SUSTAINABLE DEVELOPMENT: EPISTEMOLOGICAL CHALLENGES TO SCIENCE AND TECHNOLOGY

Gilberto Gallopín, October 2004

INTRODUCTION

It has become evident that, despite important success in the comprehension and manipulation of many phenomena (particularly at molecular and lower levels) the prevailing scientific and technological approach is showing important deficiencies in the management of problems of "organized complexity" (Weaver 1948) typical of the field of sustainable development.

The present condition of the planet seems to be characterized by massive and deep changes spanning the local to the global scales, in its human and ecological components: on the one hand, the world now is moving through a period of extraordinary turbulence reflecting the genesis and intensification of deep economic, social, political, and cultural changes associated to the current techno-economic revolution. In addition, the speed and magnitude of global change, the increasing connectedness of the social and natural systems at the planetary level, and the growing complexity of societies and of their impacts upon the ecosphere, result in a high level of uncertainty and unpredictability, presenting new threats (and also new opportunities) for humankind.

On the other hand, the current trends are seen to be unsustainable, both ecologically and socially (UNEP 2002, UNCSD 1997). The need for a change in direction was officially recognized at the United Nations Conference on Environment and Development that took place in Rio de Janeiro in June 1992, and reconfirmed at the World Summit on Sustainable Development in Johannesburg in September 2002.

The complexity of the situations and problems is quickly increasing (Gallopín et al. 2001, Munn et al. 1999). This is due to a number of reasons, such as: *Ontological changes:* Human-induced changes in the nature of the real world, proceeding at unprecedented rates and scales and also resulting in growing connectedness and interdependence at many levels. The molecules of carbon dioxide emitted by fossil fuel burning (mostly in the North) join the molecules of carbon dioxide produced by deforestation (mostly in the South) to force global climate change; an economic crisis in Asia reverberates across the global economic system affecting far away countries. *Epistemological changes:* Changes in our understanding of the world related to the modern scientific awareness of the behaviour of complex systems, including the realisation that unpredictability and surprise may be built in the fabric of reality, not only in the microscopic world (i.e., the well-established Heisenberg uncertainty principle) but also at the macroscopic level, as described later. *Changes in the nature of decision-making:* In many parts of the world, a more participatory style of decision-making is gaining space, superseding the technocratic and the authoritarian styles. This, together with the widening acceptance of additional criteria such as the environment, human rights, gender equality, and others, as well as the emergence of new social actors such as the non-governmental organisations and transnational companies, is leading to an increase in the number of dimensions used to define issues, problems, and solutions, and hence to higher complexity.

At the same time, a growing feeling from many quarters that science is not responding adequately to the challenges of our times, and particularly, those posed by the quest for sustainable development, has become evident.

The recognition that a new "Social Contract for Science" is necessary to deal with the new planetary situation, that business as usual in science will no longer suffice, that the world today is a fundamentally different world from the one in which the current scientific enterprise has developed, has been coming from the mainstream scientific establishment itself (Lubchenco 1997). The challenge to focus on the linkages between the social, political, economic, biological, physical, chemical, and geological systems is seen as a current imperative; dynamic cross-systemic explanations are sought where static and reductionist models once prevailed (as emphasized by the Board of Directors of the AAAS - Jasanoff et al. 1997).

The theme was also the focus of the World Conference on Science that under the rubric "Science for the Twenty-First Century", met in Budapest in mid-1999 (ICSU 1999). The documents of the conference emphasized the need for a new relationship between science and society, for a reinforcement of scientific education and cooperation, the need to connect modern scientific knowledge and traditional knowledge, the need for inter-disciplinary research, the need to support science in developing countries, the importance of addressing the ethics of the practice of science and the use of scientific knowledge, and other important issues. However, the Conference did not discuss the possibility that science itself may also be in need of change (other than mentioning the need for integration and particularly for inter-disciplinary research between natural and social sciences).

However, the nature of the challenge posed by sustainable development is such that it is highly likely that deeper changes in the nature of the scientific enterprise will be required. Changes in the methods, criteria and conduit of science have happened before; science has been constantly evolving through its history. Academic, 'curiosity-driven' research gave way after WW II to 'industrialised' (Ravetz 1996) or 'incorporated' (Rose & Rose 1976) research as the leading form of S&T system. Its associated form of intellectual property, 'public knowledge', is rapidly being driven out of the leading fields (as biotechnology and information sciences) by 'corporate know-how'.

Those changes in science have not been independent of the unfolding of historical processes in the economic, technological, social, cultural and environmental domains. The changes reflect, and impinge upon, the social practice and the public image of science and the issue of 'quality assurance' of scientific understanding and research. A response to the need for socially relevant criteria for quality assurance has been the proposal of a "post-normal science" (Funtowicz & Ravetz 1992, 1993, 1999). Post-Normal Science has been developed to deal with complex science-related issues. In these, typically facts are uncertain, values in dispute, stakes high, and decisions urgent, and science is applied to them in conditions that are anything but "normal". For the distinction between "hard", objective scientific facts and "soft", subjective value-judgements is here inverted. Very often hard policy decisions must be made where the only scientific inputs available are irremediably soft.

To put the role and potentialities of Science & Technology for Sustainable Development (STSD) in the proper context, it should be noted that lack of scientific knowledge and understanding are not the only, and not even the major, determinants of the present mismanagement of the planet[1]. In fact, the deep-rooted ecological and social unsustainability of world development patterns reflect more the influence of vested interests, political myopia, societal inertia, international and national asymmetries of power, and the overlap of economic, ecological, cultural, political, social and demographic processes generated by the intersection of globalization with the growing global ecological interdependence, than the limitations of scientific

[1] The clearly insufficient global response to the threat of climate warming, despite the wide scientific agreement and international recognition of the seriousness of the problem, testifies to this.

understanding. This means that the success or failure of the attempts to move towards sustainability will be to a very large degree contingent on the political processes towards joint action.

Having said that, S&T can play a crucial role in charting the dangers and opportunities of the road ahead and providing usable knowledge for good stewardship (Kates et al. 2001, ICSU 2002; see also www.sustainabilityscience.org); the S&T system affects directly "Knowledge and understanding" (one of ultimate drivers of the sustainability transitions -Raskin et al. 2002) and also operates indirectly through other ultimate and proximate drivers. The rest of this paper will concentrate on this role.

NODAL ISSUES FOR STSD

The problematique of sustainability exhibits a number of traits that suggest that changes (or at least serious re-examination) of some fundamental aspects of scientific and technological research will be needed in order to improve the capacity of the S&T systems to better contribute to sustainable development. The following are some of these areas that might be called 'nodal' in the sense that advances made there would reverberate through many strands of the fabric of scientific knowledge.

1. Unit of analysis.

Human activities (social, economic, etc.) and the environment are strongly coupled systems and therefore jointly determined. Besides, these systems are nonlinear, complex, and self-organizing. A clear implication of this for STSD regards its appropriate unit of analysis[2]. It has been argued (Gallopin et al. 2001) that the coupled socio-ecological system (SES, Gallopín 1991) at different scales represents the fundamental unit of sustainable development and hence the unit of analysis of choice[3].

This non-decomposability of many core issues of sustainable development is beautifully illustrated by a set of quite simple models of lake-and-managers SES(Carpenter, Brooks and Hanon 1999), extensible to other ecosystems under management (Carpenter, Brocks and Ludwig 2002). The analysis of the behavior of these coupled models provided various insights of critical strategic importance for the sustainable management of shallow lakes. One of these was the demonstration that unwanted collapse can occur even if the ecosystem dynamics are perfectly known and management has perfect control of the human actors. It was also clear that these insights could not have been obtained by analyzing the lake dynamics and the societal dynamics separately.

2. Integrated research

The fact that the basic unit of observation includes both human and natural subsystems makes STSD interdisciplinary of necessity. Integrative research is obviously not just about adding more variables, or broadening the scope to include a larger portion of reality; integration of scientific research in terms of relevance for decision–making requires a *holistic approach* (looking at wholes rather than merely at their component parts), and an *interdisciplinary research style*.

Looking at the whole from a scientific viewpoint includes the identification and understanding of the most important causal interlinkages and, more difficult, understanding the dynamics of the system. Nonlinearities and self-organization play a crucial role in the generation of the

---

[2] The basic entity being analyzed by a study and for which data are collected in the form of variables (standard definition).
[3] This, of course, does not exclude the use of other analytical units for special purposes and particular studies.

counterintuitive behavior typical of many complex systems. This implies that it is necessary to investigate how different components and processes interact functionally to generate system-level responses and emergent properties, how the system adapts and transforms itself. This is an area for deep basic and applied research. This understanding is currently much more developed for the biophysical components of the SESthan for the anthropic ones, and both are more advanced than the understanding of the behavior and dynamics of the coupled socio-ecological system.

Interdisciplinary research is often required to obtain integration (ICSU 1999, Kates et al. 2001). As with the case of integration, there is a large gap between the rhetoric and the practice of interdisciplinary research. It is not enough to put together a group of researchers from different disciplines to work in a project; it is also necessary to establish a true dialogue between the disciplines, an iterative and interactive process of mutual education and learning. This transformative dialogue is what differentiates interdisciplinary from multidisciplinary research. Some identified critical factors for interdisciplinary work are: nature of the problem addressed; psychological and cultural factors; team organization; style of interaction (of communication and of leadership); institutional factors; and social, economic, and political factors. Education and training in how to perform interdisciplinary research is often lacking in most education systems; and this is an area in which changes are required.

3. Criteria of truth

The criteria used to decide what is "true" (or better, the falsification criteria used to reject scientific hypothesis) and other rules of science need to be reexamined for the adequacy for STSD. The question of to what degree (if any) and in which way the existing rules of scientific enquiry, criteria of truth, and practice of science need to be modified in STSD is an important one. Research frequently focuses on narrow, quantifiable aspects of the problems, thus inadvertently excluding from consideration potential interactions among different components of the complex biological systems of which humans are a part.

Occam's Razor is a good example of a scientific guideline that might be changed in the new context. The rule as usually stated "one should not increase, beyond what is necessary, the number of entities required to explain anything" is still valid in dealing with a vastly complex unit of analysis, but the characterization of "what is necessary" may need drastic broadening to account for the interlinkages between the object of study and other parts of reality, in line with Einstein's aphorism "Everything should be made as simple as possible, but not simpler."

One example of the differences involved in current science that is applicable to STSD is the tension and shifting dominance between the analytical and the integrative streams in Ecology (Holling, 1998). The differences between streams include basic assumptions on causality, criteria of truth, epistemological acceptability and evaluation criteria, among others (see Table I).

The *analytical stream* focuses in investigating parts, and it emerges from traditions of experimental science where a narrow enough focus is chosen in order to pose hypotheses, collect data, and design critical tests to reject invalid hypotheses. Because of its experimental base, the chosen scale typically has to be small in space and short in time.

The premise of the *integrative stream* is that knowledge of the system is always incomplete. Surprise is inevitable. There will rarely be unanimity of agreement among peers —only an increasingly credible line of tested argument. Not only is the science incomplete, but the system itself is a moving target, evolving because of the impacts of management and the progressive expansion of the scale of human influences on the planet.

This dualism between analytical and integrative approaches is a particular manifestation of the broader differences between the analytical and systemic approaches (Saner 1999, De Rosnay 1975).

4. Inclusion of qualitative variables

Too often non-quantifiable factors are excluded from consideration, because the methods used (e.g. classical computer simulation models) cannot incorporate qualitative factors or worse, sometimes anything not quantitative is simply rejected as non-scientific.

However, the dynamics of the SES depends on a large number of complex processes, many of which are not yet quantified, and others (such as cultural processes determining social values) may not be quantifiable even in principle. Yet, the qualitative factors can be as important or more than the quantitative ones in determining the behavior of the SES.

Two comments are relevant here. First, in a number of cases rigorous (even mathematical) analysis of qualitative factors can be performed (Petschel-Held et al. 2000, Gallopín 1996, Puccia and Levins 1987). Second, even in the cases where a rigorous treatment of qualitative factors can not be performed, they can be included (at least in narrative form) in the overall conceptualization of the problem or issue, insofar as they are deemed to be causally important. This is often the case with many cultural, social, and political factors that may even be the dominant element in a problem.

In conclusion, a strong push towards developing rigorous methods and criteria to deal with qualitative information will be required for the S&T system to be better able to serve the management of the ES.

5. Dealing with uncertainty

STSD confronts many sources of uncertainty; some of them are reducible with more data and additional research, such as uncertainty due to random processes (amenable to statistical or probabilistic analysis), or that due to ignorance (because of lack of data or inappropriate data sets, incompleteness in the definition of the system and its boundaries, incomplete or inadequate understanding of the system). When we consider the complexity of the SES involved in sustainable development problems, it is clear that those sources of uncertainty can be insurmountable in practice, even if they may not be so in principle. Moreover, fundamental, irreducible uncertainty may arise from non-linear processes (e.g. chaotic behavior), in the processes of self-organisation (e.g., Prigogine showed that the new systemic structure arising from the reorganization of the elements of a dissipative system can be inherently unpredictable even in simple chemical systems) and through the existence of purposeful behavior including different actors or goal-seeking agents. Furthermore, complex 'self-aware' (or 'reflexive') systems, which include human and institutional subsystems, are able to observe themselves and their own evolution thereby opening new repertoires of responses and new inter-linkages. In those systems, another source of "hard" uncertainty arises; a sort of "Heisenberg uncertainty" effect, where the acts of observation and analysis become part of the activity of the system under study, and so influence it in various ways. This is well known in reflexive social systems, through the phenomena of "moral hazard", self-fulfilling prophecies and mass panic (Gallopin et al. 2001).

One implication of this situation is that, even in the case of the relatively simpler biogeophysical component of the SES, understanding and insight is absolutely not synonymous with capacity to predict. Equally, awareness of risks is not synonymous with capacity to reduce or control the risks.

Therefore, an engineering approach to sustainability seeking to anticipate all critical situations and building the "perfect model" may not only be doomed to fail, but it could also be exceedingly dangerous for human civilization. The scientific quest for even better understanding and predictive capacity must be complemented by new research and priority-setting strategies that do not merely recognize uncertainty, but even embrace it, becoming part of the process of change as well as probing its transformation possibilities.

6. Incorporation of other knowledges

Reaching a useful and usable understanding of the sustainability, dynamics, vulnerabilities, and resilience of SES will require a strong push to advance focused scientific research, including building up classical disciplinary knowledge from the natural and the social sciences, and an even stronger development of interdisciplinary and transdisciplinary research (Schellnhuber and Wenzel 1998, Kates et al. 2001, ICSU 2002, Gallopín 1999).

But the challenge goes beyond scientific knowledge itself; many discussions and consultations on the role and nature of S&T for sustainable development emphasized the importance of incorporating knowledge generated endogenously in particular places and contexts of the world, including empirical knowledge, knowledge incorporated into technologies, into cultural traditions, etc. (ICSU 2002).

Science for sustainable development creates historic opportunities to use inputs from other forms of knowledge, by exploring the practical, political and epistemological value of traditional/local/empirical/indigenous knowledge; the incorporation of "lay experts" in the processes of public decision-making and the research agenda makes good sense in terms of using the expertise that is available, even when it is found in unexpected places.

We lack, however, a comprehensive framework regarding the multiplicity of local knowledges that could be used as inputs for scientific research and have thus far remained largely unknown to research systems as potential sources of innovation. The key knowledge generated by the lay expert is often contextual, partial and localized, and has not been easy to translate or integrate into a more scientifically manageable conceptual framework.

The participation of other social actors, in addition to S&T professionals, at the different phases of the scientific and technological research process and in related decision-making, can be crucial for a number of reasons (ECLAC 2002): *Ethical*. The right of the sectors affected to participate in decisions that have a bearing on their wellbeing (such as the installation of a nuclear or chemical plant in their area) is undeniable. *Political*. It is essential to guarantee society's control over research and development outputs, particularly those that have an impact on health and the environment. *Pragmatic*. In certain cases (e.g. new agricultural technologies, new health treatments), it can be especially important to encourage the social groups who are the intended beneficiaries to have a sense of ownership over the scientific and technological knowledge. For this it may be essential to engage these groups at the R&D phases in order to incorporate their interests and perceptions into the process. *Epistemological*. The complex nature of the sustainable development problematique, in which biogeophysical and social processes usually overlap, often makes it necessary to consider the different perceptions and objectives of the social actors involved. Also, it is increasingly clear that it is important to combine empirical knowledge built up by traditional farmers, other cultures and ethnic groups, with modern scientific and technical knowledge (the constructive combination of diverse types of relevant knowledge).

The need to include other knowledges and perspectives in the S&T enterprise poses important methodological challenges to S&T for sustainable development, as it requires the adoption of criteria of truth and quality that are broader than those accepted today by the S&T community, yet not less solid and rigorous (otherwise, the relevance and credibility of S&T could be gravely damaged).

To what degree, in which situations, what type and in what form alternative knowledges will need to be incorporated into STSD are open questions that need to be addressed.

7. Interparadigmatic dialogues

Given the need to foster a sense of common purpose and common understanding among different social actors (government, business, labor unions, NGOs, community organizations, political parties, minority groups, etc.) if sustainable development is to be reached, it will be necessary to move beyond traditional disciplinary thinking, and even beyond interdisciplinarity, towards intercultural, interinstitutional, interjurisdictional and transdisciplinary exchanges (between scientists and non-scientists, between the modern and the traditional, between the north and the south). This will require a constructive communication and cooperation between people having very diverse mindsets, world visions, and specific objectives. In short, what Mushakoji (1979) called an *interparadigmatic dialogue*.

Interdisciplinary activities in general are defined as involving people from different disciplines, working interactively towards a common purpose; in most cases the disciplines are scientific specializations, or at least professional areas, and therefore the participants share some kind of basic platform of beliefs (e.g. trust in the scientific method). The activities are typically directed to reach a common conceptualization of the issue or problem, and to combine the different knowledges and skills in order to reach the agreed goal (Thompson 1990).

Interparadigmatic activities (both for research and action) involve a more formidable challenge. A common platform of beliefs cannot be automatically assumed or imposed, and even the sense of common purpose may be missing, at least initially. In such cases, the issue is not only how to articulate different worldviews, but also different (and legitimate) goals. The reduction of the plurality of viewpoints and interests to a single format (e.g., a mathematical model, a narrative representation, etc.) or to a single goal is neither possible nor desirable. The analysis of the objective and subjective conditions and approaches that can generate useful results in those situations, and the experimentation with the approaches, is an important component of the new kind of long-term research that is needed for STSD.

8. Science/Policy Interface

For STSD to be used effectively in the quest for sustainability, the interface between science and policy needs to be better understood. For some scientists, the problem with the utilization of science by policy is that policy-makers neither listen to, nor understand, scientists. Conversely, some policy-makers see scientists as a closed community unable to get down to earth or even to agree among themselves. An important requirement for an effective dialogue, for both scientists and policy-makers, is to realize that both communities have much to learn from each other in addressing problems involving sustainable development, and that both are required in the quest for sustainable development. The basis for the dialogue must be the recognition of the real differences in criteria and constraints exhibited by the two communities, which make them almost to appear as two different sub-cultures. For instance, scientists (particularly those working in the analytical streams of science) typically dislike to make conclusions and offer recommendations until they are satisfied that all necessary data have been collected and alternative hypotheses have been disproved; they also reject subjectivity. By contrast, policy-makers are required to act when needed even if scientific knowledge is seriously incomplete; and the incorporation of subjective information and value judgments is part of their trade.

Science/Policy dialogues are one of the basic loci of integration between understanding and action. Mechanisms to implement the dialogue and to utilize science for policy must include the capacity to make responsible judgment and adequate interpretation of the evidence. The fact that the high complexity of SES and their natural and societal subsystems implies a (often high) degree of irreducible uncertainty should not lead to policy paralysis. On the other hand, scientific uncertainty should not be read as total ignorance and a license for "anything goes" in the policy realm. Sometimes policy-makers, and particularly the powerful lobbies fighting for their interests, are only too happy to make this interpretation.

However, it must be recognized that in many cases scientific research is not producing the kind on understanding usable by policy-makers (Baskerville 1997). Sometimes scientific questions are posed too narrowly, the scales of work are incommensurable with those required for decisions, and the policy concerns are not acknowledged.

One way of dealing with this problem is to involve policy makers (personally or, at least, through their technical advisors) at the beginning of a scientific enterprise, to identify questions, variables and indicators usable for policy making. Including them from the beginning usually makes it easier to provide policy relevant knowledge, while trying to include them in late stages is usually much more difficult.

Another important reason for early dialogues between science and policy is to ensure that the potential public impact of the research is considered with sufficient anticipation (e.g. by researching risk-avoiding strategies at the same time that risks are investigated).

Innovative experiments on how to generate a dialog and indeed a partnership between Science and Policy are needed. One of those new attempts is the "Science and Policy Partnership for Sustainability" described online at http://www.consecol.org/Journal/editorial/spps.html

9. Stakeholder involvement

The possibility of the S&T system to contribute critically to the sustainability transition is connected to its capacity (and willingness) to incorporate the perspectives and concerns of the major stakeholders involved, to insure the relevance of the orientation of research to collective decision making.

This will require the involvement of scientists and technologists in broad processes of consultation and dialogue with the relevant stakeholders. One useful model (for the global climate dimension) has been the Intergovernmental Panel on Climate Change (IPCC)[4], involving sustained bi-directional interactions between the S&T community and the policy community.

The building up of the collective will and the collective institutional mechanisms required is essentially a political task, but one in which the S&T system needs to play a facilitating role. One possible direction is the involvement of the S&T community with policy-makers and stakeholders in the construction of alternative scenarios, making use of available and *ad hoc* simulation models, qualitative analysis, and goal-setting to explore alternative future trajectories of the relevant SES (Schwartz 1991, Gallopín et al. 1997, Cosgrove and Rijsberman 2000). This can be very powerful in making clear uncertainties and irreversibilities (biophysical and social) that are critical for humankind (thus helping to shape the research agenda) and the magnitude and complexity of the problem that requires the reconciliation of conflicting and disparate interests.

10. Dealing with multiple scales

[4] http://www.ipcc.ch/

Many complex systems are hierarchic, in the sense that each element of the system is a subsystem of a smaller-order system, and the system itself is a subsystem of a larger order "supra-system". The important point is that in many complex systems there is strong coupling between the different levels and therefore the system must be analyzed or managed at more the one scale simultaneously. But systems at different scale levels have different sorts of interactions, and also different characteristic rates of change. Therefore it is impossible to have a unique, correct, all-encompassing perspective on a system at even one systems level. The challenge involves the treatment of cross-scale dynamics, as well as the need to articulate (o at least make compatible) actions at different scales from the local to the global.

SOME TRAITS OF A S&T SYSTEM FOR SUSTAINABLE DEVELOPMENT

A S&T system internalizing the set of challenges discussed before would look quite different than today's dominant model.

It would be much more exploratory, receptive to alternative ideas, and visibly more holistic (but not less rigorous) than today. Embracing uncertainty and incorporating the qualitative will lead to enormously broadening the universe of solutions (and of questions); new large areas of research will open up. Its openness to other forms of knowledge, the interaction with other world-views, with the problems faced by decision-makers, and with stakeholders, would result in new, richer ways to set research priorities.

The sustainability S&T system would be exploring, applying, and teaching, a constellation of tools and methods rather than relying on a narrow set of models and tools; these tools and methods would be articulated through the search for unifying holistic principles. Flexible international research cooperation networks would be multiplied and strengthened, and interconnected with action-oriented local, regional and global networks, providing indicators of progress towards sustainability, research results, and capacity-building to policy-makers and the civil society, thus supporting the unfolding of the collective will and capacity to steer the trajectories of the SES toward sustainable development.

The emphasis on interdisciplinary activities and the opening to plural knowledges and perspectives would have large consequences for the education and training of the new generations of scientists, as well as for the forms of communicating and link scientific understanding. Schellnhuber (1999), writing in the context of planetary sustainability,posits there are three distinct ways to achieve holistic perceptions of the "Earth System": the *'bird-eye' principle* (observing from space), the *digital-mimicry principle* (constructing computer simulation models), and the '*Lilliput' principle* (building microcosms). The development of STSD might make possible the growth of a fourth way, the *'direct apprehension'* principle, based on more direct perception of the operations of wholes, combined with deep understanding of the workings of complexity. This would be a type of pattern-recognition that can be trained in much the same way people learn to identify statistical regularities in a set of points plotted in a chart. This would be supported by advances in the organization, presentation and visualization of information, making use of rational and emotional mechanisms of comprehension, combining cognitive theories with scientific understanding of SES.

REFERENCES

Baskerville, G.L. 1997. Advocacy, science, policy, and life in the real world. Conservation Ecology [online] 1(1): 9. URL: http://www.consecol.org/vol1/iss1/art9

Carpenter, S., W. Brock, and P. Hanson, 1999. Ecological and Social Dynamics in Simple Models of Ecosystem Management. Conservation Ecology 3(2): 4. [online] URL: http://www.consecol.org/vol3/iss2/art4

Carpenter, S., W. Brock, and D. Lutwig. 2002. Collapse, Learning, and Renewal. Chapter 7 in: Gunderson, L.H. and C.S. Holling (Eds.) Panarchy. Understanding Transformations in Human and Natural Systems. Island Press, Washington.

Cosgrove, W.J. and Rijsberman, F.R. 2000. World Water Vision: Making Water Everybody's Business. Earthscan Publishing, London.

De Rosnay, J. 1975. "Le macroscope: vers une vision globale". Ed. Du Seuil, Paris.

Economic Commission for Latin America and the Caribbean (ECLAC). 2002. *Science and Technology for Sustainable Development. A Latin American and Caribbean Perspective. Latin American and Caribbean Regional Workshop on Science and Technology for Sustainable Development, Santiago, Chile, 5-8 March 2002*. Report on the Latin American and Caribbean Regional Workshop on Science and Technology for Sustainable Development. Series Seminars and Conferences No. 24.

Funtowicz, S. & J. Ravetz. 1992. "Three Types of Risk Assessment and the Emergence of Post-Normal Science." in S. Krimsky and D. Golding (Eds) Social Theories of Risk. pp. 251-273. Greenwood: Westport CT.

Funtowicz, S. & J. Ravetz. 1993. "Science for the Post-Normal Age." Futures 25 (7): 735-755.

Funtowicz, S. & J. Ravetz. 1999. "Post-Normal Science - an insight now maturing." Futures 31(7): 641-646.

Gallopín, G.C. 1991. "Human dimensions of global change: linking the global and the local processes". Int. Social Science Journal 130: 707-718.

Gallopín, G.C. 1996. "Environmental and sustainability indicators and the concept of situational indicators. A systems approach." Envir. Modell. & Assessment 1: 101-117.

Gallopín, G.C. 1999. "Generating, sharing and utilizing science to improve and integrate policy". Internat. J. of Sustainable Development 2(3): 397-410.

Gallopín, G.C., S. Funtowicz, M. O'Connor, and J. Ravetz. 2001. Science for the twenty-first century: from social contract to the scientific core. Int. Journal Social Science 168: 219-229.

Gallopín, G. A. Hammond, P. Raskin and R. Swart. 1997. Branch Points: Global Scenarios and Human Choice. Stockholm Environment Institute; Stockholm.

Gunderson, L.H. and C.S. Holling (Eds.) 2002. Panarchy. Understanding Transformations in Human and Natural Systems. Island Press, Washington.

Holling, C.S. (Ed.) 1978. "Adaptive Environmental Assessment and Management". Wiley, Chichester.

Holling, C.S. (1998), "Two Cultures of Ecology", Conservation Ecology (online) 2 (2): 4 (http://www.consecol.org/vol2/iss2/art4).

ICSU (International Council of Scientific Unions). 1999. Special Issue of Science International. September 1999. Paris: ICSU.

International Council for Science (ICSU). 2002. ICSU Series on Science for Sustainable Development. No. 9: Science and Technology for Sustainable Development.

Jasanoff, S. et al. 1997. "Conversations with the Community: AAA and the Millennium." Science 278: 2066-2067.

Kates, R. W. et al. 2001.Sustainability Science. Science 292: 641-2.

Kennedy, D. 2001. "Black Carp and Sick Cow"; Science **292**: 169.

Lubchenco, J. 1997. "Entering the Century of the Environment: A New Social Contract for Science." Science 279: 491-497.

Munn, T., A. Whyte & P. Timmerman. 1999. “ Emerging Environmental Issues: A Global Perspective of SCOPE.

Mushakoji. K.1979. "Scientific Revolution and Inter-Paradigmatic Dialogues”. The United Nations University. Tokyo, Manuscript, 30 pp.

Petschel-Held, G., et al. 2000. Syndromes of Global Change. A qualitative modelling approach to assist global environmental management. Environmental Modeling and Assessment 4: 295-314.

Puccia, C.J. and R. Levins 1987. Qualitative Modeling of Complex Systems. Harvard Univ. Press, Cambridge.

Raskin, P., et al. 2002. Great Transition. The Promise and Lure of the Times Ahead. Stockholm Environment Institute, Boston.

Ravetz, J. 1996. Scientific Knowledge and its Social Problems. New Jersey: Transaction.

Rose, H. & S. Rose. 1976. The Political Economy of Science. London: Macmillan.

Saner, M.A. 1999. Two cultures: not unique to ecology. Conservation Ecology 3 (1): r2 [online] URL: http://www.consecol.org/vol3/iss1/resp2

Schellnhuber, H.J. (1998), Earth System Analysis –The Scope of the Challenge, in: Schellnhuber, H.J., Wenzel, V. (Eds.), Earth System Analysis: Integrating Science for Sustainability, Heidelberg: Springer.

Schellnhuber, H.J. (1999), Earth System Analysis and the second Copernican revolution. Nature 402: C19-C23.

Schellnhuber, H.J., Wenzel, V. (Eds.), 1998. Earth System Analysis: Integrating Science for Sustainability, Heidelberg: Springer.

Schwartz, P. 1991. The Art of the Long View. New York: Currency Doubleday.

Thompson, K.J. 1990. Interdisciplinarity. History, Theory and Practice. Wayne State University Press, Detroit.

United Nations Commission on Sustainable Development (UNCSD). 1997 Critical Trends: Global Change and Sustainable Development .United Nations, New York.

United Nations Environmental Program (UNEP). 2002. Global Environment Outlook 3 (GEO-3). UNEP.

Walters, C. 1986. “Adaptive Management of Renewable Resources”. MacMillan, New York.

Walters, C. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology [online]1(2):1. URL: http://www.consecol.org/vol1/iss2/art1.

Weaver, W. 1948. “Science and complexity”. Am. Sci. 36: 536-544.

Table I

COMPARING THE TWO STREAMS OF THE SCIENCE OF ECOLOGY

Attribute	**Analytical**	**Integrative**
Philosophy	•narrow and targeted •disproof by experiment •parsimony the rule	•broad and exploratory •multiple lines of converging evidence •requisite simplicity the goal
Perceived Organization	•biotic interactions •fixed environment •single scale	•biophysical interactions •self–organization •multiple scales with cross scale interactions
Causation	•single and separable	•multiple and only partially separable
Hypotheses	•single hypotheses and nulls rejection of false hypotheses	•multiple, competing hypotheses •separation among competing hypotheses
Uncertainty	•eliminate uncertainty	•incorporate uncertainty
Statistics	•standard statistics •experimental •concern with Type I error (in hypothesis testing, rejecting the proposition when it is true)	•non–standard statistics • concern with Type II error (failing to reject the proposition when it is false)
Evaluation goal	•peer assessment to reach ultimate unanimous agreement	•peer assessment, judgment to reach a partial consensus
The danger	•exactly right answer for the wrong question	•exactly right question but useless answer

Source: Holling (1998).