Chapter 1

[Sustainable Development and Sustainability Science] [Sustainability and Science][a]

[Word count, not including notes: 5225]

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This chapter sets the context and purpose of the monograph. It begins with a discussion of the origins and present status of the idea of sustainable development. Next, we illustrate the range of contemporary challenges facing those who would promote a transition toward sustainability. The chapter then traces emerging efforts to better harness science and technology to advance the sustainability agenda. Next, we characterize the emerging field of sustainability science. The chapter closes with a discussion of our motivation and goals for the monograph.

1.1 Sustainable Development

The challenge of sustainable development has been broadly understood since humans began to spare gravid game, fallow their fields, and dump their wastes downstream. But it received its modern formulation from the World Commission on Environment and Development (WCED, also known as the Brundtland Commission), which wrote in 1987:

> "Environment is where we live; and development is what we all do in attempting to improve our lot within that abode. The two are inseparable…. Humanity has the ability to make development sustainable: to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs."[1]

[a] Version history:
Ver 0 (071124) drafted by Clark using material from Dasgupta and presented at Nov 07 meeting.
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Through the 1990s, an increasing number of localities, corporations and nations began to bring the sustainability thinking articulated by the Brundtland Commission into their planning and operations. And by the beginning of the 21st century, sustainable development had taken its place at the high table of global affairs. UN Secretary General Kofi Annan was reflecting a broad consensus when he argued in his Millennium Report to the General Assembly that the three great interlinked challenges facing the international community in the decades ahead were helping the world's peoples to secure "freedom from want, freedom from fear and the freedom of future generations to sustain their lives on this planet."

Perhaps not surprisingly for an idea that has resonated so widely, "sustainable development" – like the comparably big ideas of "justice" and "freedom" -- has come to mean different things to different people. There is, however, some structure to this variety. As pointed out by the US National Research Council (NRC), at least four common questions about the concept are explicitly or implicitly addressed by almost every definition: What is to be sustained? What is to be developed? What is the relation between what is to be sustained and what is to be developed? Over what scales in space and time are those relationships meant to hold?[b] Figure 1.1 reproduces the NRC's efforts to classify the way different people have answered these questions in their framing of the debate over sustainability.[2]

[Figure 1-1 (NRC classification of framings) near here]

A moment's inspection of the figure suggests why arguments that are ostensibly about what impedes sustainable development or how to achieve it often turn out to be about much more fundamental differences in values and goals. The raw materials for more subtle confusions over ends and means are apparent as well. An example within the "What's to be sustained?" question, for example, is whether healthy ecosystems are viewed as an end in themselves, or merely as a means to secure key ecosystem services. With regard to "What is to be developed?" the same difficulties arise over the position of education relative to child survival. To clarify such confusions a number for formal definitions and frameworks of sustainability have been proposed. We discuss several of these later in this volume. None – including the one we present -- are entirely successful in capturing in operational form the richness and intensity of the sustainability debate. But if a general theory capturing all of the details of sustainability is neither feasible nor, perhaps, desirable, greater clarity of intention and perspective on the part of scholars working in the field is both. Let us therefore attempt at the outset of this essay to locate our treatment of sustainable development relative to the range of perspectives suggested in Figure 1-1.

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[b] BC: A fundamental question for us all to contemplate is the relationship between this empirical "4 question" classification of the existing debate and the theoretical formalization of "sustainability" that we set forth later in the book (drawing primarily from Partha's work). If we can show that, and how, our formalization addresses each of the 4 "popular" questions, that is very good indeed. If we can't, we need to figure out what to make of that fact.

For this book, we have developed a perspective on sustainability that is broad but unabashedly anthropocentric. Despite the awe in which we hold nature and the value we place on its conservation, ours is ultimately a project that seeks to understand what is, can be, and ought to be the human use of the earth. We pursue this goal, however, in the conviction that what is possible and desirable for people can only be understood through an appreciation of the *interactions* between social and environmental systems. As we set forth more thoroughly in Chapter XX, Our answer to "What is to be developed?" will thus incorporate dimensions of the economy, of peoples' well-being, and of the social institutions and other forms of capital assets on which development depends.[c] Our answer to "What is to be sustained?" embraces a somewhat narrower set of the possibilities suggested in Figure 1.1, focusing on resources and the "life support systems" provided by the interlinked geophysical, chemical, and ecological processes on which humanity depends for its well-being.

Our scales of interest are also broad. In the time domain, while recognizing that important interactions between social and environmental systems occur at all scales, we have found it most helpful to *focus* on what might be called "grandchildren" time: periods of more than years but less than centuries. Because ideas and policies, and the structure of social organizations and technologies of the present cast a significant shadow on the future, we adopt a dynamic view, emphasizing not some distant goal of achieving sustainable development, but rather on contemporary progress (or lack thereof) along a transition *toward* sustainability.

With regard to spatial scale, our appreciation of the degree to which human action has already transformed the earth on planetary scale leads us to address the sustainability question from a global perspective. That said, however, our work has also led us to appreciate that the nature of interactions between social and environmental systems can often be best understood, and effective *options* for managing those interactions often must be designed, in the *context* of specific places. How different those contexts may be for people working in or on different parts of the world is suggested in Figure 1.2. The stark contrast it portrays of sustainability challenges in the [north and south][rich and poor parts of the world] was originally drawn by one of our southern colleagues during a hot exchange at an international workshop that helped to launch the sustainability science effort we report on here.

[Figure 1.2 (Friiberg triangles) near here]

To address the importance of context, we thus emphasize in our approach the need to *identify* rather than assume the relevant scales – generally larger than the purely "local now," but smaller than the "global forever" – at which we can make most sense of humanity's continuing struggle to shape a transition toward sustainability.

In summary, the present volume rests on a normative commitment to "sustainable development," which we see as promoting improvements in human well-being while conserving the earth's life support systems. As a practical matter, while recognizing the

[c] BC: Partha, you need to check your chapter to be sure this is true, or edit so that it is.

planetary, millennial character of the sustainability challenge, we focus on integrated regional efforts embedded in a globalizing world to promote a transition toward sustainability on decade to century (grandchildren) time scales.

1.2 Contemporary Challenges

The struggle to promote a sustainability transition has clearly achieved significant progress over the twenty years since the Brundtland Commission issued its report. Nonetheless, the challenges remaining today – and those looming on the horizon -- appear more daunting and urgent than ever. Consider the following examples, which reflect the range of sustainability problems we address in later chapters:[d]

Persistent poverty and hunger: Human ingenuity over the last 30 years has led to significant increases in the productivity of natural systems used to support agriculture, helping to fend off hunger and raise living standards for hundreds of millions of people. But for some regions -- especially in sub-Saharan Africa – humanity has not yet learned how to exploit more than a fraction nature's potential to provide people with food and fiber. Moreover, almost everywhere the rate of increase in agricultural productivity is now declining and the environmental damages associated with agricultural production are accelerating. The World Bank's 2007 World Development Report bluntly concludes that the Millennium Development Goals for alleviating hunger and poverty cannot be met unless these trends are reversed.[3]

Rising costs of economic growth at the national level: China's economy has been the wonder of the modern world, growing at 9-10% annually for much of the last decade. Resulting improvements in human well-being have been substantial though uneven across regions of the country. This rapid growth, however, has brought about significant environmental degradation, now estimated to cost the country in lost health, agricultural productivity and materials damage the equivalent of at least half of its nominal GNP growth.[4] These losses, also disproportionately born across the nation, have been described by China's Environment Minister as "a blasting fuse for social instability," and resulted in a stated commitment by President Hu Jintao "to put economic growth on a more socially and environmentally sustainable path."[5]

Accelerating degradation of the earth's life support systems: Evidence is rapidly growing that the unprecedented demands made by the earth's human population over the last half century are stressing the earth's life support systems to – or beyond -- the breaking point. The Millennium Ecosystem Assessment, released in 2005, reported that more than 60% of the essential ecosystem services it surveyed worldwide were significantly degraded, including damage to the earth's fisheries, freshwater supplies, and biodiversity. And the most recent report of the Intergovernmental Panel on Climate Change, published in 2007, is already in need of revision to account for the faster than expected growth of emissions, floods, fires, and ice melt being reported in scientific conferences and the world news.

[d] BC: Are these the right examples? Should we add some? If so, which? Selected by what criteria?

Other examples of today's sustainability challenges could be cited from around the world, together illustrating a sometimes bewildering array of problem definitions, professional approaches, and conceptual frameworks. What they would also show, however, is an increasingly world-wide recognition of the urgent need for action to make development both more effective and more sustainable. Many groups are seeking to step up to this challenge, including leaders from civil society, corporations, governments and, increasingly, the scholarly community. Our focus in this volume is on the last of these groups, and on what science can bring to society's collective effort to foster a transition toward sustainability.

1.3 Science, technology and sustainability

Scientific research on problems relevant to sustainable development is not new. Basic research on the (usually one-directional) impacts of humans on the environment, or of the influence of environments on society is of ancient lineage. A tradition of scholarship on the *interactions* between people and their environments dates back at least to the 19th century work of Alexander von Humboldt and George Perkins Marsh. Historians and geographers of various persuasions have systematically pursued questions of such interactions for almost a century, while resource economics has a relevant tradition of research going back for at least 50 years. More recently, explicitly interdisciplinary studies of human-environment systems have come to occupy increasingly prominent places in national and international research agendas.[6] (The focus of this body of research is also referred "socio-ecological" systems. We have, somewhat arbitrarily, adopted what we see as the broader "human-environment" formulation for this volume, while drawing extensively from the "socio-ecological" tradition as well).[e]

Applied research on human-environment interactions has an even richer legacy. Indeed, some of the earliest writings on what is now seen as the challenge of sustainable development came from scholars concerned with the productive management of natural resources. And much of the environmental movement of the 1960s was based upon concerned scientists' delineation of the impacts of pollution resulting from economic growth. By the late 1970s, however, the inadequacies of this competitive framing were becoming increasingly clear. A more contemporary-sounding scientists' framing of the sustainability debate was articulated by the International Union for the Conservation of Nature, which argued in its 1980 *World Conservation Strategy* that goals of protecting the Earth's lands and wildlife could not be realized except through strategies that also addressed the improvement of human well-being in conservation areas. This is essentially the view that was reformulated to encompass social-environment interactions more broadly in the report of the Brundtland Commission quoted above.

Calls for integrating basic and applied research perspectives to strengthen the contribution of S&T programs to sustainable development built slowly during the 1990s

[e] BC: As agreed at our Nov 07 workshop, I have adopted in this draft the convention of referring to "human-environment systems" (rather than "socio-ecological systems") in this draft. I have inserted here an awkward statement of this convention. Should we keep this? Relegate it to a note? Reconsider?

following the UN Conference on Environment and Development (UNCED) in Rio de Janeiro. Many of the earliest and most thoughtful contributions to this discourse came from the developing world through the work of individual scholars and of institutions such as the Third World Network of Scientific Organizations (TWNSO), the Commission on Science and Technology for Sustainable Development in the South (COMSATS), the Society for Research and Initiatives for Sustainable Technologies and Institutions (SRISTI), and the South Center.[7] A further regional perspective was provided by the African Academy's *Millennial Perspective on Science, Technology and Development*.[8] European thinking of the late 1990s was exemplified in Schellnhuber and Wenzel's *Earth Systems Analysis: Integrating Science for Sustainability*, the European Union's *Fifth Framework Programme,* and a special issue on "Sustainability Science" published by the *International Journal of Sustainable Development*.[9] A number of national academies of science or other advisory bodies – including those of Brazil, Germany, Japan, the United Kingdom, and the United States also addressed the links between sustainability and global change.[10] Many of these perspectives were brought together in UNESCO's *World Conference on Science for the 21st Century*, help in Budapest in 1999.[11]

With the turn of the Millennium, discussions on science, technology and sustainability intensified significantly. From the scientific community itself, national and international stock-taking on the first decade of research on global environmental change research provided opportunities for rethinking the relationships among science, technology and sustainability.[12] In the policy arena, international environmental assessments were increasingly called upon to address sustainability issues.[13] And on the political side, the World Summit on Sustainable Development (WSSD), held in Johannesburg in 2002, created the impetus for an extensive set of workshops, consultations and declarations focused on the challenge of harnessing the potential of science and technology to social goals for sustainable development.[14] International leadership for these ventures was provided by many groups, including the International Council for Science (ICSU), the Academy of Sciences of the Developing World (TWAS), the Earth Systems Science Partnership (ESSP) of the international global change research programs, and an ad-hoc, international group of scholars brought together as the Initiative on Science and Technology for Sustainability (ISTS).[15] A cumulative result of all this activity has been the emergence of a field increasingly referred to as "sustainability science."

1.4 Sustainability Science

Sustainability science has emerged over the last decade at the center of a diverse set of research and innovation activities relevant to society's efforts to support a transition toward sustainability. Today, it has developed elements of a shared conceptual framework, sketched a core research agenda and set of associated methods, and is producing a steadily growing flow of results. The present monograph is aimed to pull together some of this disparate foundational material, with a view toward providing a resource for the growing number of university programs committed to teaching and doing sustainability science.

We propose in later chapters that our own ultimate question for sustainability science is how to improve human well-being in ways that account for the ultimate dependence of that well-being on the natural environment. By human well-being we mean not only for the current generation, but also for future generations; not only for some places at the expense of others, but for all, and humanity as a whole. In the course of addressing this ultimate question, there immediately arise a number of subsidiary challenges for sustainability science: How should the well-beings of different persons (whether or not they are contemporaries) be aggregated? How do the "assets" – human, manufactured, natural, and intellectual – inherited by each generation from its past contribute to human well-being? How substitutable, within what limits, are these assets for meeting human needs and preferences? What is the role of scientific and technological progress in improving human well-being? What role do institutions play in enabling people to use the services that various assets provide for maintaining and improving their lives? Such questions have motivated our individual efforts in the field of sustainability science, and our joint commitment to write this monograph on what we see as the present state and future prospects of efforts to answer them.[f]

Before proceeding to the particulars of our argument, however, it will be useful to sketch four broad characteristics of sustainability science that, taken together, help to distinguish *how* it addresses its questions. These are discussed below in terms of the field's i) problem-driven focus on human-environment systems; ii) integrative approach to understanding complex human-environment interactions; iii) special attention to the cross-scale dimensions of those interactions and iv) its boundary-spanning work at the interface of research and practice.

1.4.1 Problem-driven focus on human-environment systems:

Like "agricultural science" and "health science" before it, sustainability science is a field defined by the problems it addresses rather than the disciplines or methods it employs. For us, those problems are defined as the challenges of promoting a transition toward sustainability -- improving human well-being while conserving the earth's life support systems over appropriate time and space scales. Sustainability science then draws from -- and seeks to advance – those aspects of our understanding of human systems, environmental systems and their interactions that are useful for helping people achieve sustainability goals. A first approximation of the domain of sustainability science can be seen in terms of the area of overlap in Figure 1.3.

[Figure 1.3 (Venn diagram of H-E systems and SD goals) near here]

The *broad context* of sustainability science can thus be seen as shaped by the changing social goals of sustainable development, and changing human systems and environmental systems within which efforts to achieve those goals are necessarily carried out (ie. the

[f] BC: I have manufactured the preceding para from several suggestions Partha made for text to be added at other locations later in this section. I think that his basic idea – which I took to be giving the reader a tasted of the exciting stuff to come early on in the chapter and book – is right. I've done the rearrangement because I think it fits better where I have put it. I could, however, be wrong. So please advise….

totality of Figure 1.3). The *core* of sustainability science, as we see it, lies in seeking to understand how society's efforts to promote a transition toward sustainability are constrained or promoted by the the interactions between human and environment systems (the heavily shaded portion of Figure 1.3). Beyond this core, sustainability science also includes the investigation of social systems alone, or environmental systems alone, to the extent that such investigation is motivated by efforts to address the challenges of sustainability (the lightly shaded portions of Figure 1.3).[g]

1.4.2 Integrative approach to understanding complex human-environment interactions:

A second, related, characteristic defining sustainability science is its integrative approach to understanding complex human-environment interactions. The nature and extent of this commitment can be thought of in terms of a full version of the matrix partially sketched in Figure 1.4.[16]

[Figure 1.4 (the Matson matrix) near here]

Here, the rows of the matrix represent dimensions of human well-being – the "what is to be developed" of Figure 1.1. The columns, in turn, reflect some of the planet's key life-support systems -- the "what is to be sustained" of Figure 1-1. The specific examples listed here are drawn from those most prominently noted as goals or targets in recent international declarations.[h] [i]

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[g] Partha has suggested that the italicized text that follows be inserted here. I have tried, but disagree. To me, the proposed text takes one very particular cut as "sustainability" and its study, picks a fight with it, and then introduces a very specific (economists') conceptualization of sustainability and sustainability science…. All right in the middle of what I intended as a much more general effort to define the nature of the field as use-driven research on H-E systems. In my view, it just doesn't fit. I do see the merits of getting some of the exciting issues we will be dealing with up front in this chapter, and have taken some of Partha's text into the intro of this section (1.4). More generally, however, I'd prefer to see this theme developed later in the book, as we turn to our view of the content (rather than the present boundaries) of sustainability science. Alternatively, I could see it inserted earlier in section 1.2 as one of the contemporary challenges of sustainability science. But I could be convinced otherwise, so leave the text here and invite others to comment. BC.

As an example, consider the notion of "strong sustainability" that was put forward by Pearce (1988) as requiring that society as a minimum maintains the stock of every natural resource. Pearce noted that the requirement is not only infeasible, but it also makes no sense. If a society were to abide by the requirement, it would leave all minerals untouched forever. However, there is a general point that the notion of strong sustainability draws our attention to, which is that every society can be said to have inherited a multitude of capital assets from their past, consisting of manufactured capital assets (roads, buildings, machinery), human capital (health, education, skills), knowledge (scientific, technological, cultural), and natural capital (ecosystems, animal and plant populations, micro-organisms, oil and natural gas). To various extents different types of capital assets are substitutable for one another in meeting human needs and preferences. When they are substitutable, a society can justifiably violate strong sustainability. What are those extents? One task of sustainability science is to uncover them.

[h] BC: Bob Kates has done research on these, eg. Parris and Kates (2003) "Characterizing and measuring sustainable development" (ARER 28:559-86), and Leiserowitz, Kates and Parris (2006), "Sustainability values, attitudes and behaviors" (ARER 31: 413-444). If we keep the figure, we should update to the specific findings of his work.

A great deal of research and innovation relevant to sustainability focuses on problems at the level of particular "cells" of Figure 1.4 (see the green circles). Examples include studies of how efforts to meet energy needs impact the climate system or, more rarely, how the climate system impacts people's abilities to meet their energy needs or, rarer still, the interactions between human efforts to meet their energy needs and the climate systems. More integrative work, often performed in the context of international assessments, can be seen as "summing" across individual rows or columns of the matrix (see the blue ovals on Figure 1.4). Thus, the International Assessment of Agricultural Science and Technology for Development[17] is essentially a "horizontal" study, evaluating the impact of different options for meeting food needs on, among other things, the environment. In contrast, the Intergovernmental Panel on Climate Change is essentially a "vertical" study, evaluating how efforts to achieve multiple human needs jointly affect climate, and how climate change will impact human activities. To the extent that such integrative assessments are driven by sustainability goals and examine the two way interaction of (some) efforts to meet human needs with (some) aspects of the earth's life support systems, they may be seen as potential contributions to sustainability science.

A more quintessentially sustainability science problem is that posed by the prospect of significant development of biofuels over the next decades. Bio-fuel developments could have immediate implications for society's abilities to meet human needs for at least energy and food and water, while at the same time having consequences for life support systems involving climate, biodiversity conservation, the hydrologic cycle and so on (see the red oval on Fig. 1.4). Studies meant to evaluate the prospects of promoting a sustainability transition through development and deployment of bio-fuel technologies therefore need to be conducted in an integrative manner that addresses the complex interactions occurring across multiple cells and rows of the Figure 1.4 matrix. In short, such studies need sustainability science.

1.4.3 Attention to the cross-scale dimensions of human-environment interactions

As noted earlier, questions of spatial and temporal scale pose an additional dimension of complexity that needs to be addressed rather than sidestepped if science is to support

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[i] Partha suggested inserted the following italic text here. I have moved it to several paras later. Others should help us figure out where it helps most.

We propose in later chapters that by sustainable development one should mean the protection and promotion of human well-being, where by human well-being we mean not only the well-being of the current generation, but also that of future generations. Just how that can be accomplished is the central problem of sustainability science. But a number of questions arise immediately. How should the well-beings of different persons (whether or not they are contemporaries) be aggregated? How do capital assets contribute to human well-being? What is the role of scientific and technological progress in improving human well-being? And what role do institutions play in enabling people to use the services that capital assets provide for maintaining and improving their lives?

As in other fields of inquiry, it pays to begin the study of these questions in a piece-meal way.

sustainability. Human and environmental systems interact across a variety of scales. As shown in Figure 1.5, these are generally mismatched.[18]

[Figure 1.5, scales of interaction, near here][j]

The mismatch means, for example, that given a spatial scale, social processes (be they economic or governmental) are likely to be too sluggish to deal easily with the rapid changes normally associated with atmosphere, but too rapid and impatient to recognize and manage many slow but important ecological changes (eg. soil depletion). Similarly, at a given temporal scale, social processes (eg. national governance) generally have too small a span of control to manage many atmospheric phenomena, but are simultaneously too coarse to deal easily with important ecological heterogeneities. Finally, human and environmental systems, whether coupled or relatively independent, exhibit the potential for both amplifying and damping small-scale fluctuations and innovations.

Much of the challenge of promoting sustainability ends up being about dealing with the cross-scale phenomena that characterize interactive social and environmental systems. Much scholarship tends to marginalize or assume away the complexity of cross-scale, interactive human-environment systems. Sustainability science strives to embrace and understand the consequences of such complexity, and to identify the scales at which it becomes most comprehensible and manageable.

1.4.4 Boundary-spanning work at the interface of research and practice. [k]

A fourth defining characteristic of sustainability science is its uneasy position at the interface of detached scholarship and engaged practice. In part, this is due to the simple observation that successful instances of promoting a sustainability transition – whether

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[j] BC: If we keep this figure, it needs updating and, even more, targeting on HE systems beyond climate. Input needed…

[k] BC: Partha raised the question in italics below about this section. I feel too close to the text to make the call, and therefore suggest leaving it to others. In particular, I know that Pam has used this formulation with a range of audiences (though presumably not the philosophers and sociologists of science to whom Partha refers) so ask her in particular to weigh in. More generally, I could do what Partha suggests here and either drop the rest entirely, or else move it to the planned Chapter 11 on "Methods of doing sustainability science", where it would fit well. I suggest that the deciding factor be whether any reasonable fraction of you find the details of the Stokes framework as presented actively helpful in writing your chapters. If you do, we keep it and just try to tighten it up. If you don't, we get rid of it altogether, or move it to Chapter 11. Let me know your thoughts.

Partha: *Do we really beed to go into Don Stokes and his classification? At the moment it reads a trifle precious (references to Einstein and Pasteur, and so on), at least it does to me. The classification may also be controversial among philosophers and sociologists of science. If it does, those passages would merely deflect attention from the substance of what we want to say. I wonder therefore whether it wouldn't be possible to present the idea that "pure and applied research" are interlinked in a deep way in sustainability science (ie they don't come sequentially, in either direction) in a briefer way and with but a bow to Stokes, without going into his classification in any detail. That said, I don't know how strongly you feel about it, which is why I haven't tampered with the text. But should you agree with me, it would be a matter of minutes before the section in question is pruned to its bare essence. I leave it to you to judge.*

through green revolution agriculture or green chemistry -- have generally needed to draw upon both generalizable findings derived from classical scientific research *and* context-dependent knowledge derived from practice and experience. In addition, however, the need for integrating knowledge and action arises from our incomplete understanding of the dynamics of coupled human-environmental systems. Very often, the only way that we can assess the validity of a new insight or the potential of a new innovation is to put it into practice as part of a real world management regime. Policy thus becomes a primary mode of experimentation, and learning-by-doing an inescapable component of strategies for linking knowledge with action to promote a sustainability transition. Finally, there are the more mundane issues associated with the previously noted need to integrate across social and natural science disciplines in order to provide useful knowledge for managing sustainability. For all these reasons, deep epistemological questions regarding the generalizability and reliability of knowledge produced through such hybrid mechanisms thus become central concerns of sustainability science, as do practical questions of adaptive management.[19] More broadly, scientists seeking to promote a sustainability transition need to develop an ability to span not only disciplines, but the barriers separating scholars from practitioners.

Sustainability science is thus best conceptualized as neither "basic" nor "applied" research.[20] Rather, it is an enterprise centered on the "use-inspired basic research" that the late Donald Stokes characterized as "Pasteur's Quadrant" of the modern scientific enterprise. It is worth reviewing Stokes' argument briefly for the insights it provides into how good sustainability science is likely to be conducted, and what resistance it is likely to encounter from more conventional approaches. Stokes argued that the conventional dichotomy of "basic vs. applied" research was neither historically justified nor empirically useful in making sense of science as it is actually practices. In its place, he presented substantial historical evidence that the two-dimensional classification shown in Figure 1.6a was both more realistic and more helpful.

[Figure 1.6a,b (Stokes static and dynamic) near here]

In this "Quadrant Model of Scientific Research", investigators are seen as making at least two choices rather than one in their choice of topics to pursue: first, whether the objective of the study is to produce useful knowledge or not; second, whether the objective is to produce generalizable knowledge or not. One diagonal of the resulting matrix defines the classic spectrum of basic research ("Bohr's Quadrant) vs. applied research ("Edison's Quadrant"). But there is another cell in the matrix that Stokes argues has been the source of much of the most productive science in history: the use-inspired basic research typified by Pasteur's simultaneous discovery of the practically important method for what we now call "Pasteurization" of milk at the same time he was inventing the germ theory of disease. As Stokes concludes, "the mature Pasteur never did a study that was not applied, as he laid out a whole new branch of science."[21] Similarly, sustainability science finds itself probing fundamental questions of complex adaptive systems, even as it seeks to design specific, context embedded solutions to problems of mixed-use forest management.

The implications of Stokes' insights for efforts to link knowledge with action in support of sustainability are profound. These implications can best be seen in a second diagram suggested by Stokes that traces the dynamic relationships among basic research, applied research, and the use-inspired basic research of Pasteur's Quadrant (see Figure 1.6b). In this view, basic research efforts to improve understanding generally evolve independently of applied research efforts to improve policy and technology. At key moments, however, efforts at "use-inspired basic research" provide a bridge between these two separate streams of work, promoting cross-fertilization and mutual enrichment. As suggested in Figure 1.6b, a defining characteristic of sustainability science is its work in this crucial bridging role, serving the quest for advancing both useful knowledge and informed action by creating a bridge between the two.

1.5 Our Emerging Agenda

As sustainability science has been conceived, born, and begun to mature over the last decades, it has been associated with its share of enthusiasms.[1] These include multiple varieties of Malthusianism, various typologies of creative destruction, ecological footprints, preoccupations with resilience, vulnerability, and complex systems, documentation of production-consumption chains, debates about market-based mechanisms, contested commons, induced innovations and institutions, and so on. Some of these ideas have been dropped, others have stayed to shape the field as it is today. Almost all have served to energize the debate and stimulate the parallel development of data, methods and concepts upon which such progress as we have had has built.

Almost certainly, as we look back in several years on the state of sustainability science today, we will be sobered by which of our own most beloved themes and theories have turned out to have no more permanence than some of the more transient obsessions noted above. Indeed, we have turned down the suggestion that the time is ripe for a formal textbook on the subject, arguing that the field is still sufficiently immature that efforts to stabilize and formalize it would likely retard progress rather than accelerate it. So why have we written the chapters that follow?

The simple answer is for the challenge and pleasure of learning from one another. Over the last several years, each of us has been involved with some of the others in joint efforts to shape the field of sustainability science. In the course of these collaborations, we learned something of the special perspectives that each of us brought to the field through some combination of our original trainings and subsequent research. We were pleased to discover a significant degree of common ground on which we could meet and, if not always agree, at least debate one another in a reasonably informed and critical way. At the same time, however, we were sobered to find how much of what one or another of us found utterly central to the field of sustainability science remained essentially unknown if not inaccessible to the rest of us. As we began an effort to systematically read and discuss key works that we recommended to one another, it rapidly became clear that the brute force approach that might have worked when we were graduate students facing an

[1] BC: Colleagues: Please add to or subtract from this list.

upper level research seminar had limited prospects of success among a group with an average age of XX years and barely a discipline in common. As an alternative approach, we therefore asked what we felt to be the truly essential concepts, cases and methods of contemporary sustainability science that ought to constitute the common heritage of anyone (such as ourselves) wanting to contribute seriously to the interdisciplinary collaboration and dialogue necessary for the maturing of the field of sustainability science. This monograph is our first attempt to answer that question.[m]

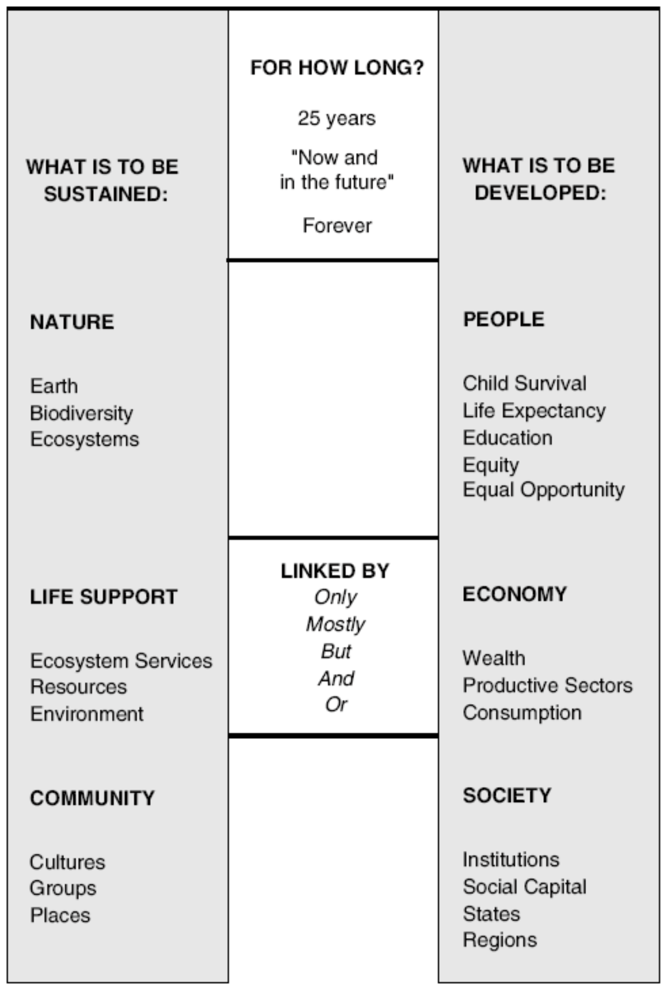
END

[m] BC: The chapter could end with an overview of the chapters to follow. Thoughts?

Figures

[See note[n]]

Figure 1.1: A classification of the many framings of sustainable development (National Research Council (U.S.). Policy Division. Board on Sustainable Development., 1999 , p. 24)



[o]

[n] I have erred on the side of inclusiveness, using most of the figures that have figured prominently in presentations that (especially) Pam, Bob and I have given on the topic of sustainability science. I suspect we should have fewer in the final draft. So let me know which are your most, and least, favorite.

[o] BC: We should think whether we want to update this to draw explicitly on the research reported in Parris and Kates (2003) "Characterizing and measuring sustainable development" (ARER 28:559-86), and Leiserowitz, Kates and Parris (2006), "Sustainability values, attitudes and behaviors" (ARER 31: 413-444). This might result in a comparable figure with a few changes, or – were we to want to be more 'modern' -- in a "tag cloud" of words or phrases found in the works they cite. A specific example of a modest change suggested by their work would be to take the "For how long?" question and rephrase its answers in terms of their "now" "MDG time of 2015", "2-generational time of 2050" and long time…. We also need to bring space into the figure, or explicitly leave it out.

Figure 1.2. Sustainability Science within a Divided World. A cartoon-like view of the sharp contrast in both perceptions and realities of resource distribution between countries of the 'north' and 'south'. The research of the “north” is global in orientation, theory-driven, and draws upon technological knowledge. The much smaller research effort of the “south” is local in orientation, action-driven, and draws upon traditional knowledge. The socio-economic, environmental, and knowledge dichotomies are exacerbated by the deepening 'digital divide'. (From Kates et al., 2001. Science 292: 641)

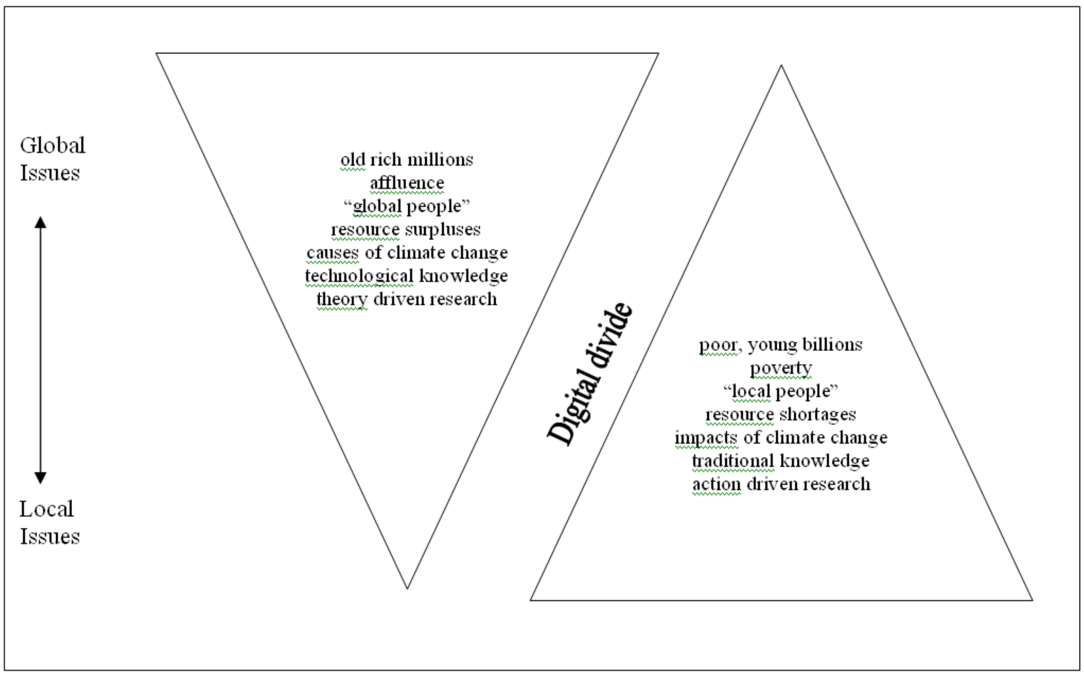


Figure 1.2: The domain of sustainability science

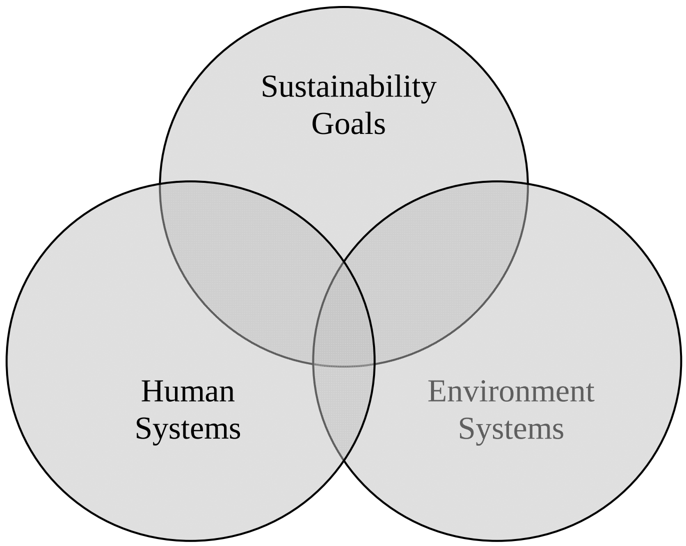


Figure 1.4: Interactions among the goals of sustainable development (derived from {National Research Council (U.S.). Policy Division. Board on Sustainable Development., 1999, p. 286, as modified by Pam Matson for AAAS 070214}

Life support systems → *Human needs* ↓	Atmosphere	Hydrosphere	Climate	Biodiversity	Others…
Food					
Energy					
Water					
Shelter					
Others…					

Figure 1-5: Complexities due to cross-scale phenomena in coupled human-environmental systems (Source: Clark, 1985)

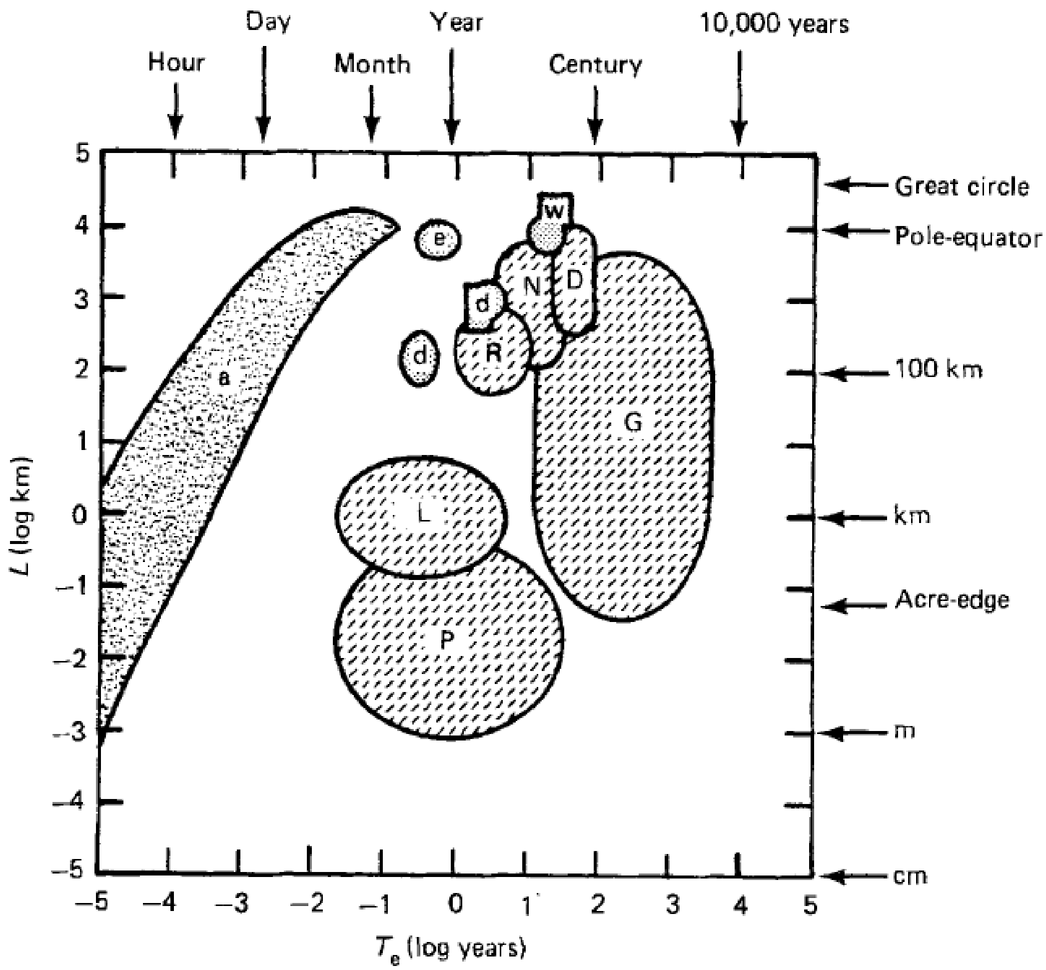
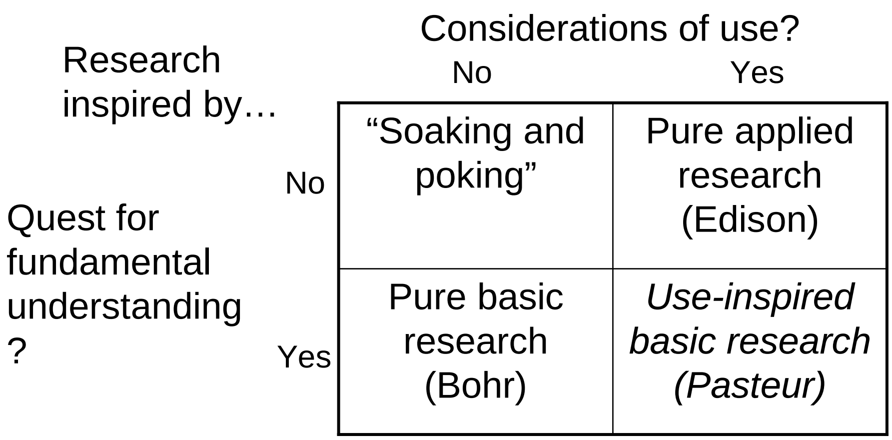


Fig. 7. Scales of interactions among climates, ecosystems, and societies. Stippled areas and lowercase letters represent climatic phenomena from Figure 3: (a) atmospheric phenomena, (e) El Niño, (d) drought, (w) warming. Diagonally shaded areas and uppercase letters represent social and ecological phenomena from Figure 6: (P) population ecology, (G) geographical ecology, (L) local farm activities, (R) regional agricultural development, (N) national industrial modernization, (D) global political/demographic patterns.

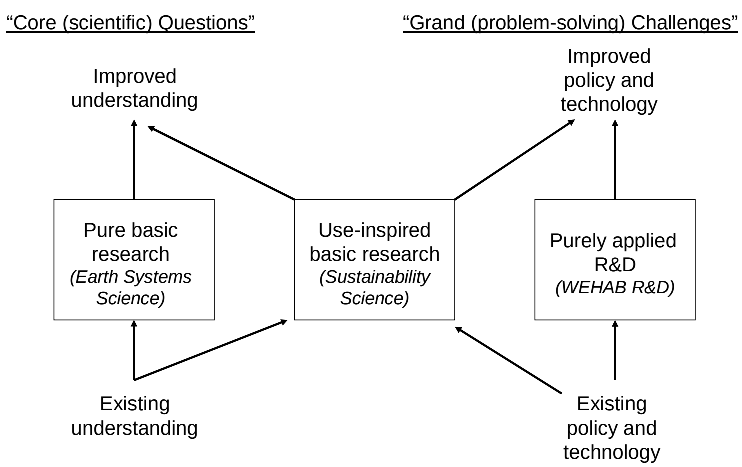
Figure 1-6:[p]

a) The Quadrant Model of Scientific Research



(redrawn from Stokes, 1997)

b) Dynamic model of sustainability science and innovation



(redrawn from Stokes, 1997)

[p] BC: Recall from the text note that Partha has queried whether the Stokes material does essential work here or, alternatively, could be dropped or moved to the methods chapter. Your views?

ENDNOTES (as references for paper; Footnotes are queries to authors)[q]

[1] WCED, 1987, p. 8.

[2] These different perspectives are dealt with in more detail in Parris and Kates (2003) "Characterizing and measuring sustainable development" (ARER 28:559-86), and Leiserowitz, Kates and Parris (2006), "Sustainability values, attitudes and behaviors" (ARER 31: 413-444).

[3] WDR, 2007. Ch. 2 < http://siteresources.worldbank.org/INTWDR2008/Resources/2795087-1192112387976/WDR08_04_ch02.pdf>

[4] World Bank, State Environmental Protection Administration of P.R. China. 2007. China cost of pollution: Physical and economic estimates. http://go.worldbank.org/FFCJVBTP40. Note that according to the World Bank, pollution and resource degradation cost the median country of the world around 1.5% of its GNP/yr, with more than ¼ of countries losing >5% of GNP/yr (World Bank. 2007. World Development Indicators. Table 3.15.) See also Lebanon and Tunisia: Owaygen, Marwan ; Larsen, Bjorn ; Sarraf, Maria. 2004. Cost of environmental degradation - the case of Lebanon and Tunisia. World Bank. http://go.worldbank.org/WW9Z8RT870 ; Columbia: World Bank. 2006. Colombia - Mitigating environmental degradation to foster growth and reduce inequality. http://go.worldbank.org/T3XEY9OGL0; Pakistan. World Bank. 2006. The cost of environmental degradation in Pakistan : an analysis of physical and monetary losses in environmental health and natural resources. http://go.worldbank.org/FBH9DFONU0; Morocco: World Bank. 2003. The Kingdom of Morocco: Cost assessment of environmental degradation. Report No 25992-MOR. http://siteresources.worldbank.org/INTMOROCCOINFRENCH/Data%20and%20Reference/20787156/259920ENGLISH010already0catalogued1.pdf .

[5] Zhou Shengxian, Minister, SEPA, quoted in *International Herald Tribune*. 2006. China offers environmental plan; focus is sustainable development. (Feb. 15, 2006). See also Economist Intelligence Unit, Forecast for China, Oct. 31, 2007. (http://www.economist.com/countries/China/profile.cfm?folder=Profile-Forecast)

[6] Such efforts go back at least to Alexander von Humboldt and his work of the early to mid 1800s, and include George Perkins Marsh and more recent groups of researchers writing in *Man's Role in Changing the Face of the Earth*, William L. Thomas, Jr., ed., with Carl O. Sauer, Marston Bates, and Lewis Mumford (The University of Chicago Press, Chicago, 1956) and *The Earth as Transformed by Human Action*, B. L.Turner II, William C. Clark, Robert W. Kates, John F. Richards, Jessica T. Mathews, and William B. Meyer, eds. (Cambridge University Press, Cambridge, 1990), pp. 25-39. See the recent perspectives on human-environment studies by B. L. Turner II and Robert W. Kates ("Contested identities: Human-environment geography and disciplinary implications in a restructuring academy" and "Humboldt's dream, beyond disciplines, and sustainability science: Contested identities in a restructuring academy," *Annals of the Association of American Geographers* 92(1): 52-74 and 79-81, respectively).

[7] Third World Network of Scientific Organizations (TWNSO), http://www.ictp.trieste.it/~twas/TWNSO.html; Commission on Science and Technology for Sustainable Development in the South (COMSATS), http://www.comsats.org.pk; Society for Research and Initiatives for Sustainable Technologies and Institutions (SRISTI), http://www.sristi.org/; South Center at http://www.southcentre.org/ (see particularly the *Elements for an Agenda of the South: Report of the NAM Ad Hoc Panel of Economists*, section 4 on "science and technology" at http://www.southcentre.org/papers/nam/namfinal-02.htm#P287_47302). See also policy statements by the International Foundation for Science (IFS), http://www.ifs.se/index.htm; the International Science Programme (ISP), http://www.isp.uu.se/Home.htm; and the Millennium Science Initiative (MSI), http://www.msi-sig.org/MSI-SIG_summary.htm.

[8] African Academy of Sciences' *Tunis Declaration: Millennial Perspective on Science, Technology and Development in Africa and its Possible Directions for the Twenty-first Century* (Fifth General Conference

[q] BC: Note that these endnotes are in rough form, with no attempt to be either parsimonious or to have things in a standard form. I will clean them up later, but would particularly welcome at this stage suggestions for what should be in the endnotes but isn't.

of the African Academy of Sciences, Hammamet, Tunisia, 23-27 April 1999), http://www.unesco.org/general/eng/programmes/science/wcs/meetings/afr_hammamet_99.htm.

[9] H. J. Schellnhuber and V. Wenzel, eds. 1998. "Earth System Analysis: Integrating Science for Sustainability." Berlin: Springer-Verlag; European Commission. 1998. "Fifth Framework Programme: Putting Research at the Service of the Citizen," http://www.cordis.lu/fp5/src/over.htm; S. Funtowicz and M. O'Connor, eds. 1999. "Science for sustainable development." Special issue of *International Journal of Sustainable Development* 2: 3.

[10] C. E. Rocha-Miranda, ed. 2000. "Transition to Global Sustainability: The Contributions of Brazilian Science." Rio de Janeiro: Academia Brasiliera de Ciências, http://sustainabilityscience.org/keydocs/brazilsci.htm; Series of Annual Reports by the German Advisory Council on Global Change (WGBU), particularly its *World in Transition: The Research Challenge, Annual Report 1996*. Berlin: Springer-Verlag, 1997, http://www.wbgu.de/wbgu_publications.html; United States National Research Council, Board on Sustainable Development. 1999. *Our Common Journey: A Transition Toward Sustainability*. Washington, D.C.: National Academy Press, http://www.nap.edu/catalog/9690.html; Science Council of Japan. 2000. *Towards a comprehensive solution to problems in education and the environment based on a recognition of human dignity and self-worth*. Science Council of Japan; Royal Society. 2000. *Towards sustainable consumption: A European perspective*. London.

[11] UNESCO. 1999. *World Conference on Science for the 21st Century: A new commitment*. http://www.unesco.org/bpi/science/content/press/anglo/4.htm.

[12] The Global Environmental Change Programmes have made "global sustainability" a center point of their research planning for the coming years (see IGBP. 2001. *Global change and the earth system: A planet under pressure*. IGBP Science Series, No. 4. Paris: ICSU, http://www.igbp.kva.se//uploads/ESO_IGBP4.pdf; and IGBP. 2001. *The Amsterdam Declaration on Global Change – Challenges of a Changing Earth*. Global Change Open Science Conference, Amsterdam, 13 July 2001, http://www.sciconf.igbp.kva.se/fr.html; Paris Workshop organized under the auspices of the Global Change Science Programmes on *Sustainable Development: The Role of International Science*. Paris, 4-6 February, 2002, (Bonn, IHDP, cited here as Global Change, 2002).

[13] Robert Watson, John A. Dixon, Steven P. Hamburg, Anthony C. Janetos, and Richard H. Moss. 1998. *Protecting Our Planet, Securing Our Future*. Nairobi: UN Environment Programme, http://www-esd.worldbank.org/planet/; Intergovernmental Panel on Climate Change. 2001. *Special Report on Climate Change and Sustainable Development, IPCC Plenary Seventeenth Session*. Nairobi, 4-6 April 2001, http://www.ipcc.ch/meet/p17.pdf; Millennium Ecosystem Assessment, http://www.millenniumassessment.org/en/index.htm. [Something needed on Millennium Ecosystem Assessment and Sustainability]

[14] These included

* a symposium hosted by the World's Scientific Academies' *Transition to Sustainability in the 21st Century* (Tokyo Summit of May 2000), http://www4.nationalacademies.org/intracad/tokyo2000.nsf/all/home;
* a series of regional workshops and consultations hosted by the international Initiative on Science and Technology for Sustainability (http://sustainabilityscience.org/ists; summarized in ICSU/ISTS/TWAS 2002. "Science and Technology for Sustainable Development". ICSU Series on Science and Technology for Sustainable Development, No. 9);
* International Council for Science. 2002. *Report of the Scientific and Technological Community to the World Summit on Sustainable Development*. ICSU Series on Science for Sustainable Development, No. 1. 20pp, http://www.icsu.org/Library/WSSD-Rep/vol1.pdf. ICSU and WFEO also prepared the follow-up document "Science and technology as a foundation for sustainable development: Summary by the scientific and technological community for the multistakeholder dialogue segment of the WSSD PrepCom IV meeting. (Report available at http://sustainabilityscience.org/ists/synthesis02/icsu_s+t_2pager_wssd-prepcom4.pdf; cited here at ICSU et al., 2002b).

[15] The contributions of these and other organizations working on improving the linkages between science and technology on the one hand, and the sustainable development agenda on the other, can be followed through the on-line "Forum on Science and Innovation for Sustainable Development" (http://sustainabilityscience.org) and the "Science and Development Network" (http://scidev.net).

[16] This matrix format was originally developed by Paul Crutzen and Tom Graedel in their contribution to my 1986 book "Sustainable Development of the Biosphere," modified by the NRC Board on Sustainable Development for its 1999 "Our common future" study, and applied to the present context by Pam Matson at the San Servolo workshop on Grand Challenges of Sustainability and, subsequently, her plenary address at AAAS.

[17] http://www.agassessment.org/

[18] I've used my own old material here, just because it's the one I know the genesis of that addresses temporal and spatial scales of social and environmental phenomena in the same study. [William C. Clark. 1985. Scales of climate impacts. Climatic change 7(1): 5-27.] But there are other candidates, including Fig. 14.13 in the Chapin/Matson/Mooney book on Terrestrial Ecosystem Ecology, and several parts of the Moran/Ostrom book "Seeing the forest and the trees," eg. Fig. 5.2 and several relevant figures and accompanying text of chapter 3 (Green, Schweick and Randolf), though these are more relevant to method than to causation. There is also a book on BRIDGING SCALES AND KNOWLEDGE SYSTEMS: Concepts and Applications in Ecosystem Assessment, edited by Walter Reid, Fikret Berkes, Thomas Wilbanks. 2006. Island Press that we may want to consult. Other suggestions?

[19] Many references to boundary work and adaptive management possible here. Also the older Parson-Clark paper from Gunderson and Holling on sustainable development as social learning. Favorites?

[20] This text is taken in large part from Clark, 2007 (PNAS editorial on Sustainability Science).

[21] Stokes, 1997, p. 13.