Leemans<br>5% Rosenberg |

With best regards

Ada Ignaciuk

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## Appendix Two: Transdisciplinary global change research

Peer-reviewed paper (accepted on 3 July 2013). Mauser W., Klepper G., **Rice M.**, Schmalzbauer B., Hackmann H., Leemans R., & Moore H. (2013). Transdisciplinary global change research: the co-creation of knowledge for sustainability. *Current Opinion in Environmental Sustainability*, doi:10.1016/j.cosust.2013.07.001.

Appendix Two is a research output of a project I was extensively involved in, including contributions to project design, implementation and management, and as a co-convenor of a project-related workshop. I am a co-author of this paper, contributing to its conceptualisation, research input and writing. Although this paper is not intended to be taking into account in the examination of this thesis, it is included as an Appendix because of its relevance to the thesis topic, specifically the description of what integration entails and a framework that we developed for integrated ES research for sustainability.

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Current Opinion in Environmental Sustainability

# Transdisciplinary global change research: the co-creation of knowledge for sustainability

Wolfram Mauser[1], Gernot Klepper[2], Martin Rice[3], Bettina Susanne Schmalzbauer[4], Heide Hackmann[5], Rik Leemans[6] and Howard Moore[7]

The challenges formulated within the Future Earth framework set the orientation for research programmes in sustainability science for the next ten years. Scientific disciplines from natural and social science will collaborate both among each other and with relevant societal groups in order to define the important integrated research questions, and to explore together successful pathways towards global sustainability. Such collaboration will be based on transdisciplinarity and integrated research concepts. This paper analyses the relationship between scientific integration and transdisciplinarity, discusses the dimensions of integration of different knowledge and proposes a platform and a paradigm for research towards global sustainability that will be both designed and conducted in partnership between science and society. We argue that integration is an iterative process that involves reflection among all stakeholders. It consists of three stages: co-design, co-production and co-dissemination.

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**Current Opinion in Environmental Sustainability** 2013, **5**:xx–yy

This review comes from a themed issue on **Open issue 2013**

Edited by **Rik Leemans** and **William D Solecki**

1877-3435/$ – see front matter, Published by Elsevier B.V.

http://dx.doi.org/10.1016/j.cosust.2013.07.001

## Introduction

Future Earth, a new 10-year international initiative on global sustainability research, was formally launched during the Rio+20 United Nations Conference on Sustainable Development in Rio de Janeiro, Brazil [1,2]. Future Earth (see also www.icsu.org/future-earth) will provide a new platform and paradigm for integrated global environmental change[a] research that will be designed and conducted in partnership with society to produce the knowledge necessary for societal transformations towards sustainability. Future Earth has been established and is supported by the 'Science and Technology Alliance for Global Sustainability' made up of ICSU, the International Social Science Council (ISSC), the Belmont Forum of global environmental change funding agencies, the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations University (UNU), the United Nations Environment Programme (UNEP), and the World Meteorological Organization (WMO) (currently as observer). This demonstrates the broad, global societal interest in, and recognition of the urgency and relevance of the topic. The Alliance also reflects agreement on the need and opportunity for moving global environmental change research towards new themes and approaches, as Future Earth is designed to do.

In this paper we first present the main research challenges of Future Earth and the need to further develop integrated research approaches. To achieve this three different dimensions of integration and their attributes are introduced. These are used to develop a comprehensive integrative framework. We thus aim to report on effective science integration and application processes to effectively address societal problems.

## Research challenges related to Future Earth

Future Earth is not some empty shell waiting to be filled. On the contrary, it builds upon decades of scientifically excellent research fostered by research programmes such as DIVERSITAS, IGBP, IHDP, WCRP and their scientific partnership, ESSP [20,52]. Furthermore, it is informed by the outcomes of several consultative, agenda-setting activities undertaken by members of the Alliance. Many of these activities have helped to raise awareness among the scientific community of new approaches to the organization,

[a] Global environmental change includes changes in the physical and biogeochemical environment, either caused naturally or influenced by human activities such as deforestation, fossil fuel consumption, urbanization, land reclamation, agricultural intensification, freshwater extraction, fisheries over-exploitation and waste production [20].

**Box 1 Research issues addressed in the development of Future Earth as formulated in [3•]:**

Grand challenges:

1. Forecasting — improve the usefulness of forecasts of future environmental conditions and their consequences for people.
2. Observing — develop, enhance and integrate the observation systems needed to manage global and regional environmental change.
3. Confining — determine how to anticipate, recognize, avoid and manage disruptive global environmental change.
4. Responding — determine what institutional, economic and behavioural changes can enable effective steps towards global sustainability.
5. Innovating — encourage innovation (coupled with sound mechanisms for evaluation) in developing technological, policy and social responses to achieve global sustainability.

Research challenge questions:

I. How can humanity feed a growing world population within sustainable boundaries of the Earth system? How can governance be aligned with the opportunities for global sustainability?

II. What risks is humanity taking in the Anthropocene, from negative implications on development to crossing tipping points with catastrophic implications for human societies?

III. How can the world economy and available technologies be transformed to stimulate innovation processes that foster sustainable development?

IV. In a rapidly urbanizing world, how can humanity design and sustain liveable and sustainable cities?

V. How can humanity succeed in a rapid global transition to a low-carbon economy that secures energy access for all and preserves the remaining biodiversity on Earth?

VI. How can societies adapt to the social and ecological consequences of warmer world, and what are the barriers, limits and opportunities in adaptation?

VII. How can natural capital, ecosystem services, and environmental processes on Earth be shared in a fair way among all citizens in the world?

VIII. What lifestyles, ethics and values are conducive to environmental stewardship and human wellbeing and how might these evolve to support a positive transition to global sustainability?

IX. How does global environmental change affect poverty and development, and how can the world eradicate poverty and create rewarding livelihoods while achieving global sustainability?

design and conduct of global change research, and have identified research challenges and related research questions that Future Earth should tackle (see Box 1). One such activity was the two-year ICSU-ISSC Earth System Visioning process, which resulted in a report 'Grand Challenges for Earth System Sciences for Global Sustainability' [3•], a second was the Transition Team[b] of Future Earth itself.

These challenges and research questions indicate that future research efforts need to focus more directly on producing knowledge required to understand and diagnose the challenges that confront societies as a result of global change.[c]

[b] The Transition Team, a committee that is leading the initial design phase of the Future Earth initiative, is comprised of seventeen members from a wide range of disciplines and countries, and also includes ex-officio members representing the main partners of the Science and Technology Alliance for Global Sustainability.

[c] The analysis in the paper does not focus solely on global environmental change, but on a broader range of global problems. Many of these are unrelated to environmental change; they have significant consequences for society but do not necessarily involve changes in the Earth system. Yet environmental change can aggravate such problems, and in some cases is already doing so. It is the complex interplay of environmental change, its global impacts and its embeddedness in social systems, that serve as the focal domain of the paper — and this is referred to simply as 'global change' in the rest of this paper.

The need for further scientific evidence should be guided by these societal challenges. In addition, the transition towards the sustainable use of the Earth's resources can only be reached through deliberate processes of transformation [4] which have to be managed creatively by societies on the basis of sound scientific knowledge.

The knowledge that should be produced through research activities to meet the research challenges formulated in Box 1 is obviously not only defined by the knowledge gaps as perceived by single scientific disciplines, but also by the priority which societies place on the sustainability challenge. It calls for new research strategies, with a strong focus on joint efforts by researchers from the natural, social and human sciences and engineering to contribute to the co-design of a global sustainable future.

At first glance it looks as if this new research strategy may convert global change research from primarily a science enterprise into an applied and even transdisciplinary (i.e. driven by stakeholders' needs) research endeavor[d] like

[d] Hirsch Hadorn *et al.* [10] for instance distinguish between basic science, applied science and transdisciplinary science. Today also terms such as solution-oriented research [2,11] or actionable science [8,12] are used to describe this problem oriented branch of science in more detail.



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energy system research, research on sustainable production systems, mobility research, or research on food water and energy security. In applied and transdisciplinary research major questions are derived from societal needs whenever their established set of scientific methodologies will need to be supplemented by newly structured and prioritized approaches and processes. Their research results should assist societies to make informed decisions. Does this model of applied research also hold true for the research that is necessary in the context of Future Earth? If yes then for the upcoming decade researchers will face a clear shift from a business-as-usual basic science to transdisciplinary research approaches where — in addition to collaboration and integration across scientific fields — research questions no longer emerge from science alone but in interaction with civil society, governments and other stakeholders.

## Integration of knowledge as a new challenge in Future Earth

The differentiation, specialization and fragmentation of science into disciplines over the last centuries have gone hand in hand with extraordinary progress both in the quantity and quality of knowledge produced. The accompanying self-dynamics of scientific progress with the division of labour and the emerging incentive systems strongly supported the trend for individual scientists or groups of scientists to invent their own languages, journals, career systems and curricula [5], and eventually to tailor their research questions according to their ability to cope with their own cultural, technological and/or organizational structures. Consequently, specifically tailored (discipline-based) scientific questions often do not address the grand societal challenges and are therefore of inadequate scope and scale for the challenges of Future Earth. On the one hand disciplines are good at providing essential knowledge, methods and tools [6]. On the other hand, disciplinary approaches tend not to have the capability to handle complex challenges (e.g. climate change, public health, food and water insecurity) that demand cross-disciplinary collaboration [7]. As a result, researchers within their scientific disciplines usually cannot adequately approach these grand research challenges of sustainability despite their being of outstanding importance to the society in which they live (and, if they start addressing these challenges, they will be 'disciplined' by their peers).

A central tenet of integrated research is researchers working on problems and in contexts of application and not in disciplines, stimulating discoveries and interactions between fields [8,9]. There are many examples in the past where failure to integrate on the one hand resulted in inadequate knowledge [53], while integration of different fields of knowledge resulted in valuable contributions of science to societal problems [54]. For instance, eighteenth and nineteenth century botanists and chemists in Europe were not able to solve the prevailing societal and scientific challenge of conquering hunger. Only the introduction of agricultural universities across Europe during the second half of the nineteenth century provided the necessary organizational, technological and cultural platforms for science to tackle a grand societal research challenge — the prevalence of hunger in Europe — by integrating knowledge that was formerly too spread out among the disciplines to be utilized by a small group of specialized scientists. Besides innovative research, this also required excellent extension services and other links to societal needs.

The integration of research from different disciplines gathered traction during World War II because of the need for problem-focused, cross-disciplinary research to achieve political and military ends [13]. The Manhattan Project and the early US Space Programme are considered informative examples of integrated research [9,14,15]. The impetus for integrated research continued over several decades after the war with the creation of new laboratories and institutes in nuclear science, radiology, biophysics, marine physics and atomic research [16,9]. Additional examples include Watson and Crick's discovery of the structure of DNA and its aftermath (benefitting from biology and physics) and the amalgamation of disciplines such as neurobiology, psychology and computer science which all led to the creation of cognitive sciences [14]. These examples demonstrate the successes of integrated problem-oriented science (particularly collaborative research between natural sciences) but they can also demonstrate that societies or their parts have to play a more active role in the definition of research foci and topics and in collaboration with science.

Recognition of Earth as an integrated system [17,18,7] drew attention to the need to integrate approaches from different disciplines to tackle scientific questions about the complex processes making up the Earth system. Examples include the quantification of the Antarctic ozone hole by atmospheric chemists and meteorologists and an improved understanding of the causes and consequences of acid rain through collaboration between atmospheric scientists and terrestrial ecologists [19,20]. At the same time, many results of integrated research provide important information for decision makers in society. For example, the 'Climate Change, Agriculture and Food Security' programme's 'Integration for Decision Making' research project provides an analytical and diagnostic framework, that is grounded in the policy environment, incorporates biophysical effects, quantifies uncertainty where possible, and ensures effective engagement of rural communities and institutional and policy stakeholders (see: ccafs.cgiar.org/our-work/research-themes/integration-decision-making). Integrated global change research results also form the basis of high-impact



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international science-policy assessments such as the 'Millennium Ecosystem Assessment', the 'Intergovernmental Panel on Climate Change', 'The Economics of Ecosystems and Biodiversity' and the recently established 'Intergovernmental Platform on Biodiversity and Ecosystem Services'. These assessments predominantly rely on integrated research efforts and also serve societal needs (e.g. through their summaries for policy makers).

## The knowledge production process

It appears self-evident that integration is essential when looking at Future Earth's research challenges. However, it seems equally clear that integration has to work against the gravity of established organizational, technological and cultural structures of today's science. In addition, integration across scientific disciplines has to consider the multiplicity of worldviews present in contemporary science [21•]: the reductionist and contextual views. In the reductionist view, gaining knowledge is achieved by focusing *only* on understanding the parts of the system. It is thus not useful to look at the interfaces and complex coupling between the entire system's components to understand the function and effect of the sum of its parts [22]. This worldview resulted in the extremely successful analytical approaches throughout science, and is largely the basis for the technological progress during the last centuries, for example, in pharmaceutical research, solid-state physics or genetics. Knowledge should — in the reductionists view — ultimately be put in a formal framework and thus be universally recognizable and to a large extent exchangeable across contexts. The focus is not on the preservation of the quality and diversity of knowledge, but on the flow and exchange of knowledge between agents, particularly between those embedded in the same scientific culture. Under this worldview, a general goal of integration would be to create interfaces between the scientific cultures and their languages, which would allow exchange and co-utilization of disciplinary knowledge.

An opposing worldview considers knowledge as being composed of different configurations and validated practices that emerge as a result of agents' learning within their natural and/or societal contexts. Thus knowledge is mostly what works in a particular context. Consequently, what is learned need not be transformed into a formal representation by using a specifically designed language; such a reduction would destroy the contextual meaning of the knowledge. In this worldview both social and natural science knowledge are interdependent and inseparable aspects of the same knowledge. The robustness of knowledge is validated by checking its impact on the considered socio-natural system of reference [23]. Under this worldview, a general goal of integration would be to protect, promote, and whenever possible, incorporate the diversity of languages and forms of knowledge in ways that become relevant for sustainability in particular contexts of application.

It seems clear that these two worldviews have very different implications with regard to integration during the process of knowledge production. In the Future Earth context this means that in essence integrated research requires a process that brings together the different worldviews with the aim of benefitting from both approaches. The predominantly reductionist approaches in the natural sciences need to be combined with the more contextual approaches of many social science methods. Any research activity addressing societal problems is likely to require a combination of reductionist theorizing and analysis with a reflection of the societal contexts in which the research is located. Finally, in societally relevant research, the gap between science as the active knowledge producer and society as the passive recipient in the knowledge production process will need to be replaced by a process of co-design and co-production of knowledge.

## Concepts of integration

Since everyone is free to define/refine research concepts, a plurality of integration concepts can be found in the literature. Transdisciplinarity, interdisciplinarity, multidisciplinarity, pluridisciplinary, crossdisciplinary and their mutual relationships, as well as their impact on how to actually do research, have been issues of intensive debate in general science and education [6,15,23–25,26•,27,28,29••,30] as well as in research on global change and sustainability [10,31–33,34••,35,36•]. As a consequence, there does not exist a common language for defining the different approaches, and this leads to many misunderstandings and barriers to communication [25].

According to Tress *et al.* [25] the strength of integration varies across research concepts, from low (participatory, multidisciplinary) to fully integrated (interdisciplinary, transdisciplinary). Much of the literature stresses that transdisciplinarity, in comparison to interdisciplinarity, is also characterized by the involvement of non-academic actors in the research process (see Figure 1). Nicolescu [37] explains that the prefix 'trans' indicates '...[working] between the disciplines, across the different disciplines, and beyond all disciplines'. And Lang *et al.* [36•] defines transdisciplinarity as a reflexive principle '...aiming at the solution or transition of societal problems...by differentiating and integrating knowledge from various scientific and societal bodies of knowledge'. But as mentioned above, the views of experts are variable (mostly in detail). In this paper it is not our aim to discuss the numerous different views/definitions from a theoretical perspective. Instead, for understanding the ongoing academic discussion we would like to review briefly the positions of two experts from different communities on the subject of transdisciplinarity.



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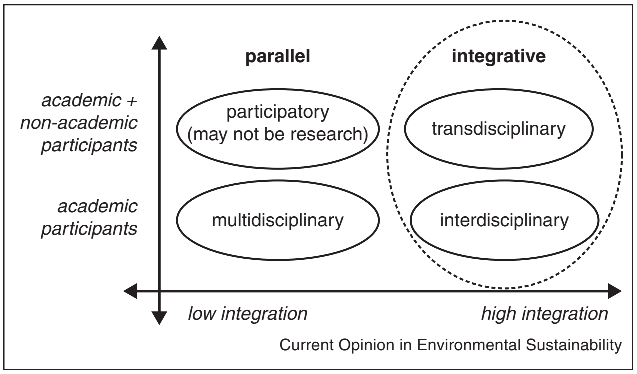
**Figure 1**




Degrees of integration and stakeholder involvement in integrative and non-integrative approaches according to Tress et al. (2005) with kind permission from Springer Science+Business Media.

Attempts to fill transdisciplinarity with content date as far back as the 1970s when Erich Jantsch postulated that innovations in planning for society at large in a government–industry–university triangle should include a far-reaching re-organization of higher education into an education–innovation system, because 'the classical single-track and sequential problem solving approach itself becomes meaningless today' [24]. Jantsch put forward the idea that knowledge creation should be organized and coordinated in hierarchical systems at four levels: purposive (meaning values), normative (social systems design), pragmatic (physical technology, natural ecology, social ecology) and empirical (physical inanimate world, physical animate world, human psychological world). This top-down coordination should follow horizontal principles within each level and vertical principles between levels and sub-levels. Transdisciplinarity, according to Jantsch, is reached at the ultimate level of coordination since 'the essential characteristic of a transdisciplinary approach is the coordination of activities at all levels of the education/innovation system towards a common purpose.' [24]. Mittelstrass [29••,38] has a more pragmatic and evolutionary view on transdisciplinarity when he contests that 'scientific cooperation in general means readiness to engage in cooperation in science, and interdisciplinarity normally means concrete cooperation with a finite duration, transdisciplinarity is intended to imply that cooperation will lead to an enduring and systematic scientific order that will change the outlook of subject matters and disciplines.' Transdisciplinarity in this context is 'a principle of research and science, one which becomes operative wherever it is impossible to define or attempt to solve problems within the boundaries of subjects or disciplines, or where one goes beyond such definitions'. It is consequently seen as a natural step in the development of scientific collaboration. For Mittelstrass it is nevertheless useful to distinguish between practical transdisciplinarity where science addresses sets of problems not intrinsic to science and theoretical transdisciplinarity that originates from more strictly scientific sets of problems.

He views for example ecological research as of the practical transdiscplinarity type. For him to solve scientific ecological problems collaboration and a 'wise and efficient coordination' of a broad range of disciplines from natural science and humanities is necessary, 'but not an extension or transformation of these disciplines'. Research on global change and sustainability in this sense is also of practical transdisciplinarity. It requires the collaboration of many disciplines, for instance physics, chemistry, biology, geography, sociology, psychology, economics, law, and/or ethics. They contribute with their specialized knowledge to the solution of these problems, 'and a wise and efficient coordination, but not an extension or transformation of these disciplines, is required' [29••].

In both positions an overall need for coordination is seen as an integral part of transdisciplinarity. The difference in these two positions lies within the assumed nature of research coordination as a more top-down or bottom-up process. Although not mentioned by either author, it is the integration of the disciplinary contributions that is at the heart of transdisciplinarity, and which gives transdisciplinary coordination a direction. Mittelstrass [29••] claims in contrast to Jantsch [24] that transdisciplinarity is not trans-scientific; it retains subjects and disciplines, which have been constituted historically, and is solely meant to overcome the boundaries between them.

## From theory to practice

Since the debate about different research approaches is still going on in science, there is no final conclusion about a 'correct' way to coordinate the sciences in an integrated or transdisciplinary manner. Nevertheless, the grand challenges of sustainability demand the development of pragmatic approaches to the integration and conduct of transdisciplinary research.

For integrated research to meet the needs of users more effectively, as well as to inform sustainable policy directions, it is therefore necessary to establish what integration means in a practical Future Earth context. This opens up several questions related to Future Earth: 'Will research undertaken within the framework of Future Earth be any different from what we commonly understand as being applied research?', 'Why should sustainability science not be considered just another branch of engineering?', 'What are the specific challenges for science with respect to the interactions between science and society that the Future Earth principles of co-design and co-production of knowledge emphasise?'.

The aforementioned theoretical discussions on what transdisciplinary coordination and integration mean for



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practical research within Future Earth were condensed to the following key question:

'How would a new platform and paradigm for global change research look like, that will both be designed and conducted in partnership of science with society to produce the knowledge necessary for the societal transformation towards global sustainability?'

This formed the basis for the German National Committee on Global Change Research (NKGCF, www.nkgcf.org) to initiate, in cooperation with ESSP, ISSC and ICSU, a workshop on 'Integrated Global Change Research: Co-Designing Knowledge across Scientific Fields, National Borders, and User Groups'. The workshop was held on 7–9 March 2012 at the Berlin-Brandenburg Academy of Sciences (Berlin, Germany) and was sponsored by the German Research Foundation (DFG). The focus of the workshop – in which over 50 senior and mid-career scientists with long-term interdisciplinary and transdisciplinary experience, as well as stakeholders from different parts of the world participated – was to discuss and evaluate current examples of integrated research, to debate the notion of integration across different fields, national boundaries and user groups as a basis for the co-design of knowledge, and to identify the key components of efforts to take forward the successful co-design and co-production of knowledge of relevance to Future Earth. Building on workshop participants' insights, this paper illuminates useful processes of integration and describes the main practical challenges to, and opportunities of, the integration of knowledge.

## The shift from business-as-usual science to a new research model in global sustainability

The societal challenges given in Future Earth (c.f. Box 1) describe problems where the need to move from disciplinary approaches to integrated (interdisciplinary and transdisciplinary) approaches is both necessary and evident. According to Lang *et al.* [36•], key arguments for moving to such new types of research collaboration are:

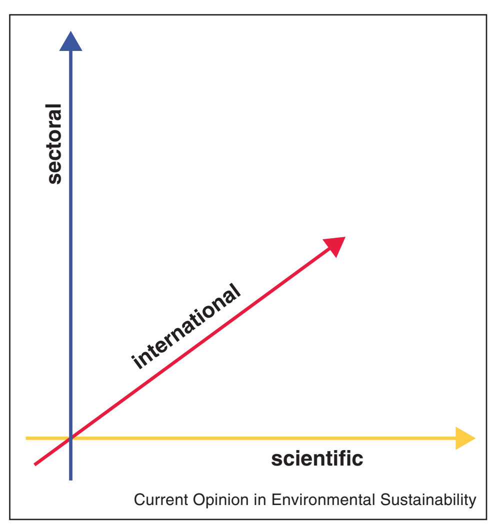
- Research on complex sustainability problems requires input from various communities of knowledge (e.g. science, business and government). Since it is not clear from the beginning what knowledge from different disciplines and actor groups will be relevant in a given context, an open, integrated process involving insights from many potential actors is required;
- Solution-oriented research requires knowledge production beyond problem analysis and the provision of system understanding. Goals, norms and visions need to be included, as they provide guidance for transition and intervention strategies[e];
- Collaborative efforts between researchers and non-academic stakeholders promise to increase legitimacy, ownership and accountability for the problem, as well as for the solution options.

Despite sustained pleas for integrated research in global change and sustainability science [18,39–43], integrated approaches have yet to be implemented in environmental science to the extent that Jantsch [24] or Mittelstrass [29••,38] have proposed. We therefore considered it worthwhile to examine more closely integration and transdisciplinarity, which is a key element of integration. We also support the understanding that transdisciplinarity is a reflexive learning process that goes beyond interdisciplinary research and involves academics and non-academics (e.g. stakeholders, decision makers of policy, society and economy). This follows the view of several other authors, for example [10,25,36•,37,44].

From the practical perspective of what integration could be, we suggest — based on the discussions in the workshop — to distinguish between three different dimensions of integration (see Figure 2):

(a) *Scientific dimension of integration*: This addresses the integration of knowledge, concepts and methods from different scientific disciplines. Case studies of different approaches towards scientific integration (e.g. food systems, water security, climate change and land management) were presented and discussed,

**Figure 2**




The transdisciplinary Future Earth integration space as seen by the Berlin workshop (March 2012); *scientific integration* = integration across academic and social sciences, humanities and engineering) disciplines, *international integration* = integration from local to global and across nations and cultures and *sectoral integration* = integration across science and society.

[e] This is an example where the reductionist and contextual approaches to scientific inquiry need to come together.



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along with experiences gathered from integrated research projects [45–50]. Workshop participants indicated that scientific integration can either be organized by: (I) developing a common mission, (II) developing a common conceptual framework and language, (III) considering cross-cutting issues, or (IV) combining methodological approaches. Integration can operate at least in three different modes: additive (e.g. a cost benefit analysis of a certain climate policy option), combinatory (e.g. representative climate projections and socio-economic scenarios), or systemic (e.g. Earth system models with complex feedbacks).

Regarding coordination of scientific integration, four points were identified, which need to be addressed in a systematic manner:

i. How to integrate across scientific disciplines in a consistent way? The three modes of scientific integration do not ensure that the integrated entities fit in their data, assumptions and understanding, and that comparing apples with pears is avoided. There is a general lack of systemic approaches that are designed to identify inconsistencies in integration. And there is a lack of communication among representatives of the different approaches.
ii. Scientific integration versus scientific autonomy of disciplinary research. Research results from participating disciplines form the basis on which to integrate. To what extent do the interdependencies established through integration between the participating disciplines dictate their research topics and how can the two worlds (i.e. integrated and specialist) co-exist?
iii. How can the necessary critical reflexivity on boundaries of science and knowledge be organized between disciplines? Integration creates interfaces between the participating disciplines and with the outside, non-scientific world. The criteria of where and how and with which contents to establish these interfaces is still an open question.
iv. How can we develop new concepts, processes and common scientific languages? The case studies demonstrate the importance of communication between the participating scientific disciplines and stakeholders for successful integration. It is not yet clear which concepts and processes are most suitable to support communication and what the properties of integration languages should be.

(b) *International dimension of integration*: This dimension addresses the world-wide character that international research initiatives like Future Earth seek to promote, the local-national-regional character of sustainable solutions and the need to include all relevant knowledge from epistemic communities across countries, regions, cultures and societies.

Sustainable development and global change are common scientific challenges that bring together people with very different values and worldviews to cooperate in research [51]. The exploration of suitable institutional, economic and behavioural changes towards global sustainability will lead to solutions that are highly dependent on, and tailored to, local, national and regional cultural, economic and natural contexts. Integration of research questions, from the local to the global and back, means considering the other scales when carrying out research on the one scale (be it local, national, regional or global). This ensures that differences in cultures, interdependencies between regions and institutional dependencies are adequately (i.e. in an equitable fashion) taken into account.

Regarding international integration five critical points have been identified by the workshop participants:

i. How to best solve the problem of fit? International integration should fit the scale of the social–ecological problem and challenge to be addressed. The region and scale for international research integration (local–national–regional–global) should depend on the problem to be addressed.
ii. How to ensure that basic research principles and standards are met?
a. The universality principle: people should have a right to have equal access and means to agenda setting, data, methodologies and results.
b. Universal standards of quality of science (e.g. transparency, replicability, excellence and data quality) while respecting the possibility to frame the problems to be addressed differently and bringing different conceptual and methodological tools to bear on those problems.
c. Diversity in the research and knowledge systems and language should be preserved and respected.
iii. How to reduce the strong asymmetries in research capacities, money and power among the international partners from the developing and developed worlds?
iv. How to identify best solutions from different regions through the benchmarking of best practices; how to exchange, replicate, adapt and integrate methodologies of research developed under different national/regional contexts?
v. How to best integrate for collection and common use of environmental and societal data from different regions of the World?

(c) *Sectoral dimension of integration*: This dimension addresses the co-design and co-production of knowledge between actors from the state, knowledge institutions, market and civil society sectors so as to achieve a mutual understanding of the kinds of research questions that need to be addressed and the ways of doing so. The purpose of sectoral integration is to ensure that, through joint, reciprocal framing,



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design, execution and application of research, science and societies approach the transformations towards sustainability in a structured and knowledge-driven way. The integration of stakeholders and decision makers, who were formerly distant to the process of scientific agenda-setting and knowledge creation into these processes, both enhances mutual understanding and mutual responsibility. No definitive blueprint exists yet for this dimension of integration; it comprises new forms of learning and problem-solving action of different parts of society and academia that have not traditionally been in close contact.

Regarding sectoral integration, three critical aspects were identified by the workshop participants:

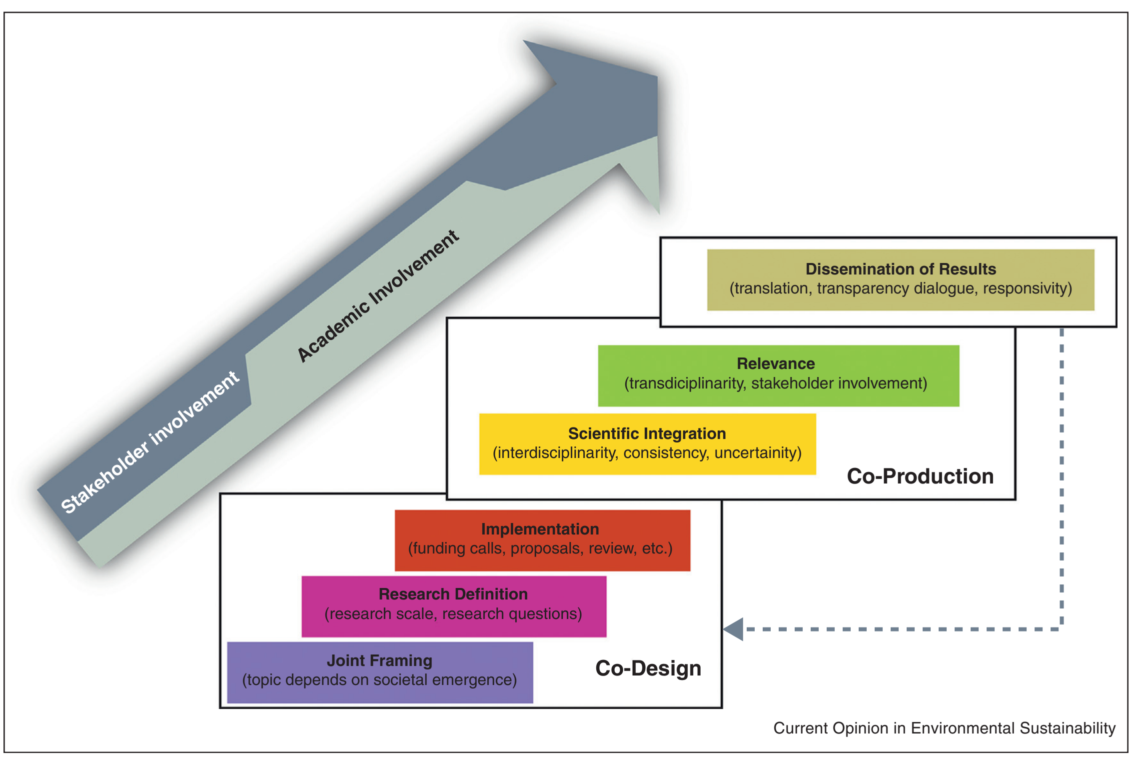
i. How can communication between the different actors from state, knowledge institutions, market and civil society sectors be best organized to become effective? The common difficulty of communication among scientists from different disciplines takes on a further dimension when it is joined by discussion on the same topic with stakeholders from different societal sectors. Therefore, it is not clear how to embed such discussions and how to establish a common knowledge platform for the partners.
ii. How to define sectors and relevant actors in each context according to the research issue identified? No mechanisms are available to decide in a non-exclusive way which sector should participate in the definition and solution of a research issue.
iii. How to best translate results from research into knowledge that is useful to society, and how to best translate societal needs for knowledge into science questions and operational research programmes? A number of initiatives have been started or are in the process of design, such as the Climate Service Center (CSC) in Germany (www.climate-service-center.de) or the climate services envisaged by the WCRP (www.wcrp-climate.org). It will remain to be seen whether these attempts will be capable of providing an appropriate platform for fruitful, integrated communication between science and society.

All three dimensions need to be realized if a successful transdisciplinary global change research system is to be implemented. Furthermore, these three dimensions of integration build the basis for the proposed model of co-creation of knowledge within the Future Earth process.

## Co-creation of knowledge

We propose a framework for integration (Figure 3) within the Future Earth context. The process of co-creation of knowledge — as it was developed during the workshop — consists of three fundamental steps throughout which both academia and stakeholders are involved to

Figure 3




Framework for interdisciplinary and transdisciplinary co-creation of the knowledge castle.



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varying degrees: co-design, co-production and co-dissemination. During these consecutive steps the three dimensions of integration are of varying importance to the overall knowledge creation process.

It starts with the *co-design of the research* agenda through sectoral integration between stakeholders and decision makers from the relevant societal sectors and science to develop a viable research issue to the point at which it can be handed over to the broader scientific community. The process of co-design starts with the joint framing of sustainability challenges faced by society. The next step concerns the translation of the sustainability challenge into a definition of the required knowledge that needs to be offered through research. Important issues are the scale, both spatial and temporal, of the required research and the necessary depth of international and scientific integration. In the process of research definition, the research questions are portioned into manageable research projects. This step leads to research management procedures like research funding calls, proposals and reviews, which are either well established or which have to be tailored to the specific integrated project by the funding agencies. During the co-design phase stakeholders and academic participants work in a coordinated, integrated way to best establish a common understanding of the research goals, to identify the relevant disciplines, participants and the scientific integration steps necessary to approach the topic, and to agree on the roles the different groups have in advancing towards the research goals.

The second *step* consists of the *co-production of knowledge*. Here, the transdisciplinary focus is on scientific integration. During this phase integrated research is conducted as a continuous exchange among the participating scientists and with the stakeholders. Scientific integration takes care of proper interdisciplinary approaches and interfaces, which ensure consistency of the research process across the participating disciplines and also deal with questions of the uncertainty of the results. Scientific integration also ensures that the necessary disciplinary research questions are derived from the overall needs of the project and then researched by the respective discipline, and that the scientific quality is maintained in the research process. Finally, dialogue between stakeholders and scientists ensures the exchange and interaction of their respective knowledge and thereby ensures the societal relevance of the research

The last step consists of the co-*dissemination of the results* among the different societal groups. This includes publication of the acquired knowledge also in accessible language, translation of the results into comprehensible and usable information for the different stakeholders, and an open discussion on the valuation, applicability and relevance of the results among groups of conflicting interests. This open discussion of the results and the consequential actions taken by society towards reaching the goal of sustainability leads to new research questions, which will then jointly be framed, which initiates a new transdisciplinary research cycle. Figure 3 demonstrates that integration is an iterative process that involves ongoing reflection among all participants.

## Conclusions and the way forward

Carrying out research that will fulfil the ambitions of Future Earth means committing to do science together with society: in other words, to commit to transdisciplinary and thus integrated processes of co-designing research agendas and to co-producing knowledge with researchers, decision makers and stakeholders for addressing challenges for global sustainability and developing possible solutions. Integrated research provides a better understanding of the multiple drivers, interdependencies and complexities of global sustainability challenges. It provides knowledge that is better able to contribute to the development of robust policy solutions and their effective, equitable implementation.

Integrated research works across scientific disciplines, across regions and across societal groups. It is problem-oriented, driven by contexts of application, and starts with the joint framing of research topics and questions. It requires the involvement of researchers, stakeholders and decision makers throughout the entire research process, from co-design through co-production to effective delivery, and thus demands clarity about the roles and responsibilities of those involved.

Integration upholds scientific integrity in reflexive learning processes that bring together different actors and knowledge practices. It builds on, and supplements, traditional processes of disciplinary research.

Co-production of knowledge in global change research changes the way research is done and needs new methods and concepts. It requires appropriate communication tools, institutional arrangements, and tailored funding possibilities. In this it can draw on other experiences, such as those mentioned earlier (e.g. the Manhattan Project and CCAFS).

Successful integration calls for critical reflection at all levels — among researchers, funders, and science policy makers — on the role of science in global sustainability, and on the practices of research and research management that will be needed to make this new type of relationship between science and society come to life.

We tackled the question of integration of knowledge and to begin a process of reaching a new international consensus on, and commitment to, integrated sustainability research. From the science perspective, involving funders



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and science policy makers presents challenges as well as great opportunities for providing the necessary institutional framework. The challenges, that must be met, involve:

- **Develop new processes and skills:** Integration requires strong process-oriented skills (inter-personal, communication and facilitation), as well as organizational and managerial competencies, that are not always available and may require professional support or training. Educational institutions as well as funding agencies will play an important role in this.
- **Deal with inertia to change:** Integration also requires critical reflection on the role of science in global sustainability and on the limitations of doing business-as-usual research. This, in turn, requires an openness to change. Neither process is necessarily easy or comfortable for those involved.
- **Clarify roles, responsibilities and rules of engagement:** Integration is research coordination, which spans the entire research process. Different actors will have different levels and forms of involvement in different parts of the process. This requires clarity about roles and responsibilities, about who makes decisions when, and about how to appropriately safeguard scientific integrity and relevant standards of quality.
- **Establish integrated institutions:** The disciplinary-based practices and structures of existing educational and research systems are not conducive to integrated efforts, and will need to be supplemented with new, integrated structures.
- **Develop support systems:** The same is true for typical academic reward and career advancement systems, as well funding mechanisms — including selection and evaluation procedures. Integration calls for a critical review of such systems.
- **Remove persistent inequalities:** In terms of access to power and resources, as well as research capacities, the world of science is plagued by persistent inequalities that pose a fundamental challenge to the deeper levels of collaboration that integration calls for.

To adequately approach these challenges of co-design, co-production and co-dissemination of knowledge, the following requirements are necessary from the outset:

(i) the design and implementation of new support and management structures,
(ii) the development of a diversity of skills for managing integration processes, including the necessary reward structures, and
(iii) adjustments to funding mechanisms, including selection and evaluation procedures.

Future Earth provides major opportunities for advanced sustainability research by providing both the necessary international institutional structure and the platform for defining a research agenda for the next decade of research. The Berlin Workshop has clearly shown that the challenge of integrated research requires a focus on a number of additional aspects. Integration will not happen by itself but needs active support and organizational adjustments in the research process. Future Earth is now in a unique and powerful position to: firstly, promote critical reflection on what kind of science we want for what kind of world; secondly, provide a platform for discussions about the implications of promoting the co-design and co-production of knowledge for global sustainability; thirdly, suggest the introduction of appropriate research management processes and structures, as well as funding modalities and other support systems, to make integrated research across scientific fields, national borders and user groups a reality; and fourthly, work with members of the International Science and Technology Alliance for Global Sustainability that established Future Earth to build a sound, practical understanding of Future Earth processes in broader systems of research at national, regional and international levels.

## Acknowledgements

The authors would like to thank the Deutsche Forschungsgemeinschaft (German Research Foundation, DFG) for funding the workshop 'Integrated Global Change Research: Co-Designing Knowledge across Scientific Fields, National Borders, and User Groups' and workshop participants for contributing to a greater understanding of integration and the challenges and opportunities of transdisciplinarity described in this paper.

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Please cite this article in press as: Mauser W, et al.: Transdisciplinary global change research: the co-creation of knowledge for sustainability, Curr Opin Environ Sustain (2013), http://dx.doi.org/10.1016/j.cosust.2013.07.001

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## Appendix Three: Response to Paper E

LETTER

# Reply to Rice and Henderson-Sellers: Survival of the fittest is not always the best option

We would like to thank Rice and Henderson-Sellers (1) for their Letter, which largely reiterates a number of the issues brought up at the Sackler Colloquium "Fostering Advances in Interdisciplinary Climate Science" and discussed in our introductory review of this event (2). In particular, Rice and Henderson-Sellers discuss the fact that barriers to interdisciplinary research have long been recognized, that interdisciplinary fields can develop into independent disciplines, and that fledgling interdisciplinary fields would benefit from more imaginative avenues of support.

However, we disagree with Rice and Henderson-Sellers (1) in their suggestion that emerging interdisciplinary sciences should undergo an unsteered process of natural selection, so that weaker aspects are weeded out. Science is undoubtedly a competitive field in which ideas compete for funding, journal space, and, ultimately, community acceptance; however, the notion that this competitive selection is always optimized and beneficial, particularly in a field as expansive as interdisciplinary climate science (which has entrained disciplines as diverse as machine learning, economics, mental health, etc.), seems misguided. To extend their business analogy, a new business in a market without regulation is generally at a decided disadvantage—the established businesses often have the means to protect their interests and can frequently determine or change the rules of the game (i.e., the laws of natural selection) through their size and unregulated influence. Without a level playing field, there is nothing natural about the scientific selection process, particularly if established disciplines can exert their influence on agencies and journals and, in so doing, protect their funding streams and self-interests. Even if the best science emerges in the end, many resources may be squandered along the way, and the advance of scholarly understanding is unlikely to be optimized.

Natural selection is not a progressive process in which organisms evolve to a more perfect ideal [i.e., as proposed by Lamarck (3)]; rather, it is simply a response process dependent, in part, on the reproductive time scale of the organism (4). Science, on the other hand, is a progressive process through which we hope to develop a more complete understanding of our universe. To move forward, science needs to invest in ideas without excess focus on short-term gains. A diversity of approaches and multiple lines of inquiry need to be supported through time. Such investment is critical for the development of excellence in scholarly thought, whereas selection, in business and in nature, can unduly reward short-term gain.

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**1** Rice M, Henderson-Sellers A (2013) Surviving the growing pains of the inter-to-disciplinary lifecycle. *Proc Natl Acad Sci USA*, 10.1073/pnas.1306270110.
**2** Shaman J, Solomon S, Colwell RR, Field CB (2013) Fostering advances in interdisciplinary climate science. *Proc Natl Acad Sci USA* 110(Suppl 1):3653–3656.
**3** Lamarck JB (1809) *Philosophie Zoologique, ou Exposition des Considerations Relatives à l'Histoire Naturelle des Animaux*; trans Elliot H (1914) [*Zoological Philosophy, an Exposition with Regard to the Natural History of Animals*] (MacMillan, London). French.
**4** Darwin C (1859) *On the Origin of the Species by Means of Natural Selection* (J. Murray, London).

Author contributions: J.S., S.S., R.R.C., and C.B.F. wrote the paper.

The authors declare no conflict of interest.

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Shaman, J., Solomon, S., Colwell, R. R., & Field C. B. (2013). Reply to Rice and Henderson-Sellers: survival of the fittest is not always the best the best option. Proceedings of the National Academy of Sciences, 110 (29), E2664; DOI: 10.1073/pnas.1307874110

Appendix Four (pages 209-210) removed from Open Access version as they may contain sensitive/confidential content.

Appendix Five (pages 211-212) removed from Open Access version as they may contain sensitive/confidential content.