The participatory design of an ecosystem approach to monitoring in support of sense-making: What's the Point?

by

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A thesis
presented to the University of Waterloo
in fulfilment of the
thesis requirement for the degree of
Master of Environmental Studies
in
Environment and Resource Studies

Waterloo, Ontario, Canada, 1999

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Abstract

Environmental monitoring initiatives are typically conceived as strictly scientific affairs designed to provide support for managerial decision-making; as a consequence most initiatives are centered on a formal mandate or an overarching mission statement that provides direction for monitoring activity. But official frameworks tend to marginalize lay perspectives as experts pursue disciplinary rigor at the expense of public input, a situation not in keeping with the spirit of the biosphere reserve concept. This thesis argues that an alternative design approach that reaches beyond scientists and resource managers is necessary.

Environmental monitoring under an ecosystem approach is subject to scientific, social, and bureaucratic demands that defy easy disentanglement. A medley of factors influence how data are collected, interpreted, and used; neglect of these 'soft' dimensions runs the risk of failing to win the enduring support of stakeholders. There is a need to coordinate activity and to partially align multiple perspectives—this is the 'soft underbelly' of integrated monitoring that gets short shrift in most designs.

While there is much monitoring being done in and around the Long Point World Biosphere Reserve, there is little coordination among monitoring groups and no obvious way to combine disparate data sets in a meaningful way. This thesis describes the elements of a locally-sensible framework for monitoring practice that is mainly concerned with trying to make sense of confusing and ambiguous situations; it strives to integrate the *why*, *what*, and *how* of monitoring in as transparent a manner as possible by crafting 'boundary objects' that help to congeal understanding and provide centers of coordination. Using principles of participatory design in the soft-systems tradition, the overall intent is to primarily support sense-making, not decision-making; to generate searching questions, not final solutions; to facilitate learning, not control.

Acknowledgments

I owe thanks to many people. The forbearance of my thesis committee (James Kay and George Francis) as I wended my way through the Library of Congress classification system was nothing short of astonishing—the long leash was deeply appreciated, as were the innumerable suggestions along the way. The many rousing discussions I enjoyed with members of our graduate discussion group (aka the “Dirk Gently Gang”) also helped to crystallize many half-formed notions.

I am indebted to the Long Point World Biosphere Reserve Foundation, who invited me to contribute to their deliberations and provided extra help in the form of monies for travel and materials. I extend kudos to Rhona for her stalwart patience, notwithstanding her occasional sigh of exasperation upon gazing at the self-replenishing mass of books and papers that crowded my workspace. And my thanks to the folk who generously donated their time and thoughts during the interview portion of this study.

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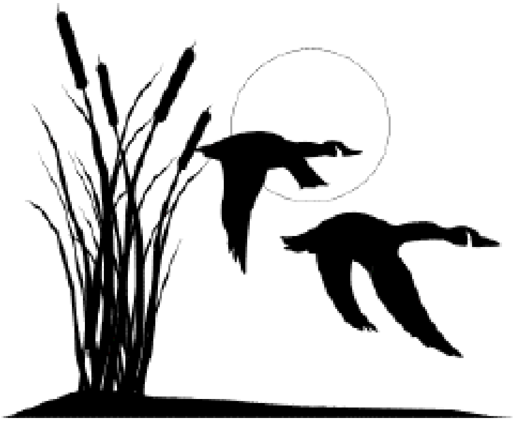

Chapter 1

Introduction: Confessions of a gadfly

All possibility of understanding is rooted in the ability to say no.

Susan Sontag,
On Photography

1.1 Who's afraid of epistemology?

In November of 1991 a claim was staked by global change scientists gathered in Vienna by the International Council of Scientific Unions to prepare for the 1992 UNCED (the "Earth Summit") in Rio de Janeiro:

> All components of the Earth System (including atmosphere, ocean, land surface, cryosphere, hydrosphere, and biosphere) must be monitored on a global basis and in sufficient detail as a basis for detecting and predicting environmental change. This requires support for substantially enhanced **programs of Earth System observation** planned under the WWW, GAW, GEMS, GCOS, and GOOS. (Doodge and others 1992, 10)

This recommendation—one of many—was put forth in the summary statement of the *International Conference on an Agenda of Science for Environment and Development into the 21st Century* (ASCEND 21). Now a recommendation like this one can be interpreted partly as an attempt to secure more resources for research, partly as a move to rejuvenate a languishing aerospace sector, and partly as an indicator of official expectations about environmental monitoring; it is these expectations that I wish to address, particularly in light of current thinking about complex systems.

Monitoring initiatives are typically portrayed as being exclusively scientific affairs designed to provide support for managerial decision-making; consequently, most initiatives are centered on a mandate: an overarching mission statement or a legislative warrant that provides general direction for monitoring activity. But biosphere reserves around the world reflect unusual circumstances: they display a diversity of local concerns and informal practices that do not fit easily within traditional management plans bent toward making decisions that are scientifically and legally defensible. Biosphere reserves are designated by UNESCO at the request of national committees; the expressed hope is that they can demonstrate practical approaches to conservation and development on a regional scale (UNESCO 1998). The nomination process itself is largely driven at the local level, often by a loose coalition of supporters with diverse affiliations.

Applying for designation requires some measure of official support, and the degree of community input varies. But once an area has been duly designated, the real work begins: trying to breathe life into the biosphere reserve concept, an undertaking I do not view as an exercise in regional planning. Official efforts tend to marginalize lay perspectives as technical experts pursue disciplinary rigor at the expense of genuine public contributions, a situation not entirely in keeping with the spirit of the concept. An alternative design approach that reaches beyond scientists and resource managers is necessary.

This thesis touches on many topics: complexity, systems ecology, philosophy of science, sociology of knowledge, information systems design, and organization theory. Why embark on such a Grand Tour through the Library of Congress classification system? Because these fields of inquiry are all implicated in environmental monitoring and ecosystem management. Ecosystem initiatives everywhere interweave technical, bureaucratic, social, and political issues in ways that defy easy disentanglement; our experiences with such initiatives would suggest that they are not easily 'engineered' by technical experts directed to find a solution that minimizes the misfit with some fixed prior specification. Is it possible to adopt an alternative design approach that strives to do justice to the essential richness, ambiguity, and scrappiness of real situations? This thesis offers a rationale for—and a preliminary outline of—such an approach, but it forgoes austere methodologizing in the 'hard' systems tradition. I prefer a looser, more pragmatic orientation that draws on the principles of 'soft' systems thinking, a style of inquiry that owes much to the applied work of practitioners in Europe (especially Peter Checkland and his colleagues at Lancaster University). Some key distinguishing characteristics of work conducted in this mode are:

- a focus on learning and achieving coherence among divergent perspectives on a problematic situation
- a rejection of the notion that meaning is intrinsic and static

Subsequent chapters will have much more to say about what this looks like in practice, but I should clarify what I mean by learning. In a recent book canvassing beliefs about the nature of learning, Wenger (1998) argues that learning is a process of social reconfiguration that requires sufficient structure to accumulate experience, yet enough flexibility to permit the (re)negotiation of meaning. A community of practice is Wenger's preferred 'level of analysis', with a focus on participation; the active production of meaning entails interpretation and action on the part of participants who encounter both resistance and malleability in the course of doing their work: "Meaning is not pre-existing, but neither is it simply made up. Negotiated meaning is at once both historical and dynamic, contextual and unique" (1998, 54). I will draw on some of Wenger's ideas about learning as they are pertinent to the distributed and decentralized practice of environmental monitoring within many biosphere reserves.

Wenger declared that "our designs are hostage to our understanding, perspectives, and theories" (1998, 10). While 'hostage' may be too strong a word here, a little self-awareness (or reflexivity) can go a long way; much can be gained by paying attention to how inquiry into a problematic situation is structured and conducted. So this journey—which I hope will not strike the reader as a random walk!—has many waypoints en route to a framework for community-based monitoring in a Canadian biosphere reserve. But my aspirations are fairly modest: I hope to convincingly highlight some of the difficulties that arise when a monitoring initiative is considered to be a strictly technical exercise aimed at improving the prediction and control of natural systems. To this end, I will outline an ecosystem-based approach for undertaking the participatory design of a locally-sensible framework that integrates the *why*, the *what*, and the *how* of monitoring in as transparent a manner as possible.

Many scientists—ecologists in particular these days—are wont to wring their hands in frustration over the fragmentation and disarray that is said to characterize their discipline. In an extended critique that sparked much debate, Peters (1991) argued that ecology often suffers from a lack of predictive power. Weiner has stated that ecology seems to progress more slowly than, say, molecular biology: "We are debating many of the same issues that we were decades ago" (Weiner 1995, 153); while he took Peters to task for overemphasizing prediction at the expense of explanation, Weiner also called for more predictive models and testable hypotheses. In a recent essay James Brown, a noted ecologist at the University of New Mexico, decried the lack of fundamental progress in ecology over the last twenty years—he expressed concern that more and better data have not led to the development of a body of theory that encompasses the "infinite variety" and "universal features" of organism–environment interactions (Brown 1997). It strikes me that the prospects for developing such all-encompassing theories are poor, especially beyond the rarefied confines of a laboratory.

Methodological and ontological unity are metaphysical assumptions I'm prepared to put aside for a number of reasons. The disunity of science, particularly at the phenomenological level, is hard to ignore; numerous cultural studies belie the monolithic accounts of science on both metaphysical and methodological grounds. Pluralism is in the air as realists, anti-realists, and those who gambol somewhere in between struggle to construct or deconstruct an orderly basis for scientific knowledge. Historical and sociological investigations conducted over the last quarter century (under the rubrics of 'sociology of scientific knowledge' and 'science and technology studies') have done much to show just how austere the textbook caricatures of 'scientific method' really are[1]. These studies have, through often minute scrutiny of laboratory practice, tended to deflate much of the folklore surrounding the place of truth, objectivity, and rationality in experiment and theory development. Dupré sees science as a mixed bag of classificatory schemes predicated on different background assumptions, a "loose and heterogeneous collection of more or less successful investigative practices" (1993, 238). Pickering (1995) also emphasizes the performative aspects of scientific work in describing how experimental practice is patchy and scrappy, not unitary; his pragmatic realism takes issue with what he calls the *spectator theory* of knowledge by pointing to the contingencies of practice that intertwine (or "mangle") technical and social elements through a dialectic of resistance and accommodation:

> On the one hand, what counts as empirical or theoretical knowledge at any time is a function not just of how the world is but of the specific material–conceptual–disciplinary–social–etc. space in which knowledge production

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[1] Ah, the scientific method; while observation, hypothesis, and experiment are usually singled out as the defining stages, the precise ordering has been much discussed over the decades. The recent turn against the rhetoric of unity draws on studies that point to the contextual aspects of scientific practice. Barnes, Bloor, and Henry (1996) use historical case studies to introduce some of the basic themes.

> is situated. On the other hand, what counts as knowledge is not determined by the space in which it is produced. (Pickering 1995, 185)

Upon wading through the voluminous systems literature of the last fifty years, one might be forgiven for supposing that general systems theory provides a language for talking about almost anything without stooping to practical consequences. It may be that vacuous generalities fly thick and fast only if one remains resolutely committed to theoretical monism and methodological unity. There is at present no coherent, *universal* theory of systems dynamics—the label 'complex systems theory' conceals a pot-pourri of approaches that incorporate divergent assumptions and expectations. This is not necessarily a loathsome state of affairs. Indeed, I'm inclined to follow Feyerabend (1978) in rejecting the notion of a stable, universal scientific method[2].

Methods and models should be applied only after due consideration of their suitability, not blindly grabbed from a 'toolkit' on a whim. Put more succinctly: I urge pluralism, not eclecticism. The basic position adopted here is one of complementarism involving the reflective application of appropriate methods. I'm sympathetic to Nagel's assertion that objectivity is both underrated and overrated: "It is underrated by those who don't regard it as a method of understanding the world as it is in itself. It is overrated by those who believe it can provide a complete view of the world on its own, replacing the subjective views from which it has developed" (Nagel 1986, 5). I wish to avoid the extremes of becoming mired in either a totally credulous objectivism that refuses to examine its own foundation, or in a staunchly incredulous constructivism that admits no foundation whatsoever.

1.2 What's the Point?

In April 1997 about a dozen people met in the field station at the Big Creek National Wildlife Area near the small community of Port Rowan, on the north shore of Lake Erie. The topic under

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[2] Aligning myself with Paul Feyerabend might strike some people as a dubious, if not preposterous, move. He's usually derided as the fellow who offhandedly proclaimed that "anything goes" in science. Feyerabend's style of argument and his occasionally flippant retorts may put off many readers, but probably the most important thing to appreciate is that he argued for *epistemological* anarchism—he considered all methods to have limits and often inveighed against what he called the "positivist hangover" (Feyerabend 1993).

discussion was a set of indicators to complement the Community Action Plan that was produced in 1994. The action plan is a compilation of goals and activities related to the environmental health of the Long Point Bay area (Long Point World Biosphere Reserve Foundation 1994). As a participant, I noted considerable interest in adopting an 'ecosystem' approach rather than a conventional sectoral approach, and for many this seemed to require some sort of systemic framework to link proposed indicators. A framework was not forthcoming then, but the discussion did highlight a perceived need for an appropriate integration framework.

The Long Point area has considerable natural and cultural significance. The long sandy peninsula and its associated dunes and wetlands lie at the heart of a biosphere reserve that was designated in 1986 under the UNESCO Man and the Biosphere Programme. Given that the designation confers no statutory obligations, breathing life into the concept requires concerted effort to bring together people holding diverse interests and expectations. Securing local involvement and interagency cooperation are central to realizing a functioning biosphere reserve; these are tasks that lie beyond the purview of traditional management frameworks.

Long Point is an important staging area for North American waterfowl, and is listed as a wetland of international importance under the Ramsar Convention[3]. It also supports many recreational pursuits such as boating, hunting, fishing, bird watching, camping, and naturalist activities. Several workshops over the years have identified cultural stresses that are perceived to deleteriously affect Long Point ecosystems. Most recently, development activities have been identified as the preeminent stressors, followed by exotic species and shoreline alterations (Craig, Robinson, and Langford 1993). It's safe to say that there is considerable concern about the health of the local environment.

There is quite a bit of monitoring being done in and around Long Point, yet there is little coordination among monitoring groups and no obvious way to combine disparate data sets in a meaningful

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[3] For more information about biosphere reserves in Canada, see <http://www.cciw.ca/mab/>. Some general information about the Long Point biosphere reserve is available online at: <http://www.cciw.ca/cbra/english/biosphere/br_longpoint/intro.html>. The official web site of the Ramsar Convention on Wetlands can be found at: <http://www.ramsar.org/>.

way. Nevertheless, there is considerable local interest in gaining a better appreciation of environmental conditions. A project completed in 1996 compiled survey information pertaining to monitoring activity in the region. Almost 60 programs were summarized, representing work conducted by government agencies, regional authorities, and non-governmental groups (Poff 1996). The report conveys the diversity of features and processes being monitored: beach water quality, migratory waterfowl, coastal processes, forest health, regional demographics, and more. Yet how are we to combine such disparate data sets in a meaningful way? Jeff Robinson, the Past President of the Long Point World Biosphere Reserve Foundation, commented in the local community paper: “What seems to be needed now is some method to assess how well we’re doing in maintaining the things we value and need the most” (*Port Rowan Good News*, December 1997, 13).

What might be a reasonable way to proceed? An environmental monitoring initiative can be viewed as a distributed information system that undertakes to collect, interpret, process, store, and report relevant data. Looked at this way, an environmental information system is not a purely technological object: it is a distributed *human activity system*, not just a gray box murmuring quietly to itself in an air–conditioned room somewhere. To be blunt, an information system encompasses more than a computing system—it is a multifarious and irremediably ‘soft’ artefact. It is a major premise of this thesis that the broader social context of information use cannot be ignored if a useful, relevant monitoring initiative is to emerge. Davies and Wood–Harper (1989) described three paradigmatic frames that make different assumptions about information systems development: sociological, datalogical, and computational. Noting that the dominant approach “is highly rational and has no notion of politics, power, or culture” (1989, 70), they proposed a ‘meta-methodology’ to show how different methodologies may be best suited to different stages of design (Box 1–1).

The social implications of information systems is a growing area of research. As a complement to purely datalogical methods, interpretive methods have been increasingly employed to study the contexts in which information systems are designed and used. Walsham (1993) considers information systems in organizations from an interpretive perspective that favors a more human-centered conception of design that looks beyond the production of a hardware or software specification:

> The design and development of computer-based IS involves a *social process of communication, learning, and negotiation*, both within and between stakeholder groups including IS analysts, users, and other interested parties such as senior management. (Walsham 1993, 201)

Box 1–1
The Multiview systems design life–cycle (*Source*: Davies and Wood–Harper 1989)

1. *Analysis of human activity systems*: sociological & datalogical methods
2. *Information modelling*: datalogical methods
3. *Analysis and design of socio-technical systems*: datalogical & sociological methods
4. *Design of the human-computer interface*: datalogical methods
5. *Designing technical subsystems*: computational & datalogical methods

I am chiefly interested in the participatory design of a monitoring framework that will support local aspirations and contribute to sense-making, but I will have little to say about hardware and software configurations. An understanding of the ways in which environmental information is produced, exchanged, and used requires some crucial preliminary 'spade work'. But this is easy to overlook in a climate of technological optimism that overflows with a giddy enthusiasm for more powerful processing architectures and visualization techniques.

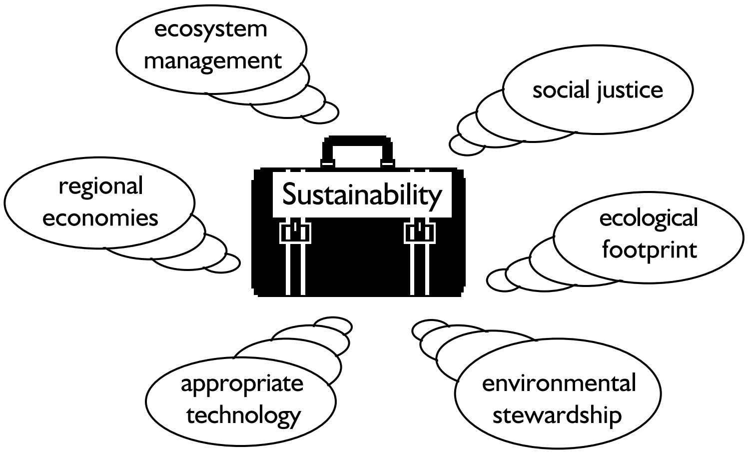
In laying out a social theory of learning, Wenger (1998) discusses design issues with respect to learning on the part of communities of practice (or constellations of practices), and highlights the centrality of negotiated meaning. Such negotiation hinges on a fundamental duality between *participation* and *reification*. Participation entails membership and mutual engagement in some social enterprise; reification denotes the production of 'objects' that help to congeal experience by creating focal points for the negotiation of meaning (e.g. abstractions, tools, stories). The need for coordinating perspectives and establishing coherence is a basic preoccupation of individuals engaged in the negotiation of meaning. But it is an inherently ambiguous exercise that can elude precise specification:

> Effective communication or good design, therefore, are not best understood as the literal transmission of meaning. It is useless to try to excise all ambiguity; it is more productive to look for social arrangements that put history and ambiguity to work. (Wenger 1998, 84)

1.3 Unpacking sustainability

Throughout this thesis a few portmanteau-words crop up—these are multidimensional terms that admit a variety of interpretations. There are many such words: rationality, biodiversity, and complexity, to name a few. Sustainability is the first such word. A reasonably ambitious reader does not have to dig deeply to uncover dozens of definitions that carry many connotations (Figure 1–1).

Figure 1–1
Sustainability as a portmanteau-word



The 'Brundtland Report' of 1987 thrust the concept of sustainable development into the limelight, but the idea was cast in terms of fairly orthodox global economic policies; it was proclaimed that

> sustainable development does imply limits—not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities. But technology and social organization can be both managed and improved to make

> way for a new era of economic growth. (World Commission on Environment and Development 1987, 8)

Since rank developmentalism leaves a sour taste in the mouths of some folk, numerous competing interpretations have emerged under the umbrella of 'sustainability'. Strictly technocratic definitions have been tempered with social and ecological considerations. Milbrath (1989) distinguished two general formulations: resourcist and transformationalist. Resourcist accounts tend to subordinate nature to human use and enjoyment, leaving the basic structure of modern industrial society largely unexamined. In contrast, transformationalist approaches are espoused by a 'vanguard' who "believe there must be sweeping changes in lifestyles and social structures—that we must build a new society" (Milbrath 1989, 164).

The Earth Summit of 1992 generated a vast literature on the heels of *Agenda 21*[4], the action plan that emerged from the conference. The preamble to this heavily negotiated document called for a global partnership for sustainable development and expressed some lofty goals:

> However, integration of environment and development concerns and greater attention to them will lead to the fulfilment of basic needs, improved living standards for all, better protected and managed ecosystems and a safer, more prosperous future. (Robinson 1993, 1)

Five years later a number of reviews were undertaken. The Earth Council convened the *Rio+5 Forum*[5] at Rio de Janeiro in March, 1997. In a summary statement the Chairman of the Council noted that "the basic concept of sustainable development is still not well understood and the policies and structures required to implement the Earth Summit agreements are still not in place" (Earth Council 1997, par. 6). A review mandated by the UN General Assembly made similar observations. While many policy developments and new institutional arrangements were acknowledged, concrete progress has been halting: "It is still too early to see widespread quantitative results" (UN Department for Policy Coordination and Sustainable Development 1997, par. 112).

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[4] The complete texts of Agenda 21 and the other UNCED agreements are available online from the UNDP gopher server at <gopher://gopher.undp.org:70/11/unconfs/UNCED/English/>.

[5] A summary of the Rio+5 Forum proceedings and the companion reports are available from the Earth Council's Earth Network website at <http://www.ecouncil.ac.cr/rio/>.

No contemporary discussion of environmental issues can overlook the concept of sustainability—it is the leitmotiv of many strategies, particularly on the international stage. Perhaps it is the obvious disparities in consumption patterns that make the concept so cogent on a global scale. As the search for appropriate 'policy instruments' proceeds, the theme has percolated downward to national, regional, and even community levels. I will not expend much effort to tease apart the many nuances of sustainability—others have done so at considerable length. Many published works have examined the international, national, and local implications[6]. Despite the cool tones used to urge growth by other means, the nature and scope of institutional reform remains hotly contested. David Orr refers to a reluctance to deal with uncomfortable and demanding issues and castigates those who offer global prescriptions:

> Planetary management has a nice ring to it. It places the blame on the planet, not on human stupidity, arrogance, and ecological malfeasance, which do not have a nice ring. It avoids the messy subjects of politics, justice, and the discipline of moral choice. Planetary management, moreover, appeals to our desire to be in control of things. It appeals to our fascination with digital readouts, computer printouts, dials, gauges, and high tech of all sorts. (Orr 1992, 157–158)

I'm inclined to echo Orr's assertion that sustainability hinges on "the careful adaptation of people to particular places" (1992, 33). I believe that sustainability is most readily engaged in the local arena where the difficult choices are most palpable; but these choices are not easily resolved through administrative fiat, a casual directive to "Make it so". I shall leave the global arena to the cadres of summiteers and aspiring planet handlers[7]. One

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[6] Carew–Reid and others (1994) provide a handbook for building a national strategy for sustainable development. Selman (1996) reviews methods for approaching local sustainability. Hardi and Zdan (1997) offer a set of case studies (national, subnational, and organizational) they review in light of the 'Bellagio Principles' for assessing progress toward sustainable development.

[7] Global change research aims to advance our understanding of the 'total Earth system'. The summary report of the U.S. Global Change Research Program is larded with discussion about the integrated assessment of global change under the banner of Earth system science (Committee on Environment and Natural Resources 1997b). NASA's contribution to this effort is its Earth Science Enterprise, formerly known as Mission to Planet Earth; a promotional document (National Aeronautics and Space Administration 1998) describes the agency's program to characterize, understand, and predict global climatic changes (with an annual budget of $1.37 billion for FY 1998, no less). Kennel, Morel, and Williams (1997) consider the prospects for an integrated global observing strategy.

handbook for strategists, entitled *Gaia: An Atlas of Planet Management*, avers that the transition to sustainability "will demand a management exercise on a scale unequaled in human history" (Myers 1993, 254). Now the thing about international advisories and the managerial formulations they spawn is that real people living real lives tend to get quickly aggregated right out of the picture; what remain are caricatures of rational actors far removed from vulgar circumstances.

The many discussions taking place in international forums have spurred much sub-national activity in recent years. While grass roots action is nothing new, official sanction and supporting mechanisms established in the interest of 'capacity–building' are fairly recent developments in this new era of partnership. For example, Environment Canada launched the Millennium Eco-Communities Project in June, 1998 to encourage community projects that focus on four priority issues: clean air, clean water, climate change, and biodiversity[8].

Jamieson (1998) suggests that meaningful discussion about sustainability is unlikely if talk strays too far from concrete situations: "At the global level, there is too little by way of shared beliefs and values to provide enough content to ideas of sustainability to make them effective" (1998, 189); he maintains that the concept can nevertheless usefully structure conversations, supply a common vocabulary, and help draw in diverse parties. So while policies or 'master plans' can be enabling—by conferring legitimacy and assigning responsibilities, for example—they are almost never determinative. From an ethnomethodological standpoint Suchman (1987) has argued that plans, insofar as they downplay local contingencies, are only a weak resource for purposeful action—coherence is more a product of moment-by-moment interactions than of preconceived schemas[9]. Nevertheless, traditional planning models that see action as a form of problem-solving command widespread allegiance. Much effort is dedicated to measuring and eliminating the gap between what is and what should be.

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[8] The Eco-Communities web site at <http://www2.ec.gc.ca/eco/main_e.htm> outlines the program.

[9] Other researchers have similarly highlighted the sheer *situatedness* of action and learning. See *Situated Learning: Legitimate Peripheral Participation* (by J. Lave and E. Wenger, 1991), or *Cognition in the Wild* (by E. Hutchins, 1995). A special issue of the journal *Cognitive Science* (v17, 1993) is also informative.

1.4 A passion for indicators

Assured that a firm grasp of the facts provides a sound basis for making decisions, we place a high priority on collecting data. A great deal of work has been directed toward monitoring and managing for sustainability. Indeed, these activities lie at the heart of any 'rational' plan developed in accord with the instrumental presumption that information alone motivates action. Not long after the Brundtland Report was released, many countries started to work on reporting frameworks that would permit national information systems to track environmental performance. Canada issued three national state-of-the-environment (SOE) reports (in 1986, 1991, 1996) until the directorate responsible for producing them was disbanded in March, 1997. Now, instead of comprehensive country-wide reports a series of multidisciplinary assessment reports that focus on particular issues or regions will be compiled to provide a scientific overview. According to the draft guidelines, the aim is to promote the use of science in policy-making: "Reliable and accessible information that links environmental, economic, social and health factors is critical to improving decision-making for sustainable development" (Environment Canada 1998b, 53).

Chapter 40 of *Agenda 21* deals with information for decision-making. Paragraph 40.4 expresses a need to fill the 'data gap': "Indicators of sustainable development need to be developed to provide solid bases for decision–making at all levels and to contribute to a self–regulating sustainability of integrated environment and development systems" (Robinson 1993, 628). The report calls for the overall strengthening of data collection activities, improved methods of assessment, and the eventual use of sustainability indicators in national accounts. The demand for more and better information has not abated—the five–year progress reports continued to note persistent data gaps and reiterated concerns for effective monitoring and data harmonization.

The desire for comprehensive monitoring at all levels is pervasive. Global change research programs in particular tend to express vaunting ambitions. A report on the U.S. Global Change Research Program (USGCRP) proclaims that: "The goal of the USGCRP observation and monitoring program is to ensure the availability of a long–term, high–quality observational record of the state of the Earth system, its natural variability, and changes that are occurring over extended time scales" (Committee on Environment and Natural Resources 1997b). Here in Canada, the Ecological Monitoring and Assessment Network (EMAN) has been established by Environment Canada to provide "scientifically defensible rationales" for pollution control activities and resource management practices (Ecological Monitoring Coordinating Office 1997). Around the Great Lakes, the binational Great Lakes Water Quality Agreement obliges public agencies to report on progress toward the goals of the Agreement (International Joint Commission 1997). The focus of the 1998 State of the Lakes Ecosystem Conference (SOLEC '98) was the identification of an umbrella list of broad, system-wide indicators (Environment Canada, 1998a).

The measurement of environmental trends, conditions, and processes poses some enormous challenges that either go unrecognized or are glossed over in the fervor to establish electronic information systems using state-of-the-art technology. The difficulties encompass theoretical and practical concerns that come to light when actual monitoring programs are examined with respect to underlying assumptions and data management activities.

The state variable approach underpins most conceptualizations of environmental systems. Rooted in the mathematical theory of dynamical systems, the approach postulates that system properties are functions of state factors. For example, Bailey (1996) proposes that regional macro-climates can be defined in terms of controlling factors associated with climate and landform:

$$\text{soil \& biota} = f\ (\text{climate, landform})$$

Similar reasoning informs most modeling efforts. Such thinking brings some rather strong assumptions into play, and these may not always be warranted for complex systems. The 'Newtonian' formalism is arguably best suited for investigating the simple, closed systems for which it was developed—its extension to biological systems in particular is far from straightforward. A number of researchers have explored the issue. In a series of monographs Rosen (1978, 1985, 1991) presented a thorough examination of some of the problems, and other researchers (e.g. Kampis 1991; Mikulecky 1996) have followed his lead. One may reasonably question the degree to which natural systems are 'computable'.

Another issue attracting considerable attention in recent years is data management, especially as observation sets accumulate and cross-scale inference becomes more desirable. The task is not an easy one given the proliferation of groups asking different questions, using different methods at different times and places. Stafford, Brunt, and Michener (1994) lament our rudimentary ability to manage and interpret the vast amount of environmental data we collect and store; they look forward to the development of "knowledge discovery algorithms" and expert systems implemented on fast, interactive computer networks as ways to improve the management of natural resources. Geographical information systems (GIS) are widely promoted as an integration tool that readily allows the amalgamation of diverse databases to create a single, multipurpose database. The pervasive fascination with information technology fuels an ethos of "silicon positivism" (Ross 1991, 10) that vigorously pursues technological solutions and pays scant attention to the organizational and social aspects of how environmental information is acquired and used.

Combining environmental data involves far more than digitizing, converting, and merging data sets. A committee formed by the U.S. National Research Council to study database interfacing offered this note of caution: "Merely merging ecological and geophysical data by rote without seriously considering scale–related issues and their implications could result in spurious relationships and misleading analytical results" (National Research Council 1995a, 87). The report acknowledged the lack of guidelines for assisting cross-scale data integration, and pointed to hierarchy theory as a promising approach. The committee proposed ten keys to successful data interfacing (Box 1–2).

This thesis takes issue with monitoring initiatives that are designed to support the rationalization of environmental decision-making. Hajer (1995) applies the label *ecological modernization* to the comprehensive style of discourse that frames environmental problems as management problems and assumes that technical and procedural innovations are sufficient to deal with them; such discourse stops short of addressing social contradictions: "Ecological modernization does not call for any structural change but is, in this respect, basically a modernist and technocratic approach to the environment that suggests that there is a techno-institutional fix for the present problems" (Hajer 1995, 32).

Box 1–2

Keys to successful data interfacing (*Source*: National Research Council 1995a, 113)

- Be practical
- Use appropriate information technology
- Start at the right scale
- Proceed incrementally
- Plan for and build on success
- Use a collaborative approach
- Account for human behavior and motivation
- Consider needs of participants as well as users
- Create common needs for data
- Build participation by demonstrating the value of data interfacing

Most environmental monitoring programs are designed with the expectation that they will confer a predictive understanding of natural systems and thereby offer scientific support for management actions. Yet such aspirations are likely to be frustrated by incomplete knowledge and burdensome requirements for time, money, and personnel. So if improved prediction and control cannot be taken for granted, then why monitor at all? Monitoring can serve several non-instrumental purposes even if improved prediction is not in the offing:

- contribute to collective sense-making
- provide an infrastructure for learning and the acquisition of systems knowledge
- provide feedback concerning policy decisions—both outcomes and "back talk" from stakeholders
- educate participants and instill a greater awareness of locality among stakeholders

Confusing, ambiguous situations call more for sense-making than decision-making; that is, trying to sort out a welter of data and impressions in order to articulate a plausible, coherent account of what seems to be happening. Karl Weick puts it this way: "The problem is that there are too many meanings, not too few. The problem faced by the sensemaker is one of equivocality, not one of uncertainty. The problem is confusion, not ignorance" (Weick 1995, 27).

1.5 Science and sustainability

Managerial, expert-driven approaches comprise the vast majority of current prescriptions, and these take for granted the assertion that more and better information will make for frictionless (i.e. effective and efficient) decision-making. A report prepared by a subcommittee of the Ecological Society of America put forth the "Sustainable Biosphere Initiative" as a research agenda for the 1990s. The authors frankly acknowledged their assumption that "advances in understanding basic ecological principles are required to resolve many urgent environmental problems" (Ecological Society of America 1991, 405). This outlook stems from a 'public ignorance' model of policy making that supposes only a science-based account of the issue at hand can command legitimacy (Wynne 1996); such a position presents a rather disingenuous picture of the limitations of studying complex systems, and tends to marginalize local understandings. But it is an alluring standpoint that is difficult to moderate in a milieu that smiles upon technological fixes.

Another presumption that permeates much official discussion is that scientific uncertainty begets controversy. For those who subscribe to this view, the obvious course of action in a muddled situation is to get the facts straight, reduce uncertainty, and thereby dispel conflict—or pummel the critics into silence by dint of technical superiority. Even though there are many cases where science has failed to resolve policy conflicts, it continues to exert a fatal attraction for policy makers. According to Collingridge and Reeve (1986), invoking science poses a bit of a paradox in that while complex problems cry out for scientific investigation, such studies often only serve to inflame a dispute, not quench it.

Reflecting upon their study of deforestation in the Himalayas, Thompson and Warburton (1985) posited two ways to tackle an environmental problem: one can ask "What are the facts?", or one can ask "What would you like the facts to be?" Contracted by the UN to do some troubleshooting, the investigators undertook a conventional systems analysis and discovered the fractious nature of regional decision-making. They observed that

> each organization has its own definition of the problem: one that contradicts all the others and, as the decision process gets under way, is increasingly thrown into

> contention with them. These are the *contradictory certainties* and, like the organizations they support, they do not go away. (Thompson and Warburton 1985, 4)

In attempting to sort out these 'contradictory certainties' it becomes all too clear that when science and policy are inextricably mixed, uncertainty is a resource that can be either secretly hoarded or publicly apportioned—it can be hoarded when one has the power to do so, or meted out when legitimacy is imperiled. The northern Cod fishery provides a Canadian example. When the traditional inshore fishery declined in the late 1980s, the Newfoundland Inshore Fisheries Association severely criticized the stock assessment methodology used by the Department of Fisheries and Oceans, despite assurances from agency staff and offshore fishermen that all was well (Finlayson 1994). In their critique of fisheries management in Canada since the late 1970s (i.e. under the aegis of the Department of Fisheries and Oceans) Hutchings, Walters, and Haedrich (1997) decry the suppression of uncertainty and the failure to acknowledge legitimate scientific disagreements; their preferred solution to the problem of undue "bureaucratic interference" in scientific work is the creation of an independent body of fisheries scientists. The authors seem firm in their belief that science can somehow float free of institutional and political influences. Others are not so sanguine. It has been argued that the traditional account that sees conflict as a function of uncertainty gets the story backwards: scientific uncertainty is usually generated by social disagreements that prompt close scrutiny of basic assumptions and motivations (Wynne 1992).

Collingridge and Reeve (1986) advanced the skeptical thesis that policy choices are rarely sensitive to relevant scientific claims. If a particular aspect of a policy proposal carries a high error cost, then attempts by scientists to make a significant impact on the debate will be contested by powerful critics. A technical consensus becomes possible only if the error cost can be negotiated, in which case the scientific evidence alone is not decisive. Others have also been quick to deflate overly jejune ideas about how science shapes policy. A letter published in the journal *Science* created a bit a of a stir when the authors—a trio of biologists—claimed that "the scientific community has helped to perpetuate the illusion of sustainable development through scientific and technological progress" (Ludwig, Hilborn, and

Walters 1993, 36). They described some of the difficulties that hinder the attainment of scientific consensus, especially when controlled, large–scale experimentation is impossible. For these fellows, resource problems are really human problems created by a constellation of political, social, and economic circumstances. In a similar vein, Kay and Schneider (1994) asserted the futility of attempting to manage ecosystems rather than our interactions with them.

The upshot is that there are very few simple stories to be told. Multiscale environmental monitoring presents an extraordinarily demanding mix of scientific, organizational, and social issues. Furthermore, combining disparate data sets so as to yield meaningful insights is itself a problematic endeavor. In contrast to managerial prescriptions that look forward to decisions that are scientifically and legally defensible, this thesis will sketch out a means of structuring a process of participatory inquiry that aims to neither ignore contextual influences nor marginalize local perspectives.

1.6 Overview

Well, that's it for the warm-up act—now for the main event. No one possesses an overarching mandate for integrated monitoring around Long Point, and there are no built-in priorities to offer guidance. Biosphere reserves do not fit easily within traditional management frameworks, and they tend to elude bureaucratic oversight. A network can be a valuable means of sharing environmental information and expertise when responsibilities and resources are diffuse; building one doesn't happen overnight, and a little preparatory work is required to identify nuclei around which information can condense. This thesis marks a step in that direction: my key research questions are primarily concerned with the prevailing norms for monitoring work and with the interactions among groups collecting environmental data around Long Point (Box 1–3).

This document is divided into two parts. Part one provides a conceptual foundation by introducing and exploring the principal themes; part two describes my case study work and turns to the nearshore sport fishery of Long Point Bay to illustrate some of the basic ideas (Table 1–1). The general thrust of the thesis can be expressed this way:

> *To outline a soft systems approach to the participatory design of a locally-sensible framework for monitoring practice that primarily supports sense-making.*

Box 1–3
Guiding research questions

- What are the prevalent assumptions and expectations underlying the collection and exchange of environmental information?
- How does the biosphere reserve designation influence current monitoring activity?
- What are the elements of a locally-sensible integration framework?
- How can learning be supported in a distributed, heterogeneous setting?

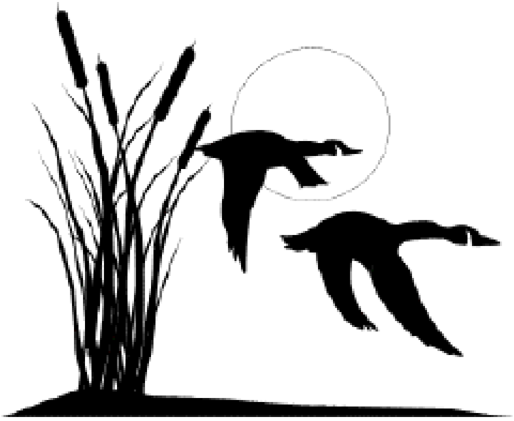
Most environmental monitoring unfolds against a backdrop of ambiguity and confusion where the crucial task is trying to make sense, not decisions. I argue that in such situations it is vital to support sense-making, not just decision-making; to facilitate learning, not control. Recall Wenger's (1998) assertion that learning requires both structure and flexibility to permit the ongoing negotiation of meaning. In other words, both excessive fluidity and excessive rigidity should be avoided; trying to find—and maintain—that middle ground is a crucial design task. The paramount challenge is to manage the tensions that arise between heterogeneity and cooperation, between learning and performance, between participation and reification.

> A design, then, is not primarily a specification (or even an underspecification) but a boundary object that functions as a communication artifact around which communities of practice can negotiate their contribution, their position, and their alignment. (Wenger 1998, 235)

Chapter two canvasses some of the many definitions of complexity, introduces Rosen's distinction between formal and natural systems, and develops the argument that system complexity is best construed as a relational property, not an intrinsic one. Different conceptions of hierarchical organization serve to uncover some contrasting ontological attitudes concerning the role of an observer.

Table 1–1
Principal themes and concepts

	Part I • Concepts
Chapter 2 *Thinking about complex systems*	✔ Current ideas about complexity ✔ the craving for generality ✔ anti-reductionist sentiments and some prevailing ontological attitudes
Chapter 3 *The mangle of integrated monitoring*	✔ a review of some proposed national and international frameworks for integrated monitoring ✔ the influence of a technocratic mentality
Chapter 4 *Ecosystems high and low*	✔ recent experiences with ecosystem initiatives in North America ✔ the role of science in the public realm
Chapter 5 *Boundary business*	✔ the significance of boundaries in the discourse of environmental management ✔ the role of 'boundary objects' in promoting coherence and alignment among stakeholders
Chapter 6 *From decision-making to sense-making*	✔ models of decision-making that contrast goal attainment with appreciation ✔ the nature of sense-making ✔ the relevance of soft-systems thinking to the design of distributed information systems
	Part II • Case study
Chapter 7 *The Long Point World Biosphere Reserve*	✔ the biosphere reserve concept ✔ the scope of existing monitoring initiatives in Long Point Country ✔ conducting the case study
Chapter 8 *Creating a sense-making portfolio*	✔ the elements of a sense-making portfolio ✔ the nearshore sport fishery of Long Point Bay as an illustrative example ✔ a status report



Chapter 2

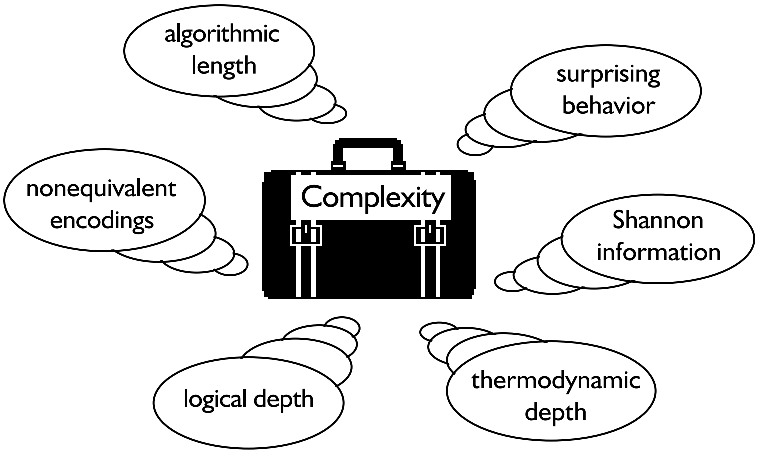
Thinking about complex systems

> Things are ‘with’ one another in many ways, but nothing includes everything, or dominates over everything. The word ‘and’ trails along after every sentence. Something always escapes.
>
> William James,
> *A Pluralistic Universe*

2.1 A craving for generality

Complexity is another portmanteau–word; it is a highly equivocal term that is larded with many nuances. Talk about complexity is much in vogue these days, spilling easily from the tongues of researchers in a bewildering array of academic fields: physics, biology, economics, computer science, psychology, anthropology, and more (Figure 2–1).

Figure 2–1
Complexity as a portmanteau–word



Many disciplines now seek to explore and better understand complex phenomena. Complex systems do not represent something new under the sun, of course, but until quite recently they have received relatively little attention. The burgeoning enthusiasm may reflect the partial exhaustion of traditional paradigmatic approaches, coupled with the steady expansion of computing capabilities. Scientific advances in recent centuries have usually followed the paths of least resistance. Levins and Lewontin had this to say about the success of what they call the ‘Cartesian view’ of nature that privileges reductionist strategies:

> Those problems that yield to the attack are pursued most vigorously, precisely because the method works there. Other problems and other phenomena are left behind, walled off from understanding by the commitment to Cartesianism. The harder problems are not tackled, if for no other reason than that brilliant scientific careers are

> not built on persistent failure. (Levins and Lewontin 1985, 2-3)

So messy problems in many areas of research remain much as they were decades ago. Does the recent penchant for complexity promise to disperse the fog of ignorance, as many enthusiastic commentators have suggested? It's much too soon to tell, and it's not even very obvious what the most promising approaches are. But the effort is overdue. Perhaps Gerald Weinberg sums it up most aptly in suggesting that "after we have been fishing in a small pond for a while, most of the easy fish will have been caught—and it may be time to change bait" (1975, 161).

In an oft–cited paper, Weaver (1948) presented a three–fold characterization of scientific problems. Problems of *simplicity* can be studied using classical analytical methods suited to a small number of variables. Probability theory and statistical mechanics can be brought to bear on problems of *disorganized complexity*, where average properties are abstracted from a very large number of variables. Then there are the problems of *organized complexity* involving a moderate number of interrelated factors that defy formal treatment. In a variant of Weaver's typology, Weinberg (1975) distinguished small, middle, and large number problems and considered the middle region to be the domain of complexity. Indeed, the regularity–randomness (or order–chaos) continuum is central in most accounts of complex phenomena. Many physical analyses start with the 'intuitive' notion that complexity is not monotonically related to Shannon information, but peaks at intermediate entropy values (Wackerbauer et al. 1994). Put another way, complex systems occupy the middle ground between order and chaos.

Systems concepts find wide purchase, and this may be due to the fact that engineering systems are part and parcel of modern technological societies. A casual reading of the systems literature quickly reveals the widespread conviction that general principles likely govern the behavior of complex systems. These principles can presumably be extracted through the study of appropriate mathematical models rooted in theories of information and computation. Bar–Yam (1997) offers a graduate-level overview of approaches along these lines. For many researchers this genre of work promises to pave the way to a truly interdisciplinary science of complexity[1].

The quest for unifying principles is a basic scientific impulse—the articulation of such principles is the cherished goal of systems thinking in many fields. While there have been all-encompassing visions with long and illustrious pedigrees, various strains of 20th century humanism have harbored strong notions of unity. General Systems Theory (or GST as duly nominated by its proponents) was popularized in the 1950s by Ludwig von Bertalanffy, probably its most vigorous promoter. He envisioned the integration of natural and social sciences in terms of isomorphic laws expressed by ordinary differential equations (Bertalanffy 1950); candidate isomorphisms include structural similarities among models and logical homologies among phenomena (e.g. logistical growth). The theoretical package Bertalanffy promulgated was intended as an alternative to classical mechanistic formulations, and it was informed by organismic principles and centered on the concept of 'organized wholes' that are hierarchically ordered. The overall methodological stance was one of perspectivism, not reductionism. But the formal character of the proposed discipline remained staunchly orthodox: "In elaborate form it would be a logico-mathematical discipline, in itself purely formal but applicable to the various empirical sciences" (Bertalanffy 1969, 37).

Boulding was another early champion who called for a gestalt-like 'system of systems', exclaiming that "the Republic of Learning is breaking up into isolated subcultures with only tenuous lines of communication between them—a situation which threatens intellectual civil war" (Boulding 1956, 198). Interdisciplinary theory building was widely heralded to promote the unity of science, given the presumed formal uniformity of nature. The general systems literature reflected this heavily theoretical outlook. A peerless expression of the unifying spirit is Miller's (1978) encyclopedic treatise on living systems, wherein he distinguishes seven levels of living systems, from cell to

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[1] A volume that surveys some of the work done at the Santa Fe Institute (Cowan, Pines, and Meltzer 1994) takes up the theme of complex adaptive systems and presents some of the ideas and metaphors that inform computational approaches to complexity: self–organized criticality, the edge of chaos, fitness landscapes, and so on. Updates on research activities at the Institute and a directory to contributed working papers can be accessed at <http://www.santafe.edu/sfi/publications/working-papers.html>.

supranational system. Each level (considered as a concrete, open system) includes 19 critical subsystems deemed essential for survival. At the heart of Miller's conceptual framework are cross–level hypotheses—173 empirical propositions—that set up formal identities applicable to the structures and processes of two or more levels. A hint concerning the author's motivations is conveyed by this statement: "If we examine formal identities between supra-national systems and other, better–understood levels of life, it must be with the fervent hope that such analyses can help to relieve some of this planet's ominous pathologies" (Miller 1978, 1019).

A theme that floats through much of the postwar systems literature maintains that the unity of science lays a basis for the unity of humankind, a line of reasoning that acquires special cogency in the face of the regional and global conflicts that have convulsed the twentieth century. It's not difficult to find traces of the sentiment that animates many erstwhile unifiers. For instance, Reiser (1958) berated scientists for failing to humanize science and socialize technology. He presented the outline of a 'Scientific Humanism' with planetary democracy as its end point: "In this time of divisive tendencies within and between the nations, races, religions, sciences and humanities, synthesis must become the great magnet which orients us all" (Reiser 1958, 2). Mathematics, logic, and scientific methods comprised the foundation of his 'Temple of Knowledge'. But the panlogism espoused by Reiser had earlier roots in the work of the Vienna Circle.

2.2 The quest for unity

The Vienna Circle was a group of philosophically-minded physical and social scientists who started working out the details of what they termed logical empiricism (or empirical rationalism) in the 1920s. The Circle looked forward to a unified science purged of metaphysical speculation. A manifesto that appeared in 1929 proclaimed that

> we have to fashion intellectual tools for everyday life, for the daily life of the scholar but also for the daily life of all those who in some way join in working at the conscious re-shaping of life. The vitality that shows itself in the efforts

> for a rational transformation of the social and economic order, permeates the movement for a scientific world-conception too. (Hahn, Neurath, and Carnap 1973, 305)

Now known as logical positivism, the program pursued by the Vienna Circle construed the aim of scientific effort to be a unified science attained by applying logical analysis to empirical observations. A plan for an *International Encyclopedia of Unified Science* was approved at the First International Congress for the Unity of Science held at the Sorbonne, Paris, in 1935. Otto Neurath, a prominent member of the Vienna Circle, was a driving force behind the plan. The *Encyclopedia* was intended to show how various scientific activities could be synthesized. Since the group was mostly interested in patterns of argumentation, they focused on the logical analysis of scientific statements. While Neurath objected to any talk of *the* system of science or a 'superscience', he saw science as a logically organized whole:

> Axiomatization of science seems to give an opportunity to make the use of fundamental terms more precise and to prepare the combination of different sciences; preliminary axiomatization has to be founded on a long evolution of science. We cannot anticipate a "final axiomatization." (Neurath 1965, 18–19)

In effect, it was the contingent unification of scientific language that the Circle was most interested in; scientific unity was a logical problem for the group, not an ontological one. This emphasis underlies Carnap's work on observation statements cast in terms of a physicalist 'thing–language' (Carnap 1965). It was the cultivation of a comprehensive scientific attitude based on an international language that motivated the encyclopedism of the interwar period.

A second global conflict intervened to dash the hopes of internationalists yet again. In its wake there arose a number of forums dedicated to forging stronger interdisciplinary connections. Two of these, one in Europe and one in the U.S., profoundly influenced postwar systems thinking: the Alpbach meetings convened in the Tyrolean Alps of Austria[2], and the

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[2] The Austrian College Society was founded in 1945 and promptly started to organize summer schools in Alpbach; the sessions included seminars, plenary lectures, symposia, and performances. The village quickly became a world center of intellectual and artistic exchange, frequented by many notable scholars. The summer schools at Alpbach are described by Feyerabend (1995) in his

Macy conferences held in New York. The temperaments that flavored the intellectual discourses were different: whereas western Europe was somewhat angst-ridden against a background of reconstruction, the U.S. was riding a tide of optimism in a sea of anti-Communist ideology.

A series of conferences exploring feedback mechanisms and circular causal systems in biology and sociology took place between 1946 and 1953 with the support of the Macy Foundation. The participants included engineers, mathematicians, neurophysiologists, psychologists, and anthropologists. The group constituted an influential cluster of individuals that included Warren McCulloch, John von Neumann, Norbert Wiener, Gregory Bateson, Margaret Mead, and Kurt Lewin. Heims (1991) undertook a historical study of the conferences and traced the early development of the new science of cybernetics. While noting that the group members did tend to apply the ideas in different ways, Heims describes the general tenor of the sessions this way:

> As if to negate feelings of helplessness and anxiety over the new danger of nuclear war, the mood at the cybernetics meetings was one of building hope for the future on [*sic*] science and technology on the one hand, psychologism on the other, and planning for an imagined Pax Americana. (Heims 1991, 177)

Wartime associations with industrial and military patrons died hard, and the enthusiasm for mechanical and technical prescriptions persisted—political scientists and economists were not invited to the meetings. Heims argues that the many discussions about homeostasis and equilibrium reflected the conservative postwar period, and tended to marginalize the 'unity in diversity' theme advocated by some members of the group (e.g. Margaret Mead and Gregory Bateson). Quite a number of partial scientific-philosophical syntheses emerged from the Macy conferences, and these helped to widely disseminate cybernetic ideas[3].

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autobiography, *Killing Time*. For several years, starting in 1948, he made shorthand records of the major discussions for the College Society.

[3] Some notable works include Wiener's *Cybernetics* (1948) and McCulloch's *Embodiments of Mind* (1965).

The Macy meetings stimulated many feedback publications in the social sciences. Richardson (1991) reviewed a number of seminal works in order to trace out the diversity of "loop views", and he singled out two feedback threads distinguished primarily by the choice of conceptual distance: the *cybernetics* thread (popular with social scientists) focused on discrete events and messages, homeostasis, and tended to be more skeptical about causal models. The *servomechanisms* thread (popular with engineers) focused on patterns of dynamic behavior, blending discrete decisions in order to devise formal models and lay bare the policy structure pertinent to industrial and economic decision-making situations. Richardson noted the considerable significance attached to computers by most researchers: "As simulation tools, computers are seen in both threads as more or less infallible deducers of assumptions that people build into computer models" (Richardson 1991, 339).

Most of the popular systems approaches were—and remain—rooted in a heroic, noncritical rationality consistent with a spirit of technocratic modernism that advocates social engineering as a way to cope with strife and obscurantism. Flood and Romm (1996, 39) note the positivist threads of GST, and put forth a Feyerabendian critique that qualifies it as a totalizing metatheory disinclined to examine its own foundations. The Enlightenment ideal of emancipation through knowledge is a venerable one upheld by a great many commentators past and present. Yet while the fervor for universal principles to guide human action is eminently understandable, it may well be doomed to frustration. Is it possible to practice a systems approach without buying into a heroic form of rationality?

There have been some trenchant critiques of attempts to transfer systems methodologies from engineering applications to public affairs. Boguslaw (1965) contrasted instrumental heuristics (e.g. efficiency) with value heuristics (e.g. participation) in systems design, and noted the dilemmas that arise when these provide different prescriptions for action. For Boguslaw, the assessment of a proposed design must start by asking "For whom and for what?" Hoos (1983) argued that systems analysis encourages the neglect of crucial social and political issues in public planning, and denied that technique can wholly substitute for thoughtful inquiry: "The systems approach, if it is ever to become conceptually sound, must be a genuine multi-disciplined endeavor, in

> which contributions from the pertinent fields of knowledge are meaningfully synthesized, and not merely homogenized into a synthetic and symbolic language" (Hoos 1983, 247).

Harking back to Wenger's (1998) account of the interplay between processes of reification and participation, the technocratic mentality is inclined to concentrate on the former at the expense of the latter. Orthodox systems approaches downplay the participatory aspects of inquiry in seeking to banish uncertainty and dissolve ambiguity through formal analysis that describes time-invariant system dynamics. And yet in distributed, heterogeneous settings intense reification can hinder coordination and frustrate the development of shared meanings (i.e. hinder sense-making). As Wenger notes, reification is double-edged—it is at once potentially enriching and potentially misleading; being mindful of both aspects helps to prevent the ossification of a "useful illusion". We tend to take our intellectual constructs a tad too seriously (recall William James' caution regarding the "fallacy of misplaced concreteness"!). A credible systems approach need not be built around some master narrative that subordinates all others.

2.3 Metaphysical disorder

It's important to appreciate that the scientific study of complexity encompasses a diverse array of approaches—one would be hard pressed to discriminate general theories among the potpourri of principles, heuristics, and methods that have all been proposed for dealing with complexity. To echo Ian Hacking in his discussion of a theory of the electron, it is more a situation of "common lore, not common core" (1995, 264). A cursory glance through the literature reveals that the label 'complex' partakes of many connotations and disciplinary characterizations. Methodological unity seems a dim hope, and this may be because different philosophical stances underpin the various approaches. I shall start by distinguishing two broad positions: *essentialist* and *constructivist* approaches to complexity. Essentialist approaches construe complexity as an intrinsic system property that can be objectively measured, whereas constructivist approaches recognize the role of an observer and highlight the relativity of system descriptions.

In everyday language something is described as complex if it confounds intuition or displays surprising behavior. In systems parlance one might say that it has many interconnected parts that defy understanding[4]. Many researchers have sought to formalize these basic notions by proposing general measures of complexity that can be applied to systems of interest. Proposed quantitative measures usually start with the idea that the complexity of a system is proportional to the amount of information needed to describe it; Klir (1985, 334) regards this as a general principle, where 'information' is understood in a syntactic sense (i.e. as a string of symbols).

Pimm (1984) described a number of measures that have been used to represent ecosystem complexity: species richness, connectance, interaction strength, and the evenness of the distribution of species abundance. Lloyd (1990) discussed the limitations of using computationally-based measures such as algorithmic information content and logical depth. He suggested that what is needed is a way to account for the amount of information processing and thermodynamic effort required to assemble the object of interest. But Lloyd offered few clues about operationalizing his ideas about thermodynamic depth; indeed, the computational demands of his approach are enormous.

What is distinctive about most complexity measures is that they purport to be perspective-free, according no role to an observer—they reflect an exophysical stance from which an observer can act upon (and control) the system of interest. The program to devise general measures of complexity reflects the desire for a unified framework predicated upon universal principles (i.e. universal simplifications). In a recent textbook Bar–Yam (1997) adopts the view that all complex systems have universal properties that can be quantitatively understood and used to guide inquiry in particular domains; Bar–Yam emphasizes an ensemble approach whereby the general properties of a class of systems are studied using statistical methods. Several working assumptions underlie the methodology:

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[4] The nature of understanding is a longstanding preoccupation of philosophers, and there are many competing accounts. It is reasonable to distinguish prediction from explanation: prediction can be accomplished using almost any sort of representation (e.g. a historical look-up table), whereas explanation tries to get at causal structure.

- don't take it apart—context is important
- don't assume smoothness—local details matter
- don't assume that only a few parameters are significant

Most complexity measures are applied to formal systems, not natural systems—this has been pointed out by Rosen (1985) in his theoretical investigations of biological systems. A formal system is syntactic: it manipulates symbols according to explicit rules, as in mathematics. A natural system is some aspect of the world gleaned through interaction. Establishing relations between the two classes of systems is the basic business of science, and Rosen portrays it in terms of the modeling relation (Figure 2–2).

Figure 2–2
The modeling relation (*Source*: Rosen 1985, 74)

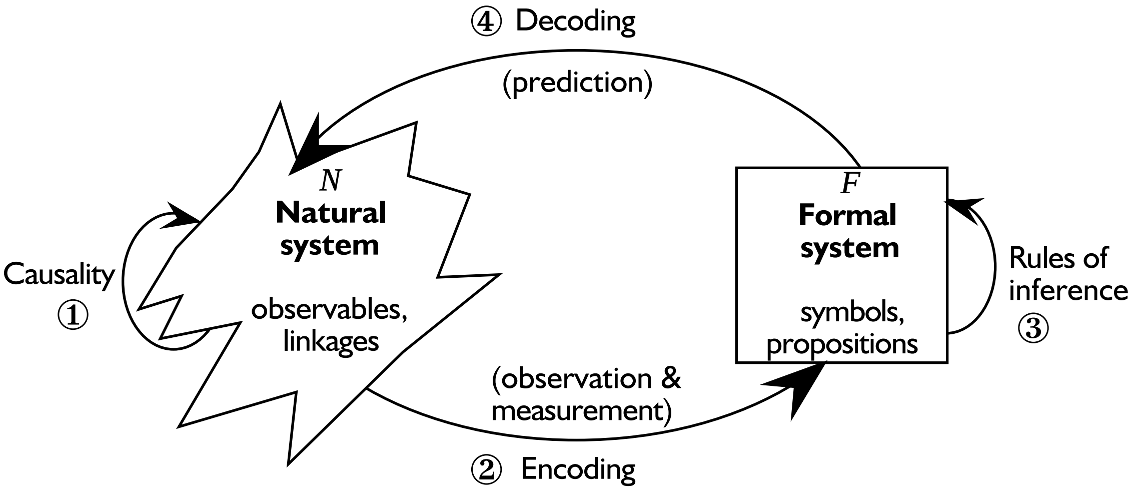

Figure 2–2 uncovers some of the nuances that arise in the course of attempting to model real phenomena, niceties that remain unrecognized or implicit for most modelers. The arrow ① represents causal entailment in N , the realm of pure phenomena, and the arrow ③ depicts syntactic entailment in F—the application of its rules of inference (i.e. its 'grammar'). The relation ② pertains to system identification, the act of encoding phenomena in N as propositions in F. The relation ④ decodes theorems back into phenomena by dint of prediction. As Rosen (1991) notes, the encoding and decoding relations have a curious status: they play a central role yet belong to neither the formal system nor the natural system.

To assert that F *models* N is equivalent to stating that Figure 2–2 commutes; that is, ① = ② + ③ + ④

This means that some causal phenomenon is faithfully captured by a sequence of astute observation, adroit manipulation of the formal system (i.e. executing an algorithm or proof sequence), and subsequent prediction that decodes derived outputs into causal particulars. Mikulecky (1996) argues that establishing commutivity is a delicate endeavor that is as much art as science. He considers the blithe assumption that a given formal system can be substituted for a particular natural system to be an error; except for the case of simple mechanisms, the execution of an algorithm according to some deduction scheme can easily fail to mimic a real process. That a complex system is not computable—that not every process can be completely encoded into a dynamical system—is a theme taken up by a few researchers in the cognitive and life sciences. In the spirit of Whitehead's process philosophy[5], Kampis (1994) introduces the concept of *self-modification* to connote the unfinished, transitory nature of systems viewed internally or from the 'inside'. He contrasts self–modification with the classical focus on essential, invariant properties (Table 2–1).

Table 2–1
Essentialism vs. self-modification (*Source*: Kampis 1994, 102-103)

Essentialism	Self-modification
• emphasis on properties and states	• emphasis on relations and confluences
• objects are locally and *a priori* definable	• objects are globally and *a posteriori* definable
• transparent causality	• opaque causality
• dynamical systems	• growing systems
• constant complexity	• changing complexity
• computable	• non-computable

As Kampis and others have shown, the program to formalize notions of complexity is not entirely straightforward. One of the most celebrated results of twentieth-century mathematics was presented by Kurt Gödel in 1931. Gödel's Incompleteness Theorem shows that axiomatic reasoning has its limits; it asserts

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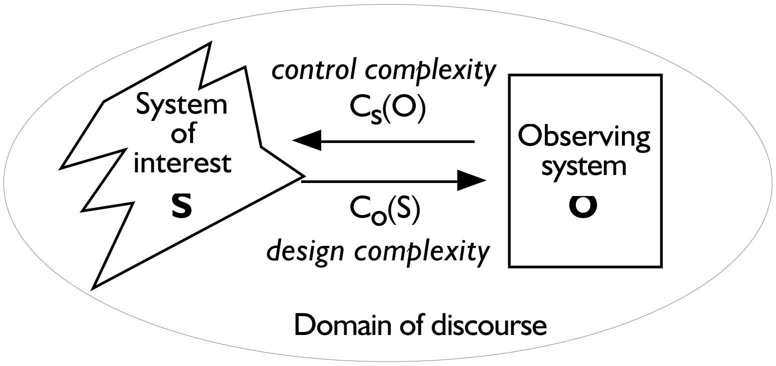
[5] A.N. Whitehead's *Process and Reality: An Essay in Cosmology* (1929) is a popular exposition of his ideas.

that any consistent logical system that is at least as complicated as number theory (i.e. arithmetic) must contain undecidable propositions—there are theorems unprovable within that formal system such that it cannot 'know' everything implicit in its axioms and production rules. More succinctly, there can be no finite set of rules for generating all the truths about the natural numbers. The Incompleteness Theorem effectively derailed the formalist program to derive a complete and consistent theory to summarize all of mathematics, and it has spawned much commentary over the decades. Many versions of the theorem exist, including the Halting Problem from computation theory. Many of these variants tend to draw on the equivalence between a formal logical system and a computer program. Casti presents this 'complexity version' of Gödel's Theorem: "There exist numbers having complexity greater than any theory of mathematics can prove" (1994, 146). The philosophical implications are many and varied, yet susceptible to being stretched a little thin; the only point I wish to emphasize here is that complexity is not a concept that admits easy formalization.

Casti (1986) denies that complexity can be considered an intrinsic system property. Instead, he views complexity as a contingent property that reflects the character of the mutual interaction between the system of interest and an observing system; this interaction is parsed as follows: the system S displays a 'design' complexity $C_O(S)$ relative to the observing system, and the observing system displays a 'control' complexity $C_S(O)$ relative to the system of interest (Figure 2–3). The reader may find it helpful to construe complexity here as the breadth of the behavioral repertoire: a narrow repertoire exemplifies low complexity.

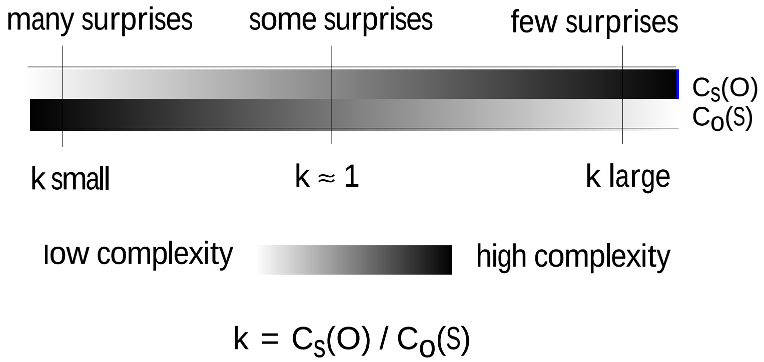
Figure 2–3
System complexity as a relational property
(*Source*: Casti 1986)



The arrows denote the flow of information (it might be useful to think of this as intensity of interaction), which is bidirectional. A common simplification rests on the supposition that information flow is one-way, such that the system receives no information from the observer. According to the more general situation depicted in Figure 2–3, the complexity of a system is intimately tied to system description and is conditioned by how an observer interacts with it. That is, a system appears complex to the extent that one can form a number of non-equivalent descriptions of it (Rosen 1977). One can also think of complexity as indicative of scope of interaction: an expansive scope suggests high complexity.

Disparities between design and control complexity are the rule rather than the exception. In fact, surprises can be seen to arise from this disparity when design complexity exceeds control complexity—a situation in which the observer lacks sufficient variety, to use Ashby's (1976) cybernetic term. In such circumstances the behavioral repertoire of the observing system, or its scope of interaction, is too narrowly circumscribed to permit regulation of the material system. Figure 2–4 is inspired by Casti's discussion and portrays a surprise continuum defined by the relative complexity of two interacting systems. The ratio $\kappa = C_S(O) / C_O(S)$ represents the magnitude of the disparity between control and design complexities, and it should be interpreted heuristically—no procedures for estimating it will be contemplated.

Figure 2–4
The surprise continuum



For $\kappa >> 1$ the observer can obtain a very rich description of the source system and make successful predictions. For $\kappa << 1$ only a rather impoverished description is available and prediction is virtually impossible. While the erstwhile manager would prefer to operate on the right side of the spectrum (i.e. few surprises), this is no mean feat. Such a state of affairs can be achieved by either drastically simplifying the system (we can be quite adept at doing this) or by expanding the behavioral repertoire of the decision-maker. If it is not possible for the observer to dominate the system (large κ), then surprises or side effects become ineluctable. Coping with complex systems thus becomes a shakier game than commonly supposed. Objectivist measures make several tacit assumptions about the properties of the observer:

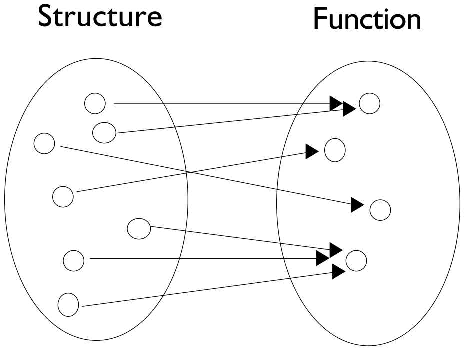
- the observer-system interaction is unidirectional—a 'bossing' relationship prevails
- the observer is omnipresent (i.e. can move freely across scales)
- the observer is more complex than the source system (i.e. large κ)

These are very special conditions that we rarely enjoy, and then only with the help of stringent laboratory controls. Take away the expensive technological aids and what remains are descriptions that incorporate the many choices made (consciously or not) by the observer(s). A description or model of a system is an abstraction that represents a way of looking at the world. Any given model, arising from limited interaction with some material system, is incomplete—there is no 'mother of all models' that can capture every aspect of system behavior with total fidelity. The system is open to interactions the model itself does not admit. In other words, surprise is inevitable and reductionism doesn't always work.

Anti-reductionist arguments have a long history in biology. And while anything that smacks of vitalism is frowned upon these days, there have been recent attempts to demonstrate the difficulties of reducing biological phenomena to fundamental laws or to a small body of interrelated models. Rosenberg (1994) ascribes the irreducibility of biology to its being a relatively more instrumental science—its usefulness is circumscribed by our computational and cognitive powers: "Our biological science will turn out to be an observer-relative science, an instrument for getting around in our world, and not something the scientific realist will embrace as the best guess as to what the world is really like" (1994, 103).

Rosenberg points out that in biological systems functional kinds may supervene on structural kinds. That is, functions are multiply realizable. While functions are grounded in structures, a given function is not necessarily identifiable with a unique structure. So supervenience is then weaker than reducibility; the mapping of structure to function is surjective ('onto', Figure 2–5). This situation blocks 'layer-cake' reductionism that presupposes lawful regularities set up a straightforward one-to-one mapping between structure and function.

Figure 2–5
Supervenience as a surjective mapping



Rosenberg holds fast to the assumption of mereological determinism: "Two biological systems with different Mendelian properties will have to differ in some molecular property or other, although two biological systems may be identical in Mendelian properties while differing in molecular ones" (1994, 23). In other words, functional kinds supervene on structural kinds. The crux of the argument here is that selection for function is blind to structure: "It is the nature of any mechanism that selects for effects, that *it cannot discriminate between differing structures with identical effects*" (1994, 27).

A more venerable line of anti-reductionist reasoning in organismic biology stresses the hierarchical organization of living systems. Part-whole relations in biological systems have spurred an area of study that focuses on patterns of integration and regulation. By distinguishing multiple levels of organization, theorists and experimentalists have investigated complex phenomena by trying to steer a course between knee-jerk reductionism and facile holism. Developmental biologists in particular were keen to bridge the old dichotomies rooted in the historical vitalism–mechanism debate. During the 1930s the Theoretical Biology Club at Cambridge singled out hierarchical organization as the central problem for biology. In her historical account of twentieth-century developmental biology, Haraway described the club as a loosely-knit paradigm community open to a range of influences: "The organismic paradigm involved the convergence of thought from mathematics, experimental embryology, biochemistry, biophysics, protein chemistry, logic, and language theory" (Haraway 1976, 134). Thus thinking about hierarchical organization proceeded from eclectic underpinnings, and even today it remains quite far-flung. Hierarchical organization is now a staple of systems thinking, where it is generally adduced as an alternative to mechanical, reductionist approaches. Two interdisciplinary symposia held in 1968 centered on the characterization of organic and inorganic hierarchies; while nothing so cogent as a theory can be discerned, the proceedings surveyed many of the basic problems and conveyed the immense scope of hierarchical classifications[6]. The term 'hierarchy' commonly entails relationships of authority or control, but looser denotations have been applied to systems that are organized on multiple levels and are not strictly confined to one-way bossing relations.

Notions of complexity and hierarchical order were not long confined to the general systems literature and they soon found a place in modern ecological theory. Allen and Starr (1982) viewed hierarchies as systems of communication in which higher levels constrain lower levels and provide the context within which lower levels function; successively faster behavior occurs lower in the hierarchy. Salthe (1985) articulated an explicitly structuralist conception of hierarchy theory and argued that a triad of three adjacent levels should suffice to describe any complex diachronic system. Lower level constraints comprise *initiating conditions* for focal level processes, and upper level constraints provide exogenous *boundary conditions*. Salthe construes the transmission of information from below as formal or material 'cause', and from above as 'regulation'.

Many of the ideas put forth by Allen and Starr were refined by O'Neill and others (1986) and packaged as a fledgling 'hierarchy theory'. According to this theory, organization results from differences in process rates. Each level acts like a low-pass filter, attenuating higher frequencies and establishing a loose vertical

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[6] The symposia were held at Huntington Beach, California and at Alpbach, Austria; the proceedings were published in 1969 under the titles *Hierarchical Structures* and *Beyond Reductionism*, respectively.

coupling. The resulting structure may or may not be nested. Rates within the surface of a holon (the term, coined by Arthur Koestler, denotes an entity interacting within a whole) are relatively rapid and uniform, and relatively slower and weaker between holons; this asymmetry of rate processes is taken to be a basic organizing principle. A system can then be seen to be rate-structured: discontinuities are useful for defining system components (Figure 2–6). Since the perceived dynamics vary with scale, system definition hinges on the actual observational protocols employed.

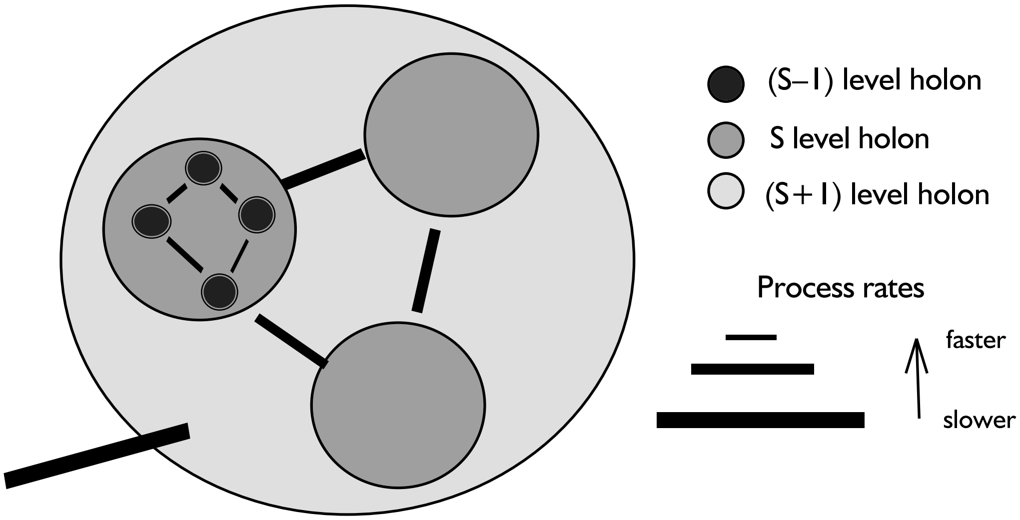

Figure 2–6
An ideal nested hierarchy (*Source*: Allen and Hoekstra 1992, Fig. 1.5)

In another monograph exploring the scale-dependency of material systems, Allen and Hoekstra echo a point made by Salthe in arguing that both context and mechanism are important in understanding complex systems:

> For an adequate understanding leading to robust prediction, it is necessary to consider at least three levels at once: 1) the level in question; 2) the level below that gives mechanisms; and 3) the level above that gives context, role, or significance. A full account of mechanisms becomes irrelevant if the context changes. (Allen and Hoekstra 1992, 9)

The U.S. National Research Council conducted a review of attempts to combine diverse environmental data, including data sets that span multiple scales. The committee charged with the task warned against merging ecological and geophysical data by rote without considering scale-related issues and their implications for analysis (National Research Council 1995a, 87). The report went on to note the lack of guidelines for assisting cross-scale data integration, but pointed to hierarchy theory as a promising approach. Hierarchy theory in its various guises represents some of the most thorough work on scale-related issues in ecology, and it promises to clarify some of the difficulties surrounding data integration and the observation of complex systems; it implies that there is no single 'correct' scale for analysis, an idea that will be taken up in more detail in chapter five which brings to light some of the thornier challenges in considering the delineation of system boundaries.

Before pressing on, I shall briefly reiterate a few key ideas introduced in this (admittedly quite abstract) section. Excessive formalism is unwarranted and unlikely to prove very fruitful when dealing with complex systems. Surprises are inevitable, and become rampant when requisite variety (in Ashby's sense) is lacking; this is the case when stringent experimental controls are impracticable. Natural phenomena unfold at multiple scales, so any monitoring initiative that neglects this aspect cannot adequately address cross-scale issues. Hierarchy theory has much to offer but, as we shall see, its proponents espouse contrasting metaphysical commitments.

2.4 Ontological attitudes

Approaches to complexity can be crudely sorted into two styles of thinking that reflect different philosophical positions, namely, objectivism and constructivism[7]. This is a crude characterization as one could also define hybrid positions occupying the middle ground between the 'pure' extremes. Objectivism holds that material reality is directly and unambiguously accessible, and it is fair to say that this reflects the dominant standpoint. Constructivism posits two fundamental aspects of knowledge acquisition: interactivity and positionality; under this view knowledge is acquired through interaction with the 'unmediated flux' from within a particular cultural and disciplinary milieu

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[7] I regard dichotomies with considerable ambivalence—they always strike me as being just a little too clean-cut and tidy. Maybe their appeal has something to do with the fact that we are bilaterally symmetrical organisms: two cerebral hemispheres, left and right hands, and so on. Imagine the richness of our classifications if we were starfish!

(Hayles 1995). Put another way, context conditions observation and each description (or model) is thus positioned and local. But not all descriptions need be judged equally acceptable or appropriate, leading to a sort of constrained constructivism.

Description assumes different guises under each approach. Table 2–2 contrasts the exo- and endo- approaches to system description[8]. The two approaches reflect views from the outside and the inside, respectively. The characterization is not exhaustive by any means, but it serves to convey the general flavor of the two ideal styles.

Table 2–2
Exo- and endo-perspectives compared

Exo-perspective	Endo-perspective
• objectivist epistemology	• constructivist epistemology
• external observer is omnipresent, aloof	• internal observer is positioned, participant
• natural systems are computable	• not all (e.g. biological) systems are computable
• one-way information flow, system → observer	• bidirectional information flow, system ↔ observer
• resists complementary representations	• accepts complementary representations

Other dichotomous characterizations can be found in the systems literature. For example, Checkland (1981) distinguishes hard-systems from soft-systems thinking primarily in terms of how structured a problem situation is: a structured situation admits precisely defined objectives, whereas an unstructured situation does not. The characterization given in Table 2–2 is very roughly congruent to Checkland's distinction (e.g. constructivism vs. objectivism), but it places more emphasis on the role of the observer. Harking back to Figure 2–4, it seems that an exo-perspective corresponds to large κ (i.e. good control, few surprises), while an endo-perspective pertains to situations for which κ is very small (i.e. poor control, surprise is endemic). A case for complementarity can be made on the basis of scope of control: when it is high an exo-physical viewpoint is warranted, but when

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[8] The distinction between internal and external viewpoints has also been made in the context of methodological problems associated with observing physical systems—hence "endophysics" and "exophysics". See the volume edited by Atmanspacher and Dalenoort (1994) for pertinent papers.

it is low an endo-physical viewpoint—along with its precepts—is more appropriate. Assuming an exo-physical perspective when the scope of control is low is a vainglorious stance.

For centuries scientific practitioners have been engaged in the often delicate task of nullifying or neutralizing context in order to strip away the local and the particular and to lay bare the general regularities of natural phenomena. Reductionism dominates systems methodology, especially when experimental manipulations are feasible—we tend to explain the behavior of an entity in terms of its internal features rather than paying close attention to how it relates to its environment. We try to discover the law-like rules that govern the behavior of constituent parts. So the heuristics of decomposition and localization are central strategies in scientific research. A system is deemed decomposable if it is seemingly organized in a modular fashion; localization is predicated on identifying a single locus of control for some behavior (e.g. hereditary traits are conveyed by DNA). These basic strategies tend to underwrite mechanistic explanations. According to Bechtel and Richardson (1993), several factors seem to motivate the search for mechanisms:

- evolutionary development may well favor hierarchical organization in natural systems
- a desire for theoretical economy
- consonance with human cognitive processes such as perception and memory

The idea that selection processes favor hierarchical organization and thus give rise to nearly decomposable systems was expressed by Herbert Simon (1962). The 'watchmaker parable' he concocted was intended to demonstrate that modular objects can be assembled more quickly if stable subassemblies exist and the construction process is subject to disruption. Salthe (1985, 145) refers to this conception as an *aggregative* model, but he considers a *fragmentation* model to be more general. In this model instabilities within a system lead to subdivision and differentiation, with new levels arising as a consequence. Salthe acknowledges that both types of formative processes can occur within a system, often with aggregation following differentiation. Levins and Lewontin suggest that disparate selection pressures promote the uncoupling of system variables, and that species adaptation occurs more readily when fitness components are somewhat autonomous;

excessive constraint—very tight coupling—confers vulnerability to breakdown (1985, 62).

Hierarchy theory lends itself to different styles of discourse according to the perspective adopted by the proponent. An exo-perspective favors an ontological style which considers a posited hierarchy as representative of the 'state-of-the-world'. An endo-perspective sees a posited hierarchy more as an epistemological device that represents the 'state-of-knowledge'. Many researchers assert that hierarchical ordering is 'out there' and is manifest as a real, tangible structure in which system dynamics can be readily isolated into discrete scales (O'Neill, Gardner, and others 1991). Salthe (1985) forthrightly declares his metaphysical commitment to entities in his "thing oriented" account of hierarchical systems; consider this glossary entry:

> HIERARCHY OF NATURE: A representation of the world as composed of entities assignable to a hierarchy of levels of organization presuming that the world really is hierarchically structured. It is meant as an ontological interpretation of data from the real world. (Salthe 1985, 292)

A contrasting view regards hierarchy theory more as a way of reasoning about the observation and measurement of natural systems. Allen and Star (1982) shrink from ontological issues and prefer a more utilitarian orientation that construes discrete levels in terms of convenience, not absolute truth. Allen and Hoekstra decry the proliferation of "naive ontological assumptions" that tend to reify tangible entities in biotic systems (1992, 161). A recent monograph (Ahl and Allen 1996) draws on cognitive science to describe how observation, perception, and learning may be related. What emerges is an overtly constructivist position that emphasizes the degree to which an observer structures experience in the course of interacting with the world:

> Notice that units and levels should not be interpreted as features of the external world, existing independently of an observer's criteria for delimiting the system. The concept of level is relative to the point of view taken by an observer. (Ahl and Allen 1996, 33)

One thing to note here concerns the relative weighting of structure and function. The exo-style of discourse focuses on structure and readily takes entities to be logically prior to processes, whereas the endo-style focuses on process and considers it to be prime.

Upper level constraints establish boundary conditions for focal level processes. Under laboratory conditions these boundary conditions are deliberately controlled so as to restrain the system of interest and eliminate possibly confounding influences. Salthe (1985) remarks that the highly stylized and condensed accounts that appear in the "materials" and "methods" sections of research papers seriously downplay the role of context and praxis in acquiring knowledge. When dealing with complex systems, it's hard to be conclusive in 5000 words or less.

It's time to summarize the position I've attempted to stake out here. I reject essentialism: the blithe assumption that we can always extract the adamantine essences of things—the supposition that good scientific practice guarantees the ascent to Truth. Instead, I favor an ontological and epistemological pluralism that is antifundamentalist, situated in the middle ground between credulous positivism and incredulous post-positivism. But the anti-fundamentalist outlook I urge stops short of asserting that we can take nothing whatsoever for granted—you can't build a house on quicksand. It behooves us to occasionally glance down at our feet and examine the ground upon which we stand; perhaps the label *constrained constructivism* or *symmetric realism* might apply. I understand fundamentalism in the sense expressed by Cartwright:

> There is a tendency to think that all facts must belong to one grand scheme, and moreover that this is a scheme in which the facts in the first category [facts acquired in highly structured environments and immured in theoretical schemes] have a special and privileged status. They are exemplary of the way nature is supposed to work. The others must be made to conform to them. (Cartwright 1994, 281)

My basic attitude is one of agnosticism, not total skepticism about the underlying orderliness of the world. We perceive the phenomenal world indirectly and imperfectly: our conceptual schemas need not be homomorphic to 'reality'. An observer plays an active role in (partially and collectively) constructing what counts as genuine knowledge. According to Ahl and Allen

(1996), an observer structures an observation at several junctures in the course of a scientific investigation:

- posing a question to focus inquiry
- defining entities (i.e. differentiating between figure and ground)
- selecting measurement protocols
- noticing phenomena or distinguishing behaviors of interest
- evaluating models (e.g. according to utility, aesthetic appeal)

I find the epistemological variety of hierarchy theory espoused by Allen and his colleagues to be most congenial to my own sensibilities. As Ahl and Allen put it: "There is no such thing as objectivity in science—only cognizance of biases, if you are lucky" (1996, 36). The significance of a positioned, value-laden observer cannot be overlooked (Figure 2–7).

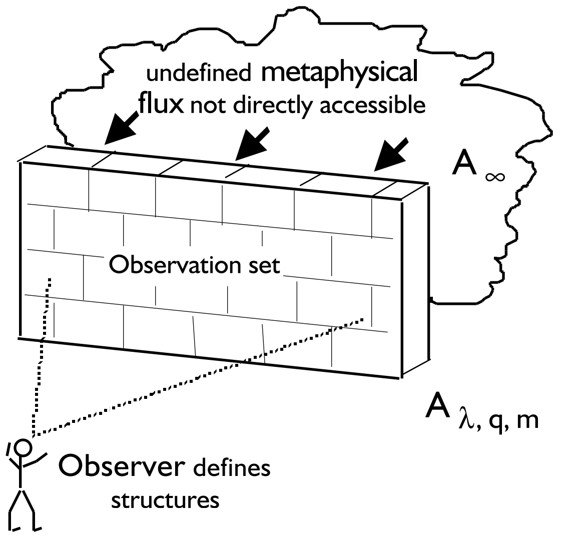


Figure 2–7
A value-laden observer imposes metadata attributes (*Source*: Ahl and Allen 1996, Fig. 2.4)

The symbol A_∞ denotes the realm of undifferentiated (i.e. pre-ontological) phenomena and suggests that the 'metaphysical flux'—the phrase is borrowed from Smith (1996)—is *inexhaustible*: the phenomenal world admits an indefinite number of possible descriptions that reflect how an observer interacts with it. An object is complex to the extent that it admits multiple descriptions. The notation $A_{\lambda,q,m}$ in Figure 2–7 provides a reminder that an observation set is not just an ensemble of pure numbers or properties—objects are distinguished through some specified mode(s) of interaction with attributes such as scale (λ), data quality (q), and methodology (m). Meaningfully combining different observation sets requires an appreciation of these *metadata* attributes. A keen appreciation of metadata is crucial when sharing and preserving data sets that have been acquired by different groups asking different questions, at different scales, using different protocols. Michener and others (1997) offer several recommendations for the development and implementation of ecological metadata: information that describes the content, context, quality, structure, and availability of a data set; their recommendations for facilitating the exchange and long-term reuse of ecological data will be reviewed in chapter five.

From a constructivist stance, perceived structure reflects how an observer has chosen to interact with a system of interest. The detached, "God's-eye" view is a delusion. Data sets are not pure, adamantine nuggets awaiting the scrying eye; they are larded with assumptions, definitions, and decisions that need to be assessed if disparate data are to be meaningfully combined—a particular perspective is 'built in', so to speak. Rosen, Kampis, Allen, and others have developed some deep ideas about the observation and description of natural systems. I invoke them primarily as philosophical allies who have thought carefully about the shortcomings of applying Newtonian concepts to complex living systems. However, running all of their ideas to ground is another thesis! Kampis and Rosen have critiqued at length classical modeling approaches built around the state concept, and argued that they are inadequate for dealing with systems that are neither closed nor mechanical. While it's much too soon to declare the advent of an alternative modeling methodology, a few researchers are engaged in preliminary work along these lines.

Clarke (1998) makes a case for pluralism about both metaphysics and epistemology; he argues that science can be practiced—and even progress—without positing the fundamental unity of either scientific methodology or of the universe at large. In lieu of presuming that the world has some basic level of organization, Clarke relies heavily on Cartwright's (1994) ideas about nomological pluralism, the doctrine that systems of laws applicable to different domains are not necessarily related to each other in a straightforward way— 'reality' may be just a patchwork.

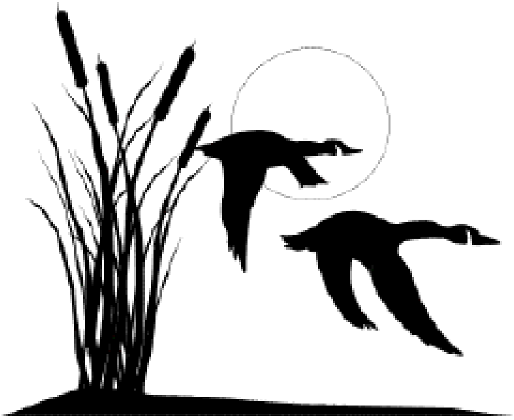
In a somewhat densely written text, Smith (1996) attempts to lay out a constructivist ontology, a sort of 'successor' metaphysics that tries to do justice to pluralism while guarding against what he calls vapid, ‘anything goes’ relativism. Smith advances the motto that “an object is something on which one can have a perspective” (1996, 117). He points out that we must struggle to fit our perspectives with other perspectives and with the unconceptualized world.

> If we should ever make the mistake of thinking that we are the whole story, moreover—that we “have it down”, that we are in control—then the world has a fortunate habit of tripping us up, of reminding us that our perspective is both flawed and partial, that ours is not the only game in town. (Smith 1996, 97)

I’ve stirred up a lot of dust in this chapter. To what end? The overall intent is to show how constructivism is a viable outlook when it comes to the observation and description of natural systems beyond the confines of a laboratory. While stringent controls often provide a warrant for mechanistic explanations of tame laboratory systems, the adoption of an exo–perspective is more dubious when grappling with systems in the wild. An active, positioned observer *filters* structure from an undifferentiated material flux; observed structures depend on the type of ‘meters’ deployed and do not reflect some pure, invariant essence. Consequently, environmental monitoring becomes a much shakier game than most accounts would have it. Interpreting and combining environmental data entails the creation and maintenance of what Bannon and Bødker (1997) have called a *common information space* within which differing viewpoints and multiple interests may be linked; this theme will be taken up in chapters five and six.

A credible systems approach need not be predicated on some overarching narrative or ‘mother of all models’. But as I will show, a variegated or *multithreaded* ecosystem approach is more concerned with promoting systemic learning and the partial alignment of multiple perspectives than with securing improved prediction and control. Let me be clear about my own convictions: I do not rule out reductionism as a useful methodological tenet, but neither do I imagine it to come with any guarantees. I decline to hold it up as the only basis for comprehending any complex system. My basic position is one of agnosticism—it’s good work if you can get it!

The next chapter delves into several proposed frameworks for integrated monitoring. For the most part these official frameworks are centered on mandates to provide a sound scientific basis for management activities. The clamor for improved coordination, standardization, early warning, and policy relevance are part and parcel of the technocratic mentality that seems to undergird most discussions of monitoring.



Chapter 3

The mangle of integrated monitoring

No data base will ever be invented that answers to the command: "Show me everything that is true and relevant."

Theodore Roszak,
The Cult of Information

3.1 Taking earth's measure

We place a high priority on collecting data. Now that many environmental issues command global attention, the scope of monitoring activities has ballooned to encompass the entire planet. This expansion has been propelled by several factors. There are a growing number of regional and national initiatives that aim to provide a scientific basis for policy, to improve legislative oversight, and to contribute to state-of-the-environment reporting or environmental assessments; these include the *Ecological Monitoring and Assessment Network* in Canada, the *Environmental Monitoring and Assessment Program* in the United States, and the *Environmental Change Network* in the United Kingdom[1]. Other initiatives are designed to support the aspirations of global change researchers to plumb the workings of the "total earth system": the U.S. Global Change Research Program, the International Geosphere-Biosphere Program, and the World Climate Research Programme, for example[2]. A glance through the associated documents suggests that when it comes to interpreting data, these programs are steadfastly optimistic about the prospects for coping with the demands of data management by means of improved information technologies.

Cross-scale inference—scaling up in particular—has long been a preoccupation of researchers in many earth science disciplines. The task becomes especially onerous when dealing with disparate data sets collected by different groups, at different times and places, asking different questions at different scales. Numerous technological solutions are being vigorously pursued, with much emphasis on devising 'realistic' simulation models to integrate information across scales, and on using geostatistical techniques to identify spatial patterns. Geographical information systems (GIS) are widely promoted as an integration tool that readily permits the amalgamation of diverse data sets to create a single,

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[1] For information concerning these national programs, take a look at the following web sites: *Ecological Monitoring and Assessment Network* <http://www.cciw.ca/eman-temp/intro.html>; *Environmental Monitoring and Assessment Program* <http://www.epa.gov/emap/>; *Environmental Change Network* <http://www.nmw.ac.uk/ecn/>

[2] Information about these global change programs can be found at these web sites: *U.S. Global Change Research Program* <http://www.usgcrp.gov/usgcrp/GCRPINFO.html>; *International Geosphere-Biosphere Program* <http://www.igbp.kva.se/>; *World Climate Research Programme* <http://www.wmo.ch/web/wcrp/wcrp-home.html>.

multi-purpose database. Some boosters even conceive of a 'World GIS' (Morrissey 1993).

Hellawell (1991) noted that 'monitoring' is a bit of an omnibus term. In the interest of clarification he distinguished three modes of environmental observation: surveying, surveillance, and monitoring. Surveying and surveillance tend to be more exploratory and open-ended than monitoring which adheres to predetermined standards or norms. According to Hellawell then, objectives go hand-in-hand with monitoring and can be roughly classified into three categories (1991, 3):

- estimating the effectiveness of policy or legislation
- assessing regulatory compliance
- detecting incipient change (i.e. 'early warning')

I prefer a looser construal of environmental monitoring, retaining the sense of directed observation but relaxing the centrality of *a priori* objectives. Furthermore, I'm inclined to paint on a broader canvas. There are a number of theoretical and organizational factors that belie the easy assertion that state-of-the-art technology can pave the way to the seamless integration of diverse environmental data sets. But addressing these difficulties requires digging below the pervasive fascination with sophisticated hardware/software configurations and enhanced visualization techniques.

The first thing to appreciate is that when people utter the words "integrated monitoring", they can mean different things depending upon their aims and expectations. These are some of the more common aims:

- harmonizing the responsibilities and objectives of participating groups and agencies
- coordinating the collection and exchange of data
- acquiring data at multiple spatial and temporal scales
- sampling multiple media (e.g. air, water, soil, biota, human society)
- merging disciplinary perspectives or models
- standardizing data management practices (i.e. storage, processing, and reporting)

Trying to accomplish all of the above is a tall order, so most initiatives concentrate on a subset of these aims. Given the disparity of intentions, environmental monitoring can be seen to encompass a mangle of technical, bureaucratic, and social concerns; this multifarious character makes for a rich assemblage of initiatives undertaken at many levels for many different purposes.

3.2 Charting progress

A striking characteristic of almost all monitoring initiatives is that they are built around a formal mandate—an overarching mission statement, interagency agreement, or piece of legislation that provides a basis for monitoring activity. Along with a mandate are bundled certain assumptions and expectations about the role of monitoring and its contributions to decision-making. A number of examples will help bring these to light.

The Niagara Escarpment, designated a UNESCO Biosphere Reserve in 1990, is a ridge of fossil-bearing limestone that cuts across southwestern Ontario. The Ontario Niagara Escarpment Monitoring Program was developed to support land use planning at a regional level by using a mix of intensive and extensive monitoring techniques, including Landsat Thematic Mapping (TM) data, aerial photography, and field observations (MacViro Consultants 1995). The program takes its lead from the objectives put forth in the Niagara Escarpment Planning and Development Act[3] (Box 3–1).

The monitoring program, which is designed to track cumulative changes in land use and ecological status, employs a mapping framework that uses Ontario Land Inventory classification units (distinguished by soil characteristics and topography) as the basic ecological units. The rationale for the program is threefold (MacViro Consultants 1994):

- monitoring the status and function of ecosystems
- assessing the short- and long-term effects of NEP policies
- providing data to support management decisions affecting the Escarpment

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[3] The Niagara Escarpment Commission is responsible for implementing the Act through the Niagara Escarpment Plan (NEP). Information about the NEP, the monitoring program, and the Commission's work can be perused at <http://escarpment.org/>.

Monitoring is portrayed as a continuous process that is hierarchically structured from upper-level objectives, to specific questions, to components, to indicators, to targets. The Plan area has been divided into three regions: southern (Niagara Peninsula), central (Halton area), and northern (Bruce Peninsula); the three regions experience different intensities of development pressures, with urban influences becoming less pronounced and agricultural issues becoming more important as one moves northward. Within the regions there are two types of monitoring sites: *control sites* in areas subject to relatively little development, and *pressure sites* in areas where development pressures are more severe.

Box 3–1
Legislated objectives for monitoring along the Niagara Escarpment (*Source*: Government of Ontario 1992, sec. 8)

- to protect unique ecologic and historic areas
- to maintain and enhance the quality and character of natural streams and water supplies
- to provide adequate opportunities for outdoor recreation
- to maintain and enhance the open landscape character of the Niagara Escarpment in so far as possible, by such means as compatible farming or forestry and by preserving the natural scenery
- to ensure that all new development is compatible with the purpose of this Act as expressed in section 2
- to provide for adequate public access to the Niagara Escarpment
- to support municipalities within the Niagara Escarpment Planning Area in their exercise of the planning functions conferred upon them by the Planning Act

Both extensive and intensive monitoring techniques have been recommended for adoption. Intensive, detailed monitoring at the site level (e.g. ground-level photography, field observations of terrestrial plots and stream reaches) is to be complemented by more extensive monitoring at the regional level (e.g. Landsat Thematic Mapping data, aerial photography). Much work has been done to establish forest biodiversity monitoring plots according to the protocols developed under the Smithsonian Institute Man and the Biosphere (SI/MAB) Biological Diversity

Program[4]. These plots are becoming increasingly popular in biosphere reserves, as much for their educational value as their scientific contribution to biodiversity monitoring (a contribution some experts have publicly disparaged, though).

Some federal environmental legislation also calls for monitoring. The 1988 amendments to the National Parks Act require Parks Canada to report on the state of ecological integrity in the national parks. Ecological integrity denotes the condition of an ecosystem such that its structure and function are unimpaired by human-induced stresses, and its biological diversity and supporting processes are likely to persist (Canadian Heritage 1998, 23); this edict shapes the goals for monitoring ecosystems in and around Canadian national parks.

The assessment of ecological integrity involves three general categories of indicators pertaining to biodiversity, ecosystem functions, and stressors. There is considerable latitude in selecting indicators to reflect local conditions. A monitoring plan for Bruce Peninsula National Park and Fathom Five National Marine Park was recently prepared in light of park management objectives[5]. The indicator framework was adapted from the one developed for the Niagara Escarpment, and includes an initial suite of about 40 indicators grouped into eight categories (Zorn and Upton 1997):

- habitat patch characteristics
- species diversity
- sensitive species
- barriers to accessibility
- species of special interest
- natural disturbances
- primary productivity
- human disturbances

The centrality of a formal mandate for integrated monitoring is especially apparent around the Great Lakes. The Great Lakes Water Quality Agreement (last amended in 1987) spawned a host of obligations on the part of federal, provincial, and state agencies in Canada and the United States. Annex 2 of the Agreement lists

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[4] The SI/MAB program is described at <http://www.si.edu/ripley/simab/aboutsimab.html>.

[5] A collection of WordPerfect documents outlining various elements of the Ecological Integrity Monitoring Plan can be downloaded from <http://www.nhb.com/eimp/>. Parks Canada formed a panel to oversee the assessment of ecological integrity in national parks: <http://parkscanada.pch.gc.ca/ecol/main_e.htm>.

fourteen beneficial use impairments that are considered detrimental to the integrity of the Great Lakes basin (Box 3–2).

Box 3–2
Beneficial use impairments for the Great Lakes (*Source*: International Joint Commission 1997, Annex 2)

i. restrictions on fish and wildlife consumption
ii. tainting of fish and wildlife flavour
iii. degradation of fish wildlife populations
iv. fish tumors or other deformities
v. bird or animal deformities or reproduction problems
vi. degradation of benthos
vii. restrictions on dredging activities
viii. eutrophication or undesirable algae
ix. restrictions on drinking water consumption, or taste and odour problems
x. beach closings
xi. degradation of aesthetics
xii. added costs to agriculture or industry
xiii. degradation of phytoplankton and zooplankton populations
xiv. loss of fish and wildlife habitat

Parties to the Agreement are enjoined to adopt an ecosystem approach to restoring and protecting beneficial uses. Remedial Action Plans (RAPs) for identified Areas of Concern and Lakewide Management Plans (LaMPs) for critical pollutants are the principal vehicles for implementing an ecosystem approach[6]. MacKenzie (1996) studied three RAP initiatives in depth and noted that institutionalization of the ecosystem approach remains quite weak: “At this early point in the evolution of the ecosystem approach, the RAPs have not fundamentally changed the predominant nature of water resource management in the Great Lakes region” (1996, 212). However, the flexible and consensus-driven process MacKenzie urges is at odds with the entrenched predilection for formalized decision methodologies.

A task force was set up in 1993 to develop a framework for indicators to evaluate progress under the Agreement. Nine desired outcomes—partly derived from the beneficial use impairments—

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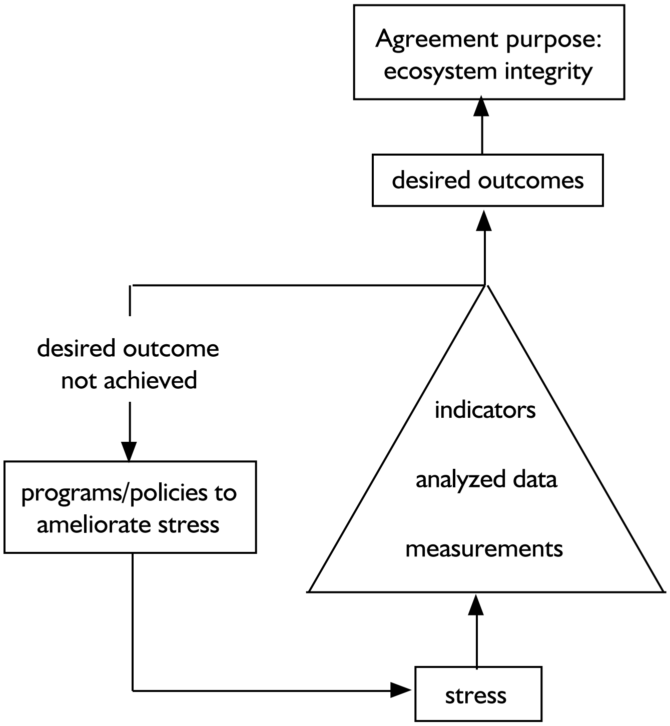
[6] The RAP programs are listed at <http://www.cciw.ca/glimr/raps/>, and more information about the LaMPs can be found at <http://www.cciw.ca/glimr/program-LaMPs.html>.

were selected to characterize ecological integrity; these interrelated desiderata are to provide a basis for selecting appropriate indicators (Box 3–3). Figure 3–1 illustrates the evaluation framework. Yet another task force was established in early 1997 to critically examine available data and to assess the feasibility of proposed indicators. A limited pilot study yielded the impression that disparate databases (i.e. those with differing protocols, formats, and metadata) hindered integration efforts (International Joint Commission 1998).

Figure 3–1
A framework to evaluate progress under the Agreement (*Source*: International Joint Commission 1996, Figure 1)



Box 3–3
Desired outcomes for the Great Lakes (*Source*: International Joint Commission 1996, Table 4)

1. Fishability
2. Swimmability
3. Drinkability
4. Healthy human populations
5. Economic viability
6. Biological community integrity and diversity
7. Virtual elimination of inputs of persistent toxic substances
8. Absence of excess phosphorus
9. Physical environment integrity

Figure 3–1 is a good example of the type of flowchart devised by many program designers laboring under the presumption that evaluating policy outcomes is an algorithmic process. Managerial formulations, marked by a preoccupation with measuring progress toward pre-defined goals, dominate current thinking about environmental monitoring. The global prescriptions generally go something like this: stipulate a desired goal-state; problematize the 'gap' between current and desired states; and take action to close this distance as efficiently as possible. All this makes for a very tidy package that takes much for granted and papers over some very real difficulties associated with complexity. For example, the prevalence of discontinuous change and fine-scale unpredictability receives scant attention, even though classical dynamical systems theory shows how unexceptional these properties are in merely 'complicated' systems.

An *attractor* is a high-level feature of a dynamical system; a geometric abstraction, it basically denotes the set to which neighboring trajectories in the phase space converge over the long-run, $t \rightarrow \infty$ (any text on nonlinear dynamics will give a more technical definition). For instance a simple, damped pendulum has a single fixed-point attractor at the origin of the position-velocity phase space, at which the pendulum arm lies vertically at rest. More complicated systems can possess multiple attractors (with quite intricate properties) lying within their associated *basins of attraction* (i.e. the set of initial conditions that converge to the attractor as $t \rightarrow \infty$). The term attractor is often used fairly loosely to suggest that the long-term behavior of a system is somehow constrained—that the system cannot be found just anywhere in the phase space, and that there are states that cannot be reached from any given initial state; this is an alien prospect to the managerial mindset. Regier and Kay (1996) provide an heuristic ecological example (an explicit mathematical representation is unavailable) of discontinuous shifts in the trophic condition of aquatic ecosystems using the classic cusp geometry from catastrophe theory, with depth and phosphorus load as the input parameters and turbidity as the output variable. Scheffer and Jeppesen (1998) also use catastrophe theory to explain the interplay between phytoplankton and macrophyte abundance in freshwater lakes; the cusp geometry represents shifts between vegetated (clear) and unvegetated (turbid) conditions in shallow lakes. Such rich dynamics promise to frustrate the desire to finely predict the outcome of rehabilitation strategies in the Great Lakes basin.

3.3 Some integration frameworks

For most advocates, integrated monitoring is about understanding, explaining, and predicting change in order to improve the quality of environmental decisions:

> Integration means more than coordination or collocation, in that it also involves timely analysis and focused research, both multidisciplinary in character. Integrated monitoring injects a new concept—the desire for coordinated multidisciplinary analysis in order to reveal the causes of changes that occur in complex environment systems. (Hicks and Brydges 1994, 3)

Ecological Monitoring and Assessment Network

The calls for integration tend to be most strident at the national level. Canada's national multi–agency network, the Ecological Monitoring and Assessment Network (EMAN), was established to provide 'scientifically defensible' rationales for management activities by supporting efforts to understand what changes are occurring in ecosystems and why (Ecological Monitoring Coordinating Office 1997). Brydges and Lumb (1998) express four general objectives of EMAN:

1. To define and measure the effects of environmental stresses and their interactions
2. To provide scientific rationales for pollution control measures
3. To evaluate and report on the effectiveness of existing management policies
4. To alert Canadians to new problems at the earliest possible stage

Environmental Monitoring and Assessment Program

Similar sentiments are expressed in the United States, where the Environmental Monitoring and Assessment Program (EMAP) is dedicated to a three-tiered monitoring approach (Environmental Protection Agency 1997):

- forming a national network of index sites to intensively monitor long-term changes (primarily in the atmosphere)

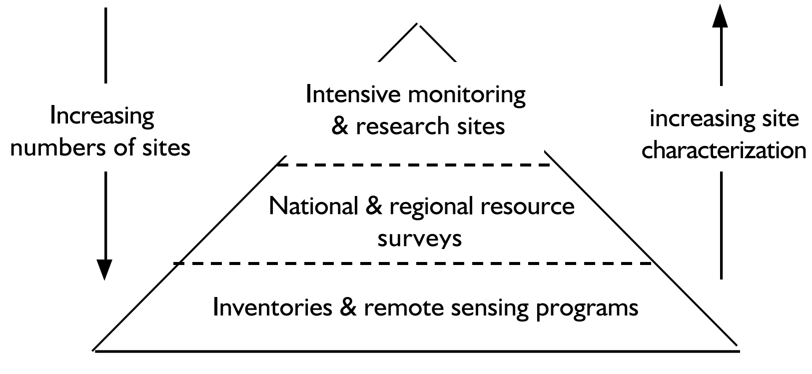
- undertaking regional-scale geographic assessments to characterize the status and trends in the condition of terrestrial, inland aquatic, estuarine, and landscape resources
- conducting national landcover monitoring using remote-sensing techniques.

The revisions to EMAP over the last several years were spurred by questions concerning its scientific basis. A review committee established by the U.S. National Research Council noted that indicator development was poorly coordinated across resource groups, and criticized the apparent lack of mechanistic conceptual models to guide indicator selection (National Research Council 1995b, 55). In the aftermath of the lengthy review process EMAP will place greater emphasis on enhancing scientific credibility in three key areas: the development of effective ecological indicators, the design of monitoring networks, and the integration and synthesis of data within and between ecological resources and tiers.

CENR framework

The revamped EMAP strategy has much in common with a conceptual framework proposed by the Committee on Environment and Natural Resources (CENR), a standing committee of the National Science and Technology Council (a cabinet-level entity). The CENR framework suggests how federal monitoring activities in the U.S. can be linked as part of a strategy for producing comprehensive assessments of natural resources: "These integrated environmental assessments should identify environmental and ecosystem trends, relate these trends to their causes and consequences, and predict outcomes of alternative future scenarios" (Committee on Environment and Natural Resources 1997a, 15). Figure 3–2 outlines the proposed scheme.

Figure 3–2
Proposed CENR framework (*Source*: CENR 1997a, Fig. 2)



Environmental Change Network

Nor have European countries ignored the clarion call for integrated monitoring. The Environmental Change Network (ECN) in the U.K. is sponsored by a consortium of government departments and agencies. The major objective is to intensively monitor terrestrial and freshwater sites for a range of variables relevant to current issues such as climate change, soil quality, and biodiversity (Lane 1997). The data management system, a hybrid one that links a relational database to a geographic information system, is intended to support multiple uses:

> ECN's primary role is to provide an integrated long-term monitoring system and information resource for scientific research to: identify and quantify natural and man-induced environmental factors, distinguish short-term fluctuations from long-term trends, improve understanding of the causes of change, and predict future changes. (Lane 1997, 88-89)

Global Terrestrial Observing System

The need for integrated multiscale monitoring is also proclaimed in international circles. A workshop held near Paris in July 1992 laid out a rationale and strategy for a Global Terrestrial Observing System (GTOS). An operational plan calls for a nested suite of monitoring networks ranked along a scale of monitoring intensity as a way to obtain data sufficient for detecting change and validating ecosystem models (Heal, Menaut, and Steffen 1993). It was initially proposed that some 50–100 sites be selected to populate an appropriate 'environmental space' (e.g. using temperature, rainfall, and incident solar radiation to classify biomes). The program was established in 1996 under the sponsorship of several international organizations. Five priority issues are the focus of activity: changes in land quality, freshwater resources, loss of biodiversity, effects of pollution, and climate change (GTOS Secretariat 1997). The basic aims are to provide guidance for data management and to promote interaction between existing global monitoring networks[7]. This mission statement appears in a recent annual report:

> The central mission of GTOS is to provide policy makers, resource managers and researchers with access to the data

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[7] There are a number of mechanisms for accomplishing this coordination (watch for falling acronyms!): the Global Terrestrial Observing Network, GT–Net <http://www.fao.org/gtos/Home.htm>; the Global Hierarchical Observing Strategy, GHOST <http://www.wmo.ch/web/gcos/pub/ghost.html>; and the Integrated Global Observing Strategy, IGOS <http://www.unep.ch/earthw/igos.htm>.

> needed to detect, quantify, locate, understand and warn of changes (especially reductions) in the capacity of terrestrial ecosystems to support sustainable development. (GTOS Secretariat 1997, 2)

The design of frameworks for integrated monitoring commands considerable attention in many quarters. Robertson (1995) put forth a number of general recommendations for large-scale programs (Box 3–4).

Box 3–4

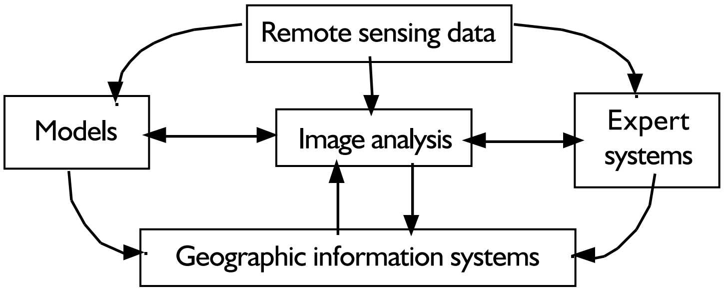
General recommendations for large-scale integrated monitoring (*Source*: Robertson 1995)

1. Establish an unambiguous design focus and clearly articulate the purpose(s) of monitoring
2. Pose specific questions and test stated hypotheses at known levels of confidence
3. Coordinate and expand existing activities to form integrated networks (to avoid duplicated effort and reduce costs)
4. Consider multiple spatial scales by conducting intensive local or regional monitoring within broader, less intensive networks
5. Include a combination of fixed-position and probability-based sites
6. Use stratified sampling within ecologically relevant components (e.g. ecoregions)
7. Monitor indicators of both ecological condition and stressors
8. Develop consistent data management procedures and formats
9. Adopt rigorous quality assurance practices

supporting information technology

In the interest of supporting decision-making, great stock is placed in information technology. That an appropriate configuration of ‘tools’ can facilitate research and resource management at local to global scales is a common refrain. An *ad hoc* group established under the aegis of the International Council of Scientific Unions offer this prescription: “The technologies which we believe are critical to improving our understanding of the best paths toward sustainable economic development include: geographic information systems (GIS), remote sensing, and modeling with expert system- and artificial intelligence-assisted methodologies” (Estes et al. 1992, 11). As Figure 3–3 suggests, all paths seemingly lead to a GIS. The sheer consistency of this outlook is quite striking; few question the prospects for collapsing dynamic natural processes onto a fixed two-dimensional grid. By and large maps enchant us—their rhetorical force should not be underestimated. Monmonier (1991) proposes this dictum for the unwary: every map must tell 'white lies'. He urges that map users espouse a healthy skepticism: "The skeptical map viewer will assess the map author's motives and ask how the need to impress might have subverted the need to inform" (1991, 158).

Figure 3–3
An integrated information system (*Source*: Estes et al. 1992, Fig. 11)



Discussion about integrated monitoring goes hand in hand with talk about environmental assessment. Many countries have eagerly embraced the prospect of undertaking broad evaluations with a regional or issue focus. In reviewing the weaknesses of 'end-to-end' climate change assessment projects, Parson advances the view that assessment work is less about doing new science and more about "assembling, summarizing, organizing, interpreting, and possibly reconciling pieces of existing knowledge, and communicating them so that they are relevant and helpful for the deliberations of an intelligent but inexpert policy maker" (1995, 463). The policy context is usually explicitly recognized in assessment methodologies, yet the science-policy relationship is variously construed. Stakeholder involvement, to take one example, challenges some deeply held views about the role of scientific information.

national frameworks for environmental assessment

Quinquennial national state-of-environment (SOE) reporting was discontinued in Canada after the SOE Directorate was disbanded in March 1997, not long after the third report was released. The new Indicators, Monitoring and Assessment Branch of Environment Canada will coordinate the production of issue- or area-related assessments. The draft guidelines mention the "new fiscal realities" and cite the need for more focused and timely information. An SOE assessment should adopt an ecosystem approach where possible and be understandable to a broad public audience (Environment Canada 1998b).

A national ecological framework was developed to support reporting and monitoring applications by providing standardized, multiscale geographic units that permit communication across disciplines and jurisdictions; it is a hierarchical scheme that distinguishes three levels of generalization: ecozones, ecoregions, and ecodistricts. Climate, geomorphology, and vegetation type underpin the classification scheme. The framework can be seen as a response to the challenge of combining information in a manner useful to many stakeholders: "One way to meet this challenge and evaluate information is to view the framework as a directory and the ecological units as a comprehensive set of information folders" (Ecological Stratification Working Group 1996, 8).

Similar work is underway in the United States, where a strategy to produce comprehensive assessments of natural resources has yielded a proposal to integrate and enhance the existing array of environmental and research networks. A conceptual framework for addressing multiple scales and processes was proposed to help assess the causes and consequences of environmental change:

> The Framework can enhance and support our understanding and predictive capability of the causes and consequences of environmental change and ecosystem response, address multiple scales of ecosystem and resource interactions, and allow ecosystem–level syntheses and assessments of data and information. This is the added value that network integration can provide, which our existing array of fragmented single-purpose networks cannot. (Committee on Environment and Natural Resources 1997a, 3)

While many resource managers are talking about integrated monitoring, few are practicing it in any meaningful way yet, and the challenges are not just conceptual in scope. For example, the National Research Council undertook a review of marine monitoring programs in the Southern California Bight. The review panel expressed concern at the failure to produce a readily accessible and coherent picture of conditions in the bight. The fragmented state of affairs was attributed to a lack of formal mechanisms for integration—much of the monitoring is centered on assessing compliance with effluent discharge permits (National Research Council 1990). The implementation of a regional monitoring program was recommended to better address public health issues, track nonpoint source pollution, and assess cumulative impacts on natural resources. However, the statutory and regulatory framework was judged to be rigid, narrow, and piecemeal; overcoming such impediments to achieving an integrated view requires a broader conception of monitoring: "Although environmental monitoring is most often considered to be within the exclusive domain of the scientific community, successful design and use of environmental monitoring depends on a system that reaches beyond scientists" (National Research Council 1990, viii).

OMNR framework

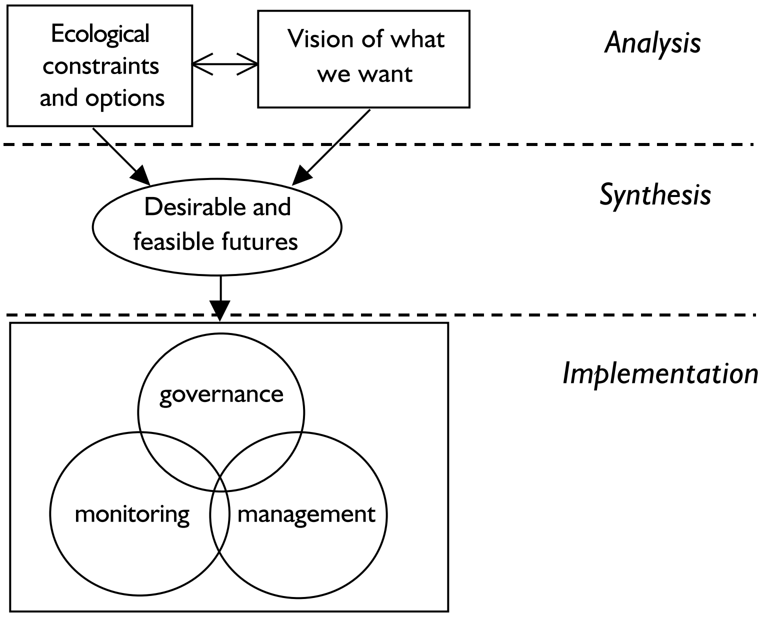
The initiatives I have briefly described here have been for the most part cast from the same mold, displaying an almost numbing consistency of language and motivation. Dryzek (1993) observes that instrumental rationality is a widely held normative model for policy analysis and planning: "In conjunction, objectivism and instrumental rationality undergird one side of modernity—clean, calculating, and homogenizing" (1993, 213). But not all frameworks are so thoroughly immersed in modern orthodoxy. Boyle (1998) presents a framework for developing policy performance indicators at a provincial level. The framework was intended to help staff within the Ontario Ministry of Natural Resources (OMNR) assess how successfully the agency was meeting its obligations under provincial land use policies. An adaptive ecosystem approach was advocated as a way to identify relevant indicators. Since some aspects of the proposed framework mark a significant departure from more traditional strategies, it warrants a closer look.

Figure 3–4 encapsulates the basic decision-making framework, which encompasses three stages: analysis, synthesis, and implementation. In many ways it represents a melding of new and old ideas centered on a traditional interpretation of what monitoring is about: "Monitoring is the process whereby we learn how well we understand the system dynamics and how close we are to achieving management goals" (Boyle 1998, 54). This statement presumably reflects the basic concerns of the client group (i.e. OMNR).

While the interplay between conceptual models and societal concerns is explicitly recognized, the tensions that arise between them are not explored in much detail. Checkland's Soft Systems Methodology (SSM) is identified as a way to help clarify visions and preferences, yet the constructivist tenor of SSM seems to have been overlooked: "The entire SSM process iterates comparison between the model of the system and reality" (Boyle 1998, 74). The implication here is that this comparison amounts to technical validation (i.e. an assessment of representativeness—section 3.3.1 is confidently entitled 'A Model of How the World Works'). But Checkland has long argued against the classical view that systems are real entities awaiting discovery 'out there'. SSM portrays a system as an epistemological device for structuring debate—a forum for working out an accommodation between different world views (Checkland 1995). One deals with models *relevant to*, not models *of*, a problematic situation.

> The crucial difference is between on the one hand an approach which assumes *the world* to be a complex of systems, some of which may be malfunctioning, and on the other an approach which makes no assumptions about the nature of the world, beyond assuming it to be complex, but assumes that *the process of enquiry* can be organized as a system of learning. (Checkland 1995, 53)

Figure 3–4
An integration framework for OMNR (*Source*: Boyle 1998, Fig. 6)



My overall impression of the OMNR framework is summarized in Table 3–1. Because the project was conducted in collaboration with the members of a single large organization, it could perhaps not afford to appear too far removed from bureaucratic imperatives; as a result, it probably reflects the exigencies of working with a corporate client. While adaptability and flexibility are urged, the organizational aversion to change and flexibility seems to have been underestimated: a year later only three indicators had been implemented. Evidently the initiative foundered due to a lack of interorganizational cooperation and insufficient resources. These are thorny issues that crop up in any attempt to undertake integrated monitoring. Chapter five will say more about these under the rubric of 'boundary objects'. The concept, drawn from the sociology of knowledge literature, provides a handle for getting at the problems encountered when different groups of people interact to create a distributed information system.

Table 3–1 The OMNR framework—a blend of old and new ideas

What's new	What's not new
• spans multiple scales • indicator development is not seen to be an exclusively scientific enterprise • surprise is inevitable • society and environment are intertwined • continuous feedback of information is essential to adaptive management	• essentialist epistemology • goal-based: centered on a formal, legislative mandate • intended to support managerial decision-making • aims for comprehensiveness

3.4 Idols and idylls

The vast majority of international and national monitoring initiatives are designed in the shadow of the 1992 UNCED agreements. The final chapter of *Agenda 21*, entitled "Information for decision-making", identifies two areas requiring attention: bridging the data gap (between sectors and nations), and improving the availability of information. Paragraph 40.16 reads:

> All countries, particularly developing countries, with the support of international cooperation, should strengthen their capacity to collect, store, organize, assess and use data in decision-making more effectively. (Robinson 1993, 632)

Official statements at all levels tend to mirror this sentiment. The uniformity of language employed in monitoring documents is striking, even astonishing; many of them are leavened with words and phrases that appear repeatedly. The most prominent terms and catch-phrases that are intoned are listed below—they constitute what I call the integration mantra (Box 3–5). As Box 3-5 suggests, most proposed frameworks and strategy documents seem thoroughly wedded to the norms of formal rationality.

Box 3–5
The integration mantra

- multidisciplinary
- conceptual model
- scientific credibility
- early warning
- coordination
- policy relevant
- decision support
- quality assurance
- metadata standards
- harmonization

Earthwatch, which serves as the UN's global environmental information system, is coordinated by UNEP with the aim of promoting and facilitating assessment activities[8]. At the first meeting of the inter-agency Earthwatch Working Party (Geneva, June 1994), the following mission statement was adopted:

> The mission of the UN system-wide Earthwatch is to coordinate, harmonize and integrate observing, assessment and reporting activities across the UN system in order to provide environmental and appropriate socio-economic information for national and international decision-making on sustainable development and for early warning of emerging problems requiring international action. This should include timely information on the pressures on, status of and trends in key global resources, variables and processes in both natural and human systems and on the

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[8] The Earthwatch web site is at: <http://www.unep.ch/earthw.html>. A discussion paper outlining the UNEP assessment strategy can be viewed online: <http://www.unep.ch/earthw/unepstr2.htm>.

> response to problems in these areas. (United Nations Environment Programme 1994, par. 3)

Fritz (1997) recounts the difficulties encountered by Earthwatch since its inception in 1973 and describes the various conceptualizations of science–policy relations that have shaped its operations. The present approach, dubbed the "assessments for policy approach", involves encouraging closer cooperation between international scientific efforts and making the results more policy-relevant (i.e. bridging the empirical and the prescriptive).

Policy relevance and decision support are overarching themes in most discussions of environmental assessment. What do these phrases mean? As one UN report states: "Decision makers need concise information, put forward in a clear and unambiguous fashion and disembarrassed of minor details. The purpose is to illuminate certain phenomena or trends, through simplification, quantification and communication" (UN Secretariat 1995, par. 19). So useful information is that which has been stripped of nuance and disburdened of complexity or waffling qualifications.

The first in a biennial series of environmental assessment reports, Global Environment Outlook-1 (GEO-1), was produced by UNEP in consultation with regional Collaborating Centres around the world[9]. Several issues are deemed urgent priorities for action: energy, environmentally-sound technologies, fresh water, and benchmark data; concerning the last, the executive summary offered this statement: "Assessments are required continually to guide rational and effective decision-making for environmental policy formulation, implementation, and evaluation at local, national, regional, and global levels" (United Nations Environment Program 1997). Chapter 4, "Looking to the Future", is based upon a technical report prepared by the Netherlands Institute of Public Health and the Environment[10]. The report presents a model-based analysis of a "conventional" development scenario. After cataloguing the many limitations of the assessment (e.g. limited scope, partial integration, highly aggregated analysis, scientific uncertainties), the authors nevertheless make this rather bold assertion:

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[9] The complete GEO–1 report is available online at <http://www.grid.unep.ch/geo1/ch/toc.htm>.
[10] The technical report (size= 3MB) is available online as a PDF file at <http://www.geo.rivm.nl/unep.pdf>.

> Notwithstanding these limitations, the 'what-if' assessment demonstrated in this report offers useful insights to support the overall aim, namely, to identify policy priorities and effective strategies for sustainable development for progress in implementing Agenda 21. (Bakkes and van Woerden 1997, 107)

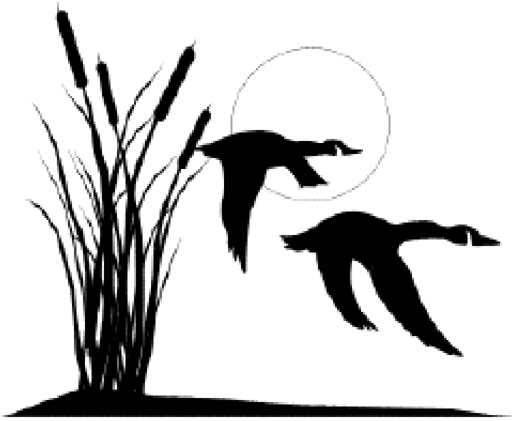
Parson (1995) offers a contrasting opinion concerning the usefulness of 'end-to-end' assessment projects pitched at a high level of generality. He argues that the implied audience of such exercises tends to be a unitary national or global decision maker endowed with wide-ranging authority. Because such decision-makers are rarely to be found beyond the pages of a textbook, the requisite decisions fall to no one in particular and the assessments have little impact upon decision makers. The unitary decision maker is a basic assumption of the doctrine of decisionism that Majone (1989) argues is of limited utility in public policy-making. The failure to distinguish between policies and decisions (the former being more far-reaching), a preoccupation with outcomes at the expense of processes, and the failure to recognize the role of justificatory arguments are other serious limitations; an over-intellectualized version of policy analysis results: "Decisionists look upon policy problems as if they were puzzles for which, given clear goals and sufficient information, correct solutions always exist and can be found by calculation rather than by the exercise of political skills" (Majone 1989, 19–20).

Rational and effective decision-making is a cant phrase that exerts a powerful pull on the imagination of managers everywhere; its appeal is rooted in the dominant view of organizations as 'goal-seeking machines'—a view that possesses a fairly distinguished pedigree. Herbert Simon, a Nobel laureate, has shaped the development of organization theory since the late 1940s. In one of his popular early works (Simon 1960), he treats 'decision making' as synonymous with 'managing', and couches both in terms of problem solving. Furthermore, Simon is inclined to construe problem solving as manipulating symbols in order to detect and reduce the difference between outcome and goal. The deployment of computers to automate and rationalize decision making in organizations is what seems to animate Simon: "We can think of white-collar organizations as factories for processing information" (1960, 5).

Goal-seeking models of human behavior tend to underwrite most accounts of the role of information in decision-making. Checkland and Holwell (1998) cite Simon's (1960) work as being instrumental in promulgating what is now the conventional model of organizational problem solving: a three-staged process that starts with problem identification, then moves on to inventing alternatives, and culminates in the choice phase; this 'set piece' conception of decision-making is by far the most common approach. A UN report discussing information strategies for implementing *Agenda 21* distinguishes five stages in a cyclical process of decision making: problem identification; policy formulation; implementation; performance monitoring; and evaluation (UN Secretariat 1995, par. 5).

Environmental monitoring is usually described in terms of decision support and performance control. The global eco-mandarins extol science and (satellite) technology as paving the way to more effective and efficient decision-making. The 'monitoring' programs of yesteryear have metamorphosed into the 'observing' systems of tomorrow dedicated to the pursuit of sustainable development. Such an approach takes much for granted about science-citizen relations and what counts as knowledge. It behooves one to consider whether the conventional outlook—rooted in a technocratic mentality that is instrumental and standardizing—is an appropriate one for designing a framework to build systems-level knowledge in a Canadian biosphere reserve.

Chapter four takes a look at ecosystem management and reviews a few of the many sets of principles that have cropped up in recent years; these principles provide a foundation for discussing the role of science in public environmental policy. The tension between expertise and participation is explored, and this leads to an examination of several alternative modes of knowledge production, such as adaptive management and post-normal science. The chapter concludes with a few words concerning the shape of what I call 'interstitial science', a mode of inquiry that is likely to remain only weakly institutionalized. Toiling in the interstices of established institutions offers better prospects for mobilizing the adaptive work required to support the development of an infrastructure for learning.



Chapter 4

Ecosystems high and low

In the first place, scientists are not wrong every time they assume that things are simple. Quite often they are right or partly right and still more often, they think they are right and tell each other so. And that is enough reinforcement.

Gregory Bateson,
Steps to an Ecology of Mind

4.1 Better, faster, cheaper?

Ecosystem management is widely hailed as a way to circumvent the shortcomings of traditional sectoral approaches to environmental management. The concept has given rise to a burgeoning literature over the last decade or so, featuring much debate about its meaning and potential. For the most part ecosystem management is portrayed as a vehicle for comprehensive and integrated resource planning, or presented as a nostrum for managers beset by complexity, uncertainty, and conflict. It seems that every other commentator unveils a set of principles or guidelines to ease the way forward. This chapter reviews some Canadian and U.S. frameworks and then focuses on the Laurentian Great Lakes, a region that has witnessed many attempts to operationalize the ecosystem approach over the last twenty years.

McCormick (1999) presents no less than nine sets of principles devised by various authors, eight of which he judges to be concordant (i.e. they all encompass environmental and socioeconomic concerns). While McCormick cites the proliferation of policy statements as evidence of the growing acceptance of ecosystem management, the many accounts of the barriers, challenges, and disincentives to implementation vividly portray the sometimes yawning chasm separating policy from practice.

During the early 1990s Environment Canada launched a bevy of regional action plans intended to enact sustainability principles[1]. A review of these activities yielded a number of considerations for the design of ecosystem management plans (Box 4–1). While the prospect of "joint risk-taking" might have considerable appeal for a beleaguered agency, there seems to be some ambivalence about public participation. One characterization of leadership maintains that it involves empowering people to make decisions in matters that affect them; yet the following paragraph favors a different style: "Leadership also implies making the right decision at the right time" (Environment Canada 1995, 5).

The Canadian Council of Ministers of the Environment has proposed a national framework for ecosystem-based management to

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[1] Summaries of current regional ecosystem initiatives can be viewed at <http://www.ec.gc.ca/ecosyst/backgrounder.html>.

further their goals of harmonization, cooperation, and coordination among governments. Four principal activities comprise the framework (Canadian Council of Ministers of the Environment 1996, 10):

- identify the issues and collate existing ecosystem knowledge
- articulate ecosystem health goals and objectives
- develop or select indicators
- conduct targeted research and monitoring

Box 4–1

Guiding principles for ecosystem initiatives

An ecosystem approach

It is important to consider all of the elements that make up an ecosystem and to examine how they interrelate. (1995,2)

Partnerships

To be truly effective, an ecosystem management plan should be designed and implemented by those that are affected by and have an interest in the outcome. (1995, 3)

Leadership

Environment Canada should provide leadership in promoting ecosystem sustainability. (1995, 5)

Environmental Citizenship

Canadians should be provided with timely, accurate, and understandable environmental information to help them make informed decisions and promote action. (1995, 4)

Science

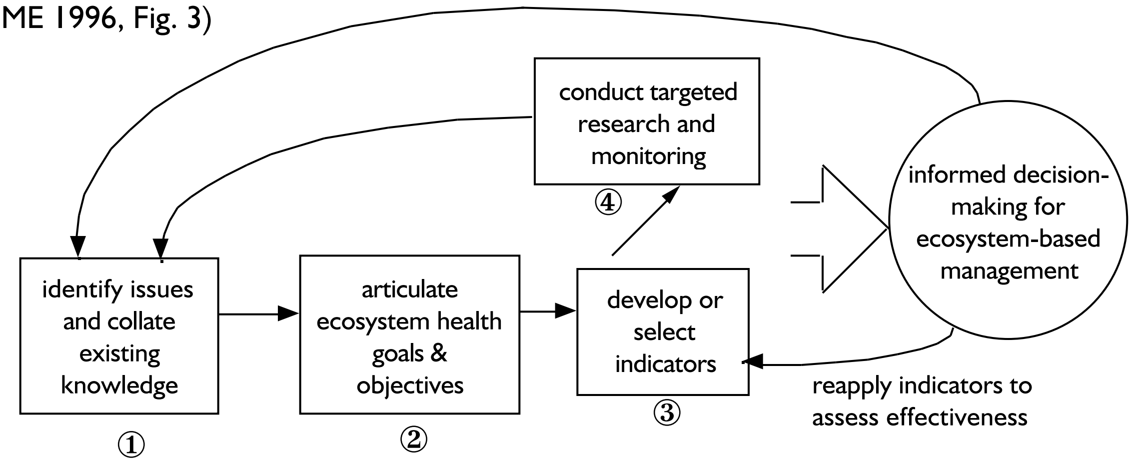
The information used in decision making should go beyond the pure sciences and encompass the broadest possible range of disciplines. (1995, 5)

(*Source*: Environment Canada 1995)

A basic premise underlies the framework: namely, that informed decision-making requires access to credible and timely information. The process is a dynamic one, as Figure 4–1 illustrates.

Figure 4–1

A framework for ecosystem-based management (*Source*: CCME 1996, Fig. 3)



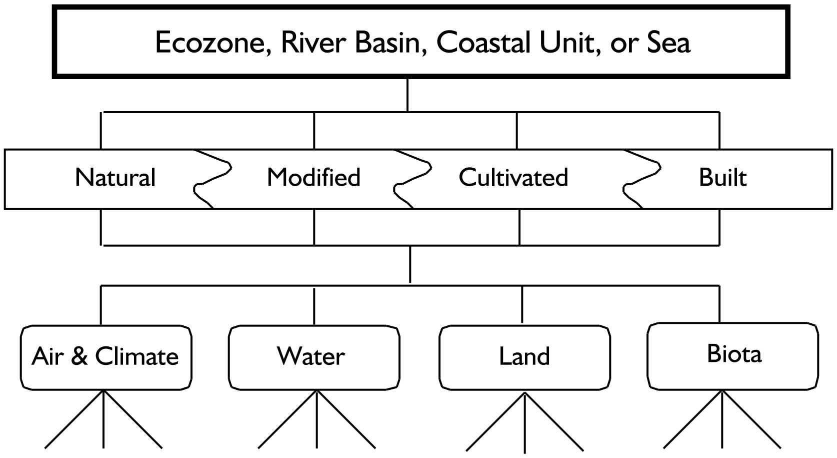
A task group convened by Environment Canada reviewed a number of case studies exemplifying an ecosystem approach (Environment Canada 1996). The coordination of multidisciplinary research, cooperation among scientists and resource managers, and integrated data management seem to be the most widely shared characteristics of these initiatives. While the task group acknowledges that there is no single recipe for success, scientific knowledge remains central despite cautionary words about limitations: "The identification of ecosystem goals and objectives, as well as the development and selection of appropriate indicators of ecosystem health and integrity, assumes a solid understanding of the processes and factors influencing ecosystem properties" (Environment Canada 1996, 19).

A national system for reporting on sustainable development in Canada was the centerpiece of a report prepared by the National Round Table on the Environment and the Economy, a body created in response to the Brundtland Report of 1987. Four indicator domains (or 'areas of diagnosis') comprise the reporting framework: (1) ecosystem integrity or health; (2) interactions between human activities and ecosystems; (3) the physical, cultural, and economic well-being of people; and (4) key cross-cutting linkages (Hodge and others 1995). The purpose of the proposed reporting system is "to improve the way we make decisions: to support informed and responsible decision making and decision-making processes" (Hodge and others 1995, 134). The maintenance or improvement of ecosystem health and integrity is advanced as a general goal for the ecosystem domain, but what this amounts to is not entirely clear. A stress-response paradigm wedded to an explicitly spatial frame of reference seems to inform the assessment process. A truncated version of one possible assessment hierarchy suggested for the Great Lakes basin appears as Figure 4–2. The reader should keep in mind that this hierarchy is not proposed as a system model but as a map of the assessment process, a way of categorizing relevant factors. Comprehensiveness seems to be the aim here: 19 basin-level indicators in 8 categories are said to reflect the health and integrity of the regional ecosystem:

- air quality
- chemical and biological characteristics of surface water
- groundwater
- cultivated land (e.g. productivity, conversion to urban uses)

- other special lands (e.g. wetlands, shorelines)
- the built environment
- biota (e.g. population health status, habitat, overall diversity)
- human health and well-being

Figure 4–2
A truncated assessment hierarchy for the Great Lakes basin (*Source*: Hodge and others 1995, 147)



Ecosystem approaches are also much discussed in the United States. A report issued by the Office of the Vice President in 1993 expressed a need to improve the implementation of environmental management so that it would "work better and cost less" (Office of the Vice President 1993). In the report the concepts of ecosystem management and environmental cost accounting were advanced as the basis for national policy. The Vice President also called for the establishment of an interagency task force to begin the development of cross-agency projects demonstrating ecosystem planning and management. Not surprisingly, the proposed "new vision" has been subject to intense scrutiny.

The General Accounting Office reviewed the plans for implementing ecosystem management throughout the U.S. federal government; four steps for translating principles into practice are recommended in its report (U.S. General Accounting Office 1994):

- delineating ecosystems using reasonable criteria (e.g. watersheds, biomes, ecoregions)
- understanding their ecologies on the basis of the best available data
- making management choices concerning the distribution and intensity of activities that can be sustained

- modifying management practices on the basis of new information—this requires continuous research, monitoring, and assessment

For some folk the notion of ecosystem management is entirely too nebulous to be useful in policy deliberations. Fitzsimmons is a vociferous critic who has argued that drastic new federal policies are not needed, that the practice of ecosystem management will only expand federal restrictions on land use and place environmental protection before human welfare (Fitzsimmons 1994). Because the ecosystem concept is "geographically amorphous", it can do little to settle legal disputes over land use or prevent policy 'train wrecks'. Instead, the use of market-based approaches should be promoted. More recently, Fitzsimmons (1996) proclaims that the transfer of the ecosystem concept from science to policy has generated much confusion and yielded more than a few buzzwords. He marshals support for the view that an ecosystem is a "mental construct", not a real entity on the landscape; this vagueness—along with the lack of an agreed-upon calculus for measurement or comparison—supposedly renders it unsuitable as a rational basis for decision-making. Much of Fitzsimmons' ire seems to be rooted in the almost quintessential American suspicion toward government interventions that threaten to infringe upon the rights of individual land owners.

The Interagency Ecosystem Management Task Force was established in 1993 and given responsibility for coordinating the efforts of U.S. federal agencies to implement the ecosystem approach. The Task Force issued a three-volume report in 1995. The following statement in the executive summary of the first volume describes the ecosystem approach:

> The ecosystem approach is a method for sustaining or restoring natural systems and their functions and values. It is goal driven, and it is based on a collaboratively developed vision of desired future conditions that integrates ecological, economic, and social factors. It is applied within a geographic framework defined primarily by ecological boundaries. (Interagency Ecosystem Management Task Force 1995, executive summary)

The summary volume emphasizes a multiple-use, stewardship ethic and looks forward to benefits such as achieving greater efficiency, reducing duplication, minimizing conflict, and improving the cost-effectiveness of federal agency programs (Interagency Ecosystem Management Task Force 1995). More than thirty recommendations address the following broad aims:

- improving federal agency coordination
- improving partnerships with nonfederal stakeholders
- improving communication with the public
- improving resource allocation and management
- supporting the role of science
- improving information and data management
- increasing flexibility for adaptive management

The report goes to some length to alleviate possible misunderstandings about ecosystem management, especially concerns about private lands and the scope of federal authority. And of course, a framework is duly provided (Box 4–2). The order in which the steps are undertaken is flexible, and not all need apply to every ecosystem initiative.

Box 4–2
A basic framework for an ecosystem approach (*Source*: Interagency Ecosystem Management Task Force 1995)

A. Define the area of interest
B. Involve stakeholders
C. Develop a shared vision of desired future conditions
D. Characterize the historical ecosystem and existing conditions (economic, environmental, social)
E. Establish ecosystem goals
F. Develop and implement an action plan
G. Monitor conditions and evaluate results
H. Adapt management practices accordingly

The U.S. Forest Service is busily engaged in trying to operationalize ecosystem management. A report that explores the matter in some depth presents four fundamental premises as a basis for managing any ecosystem (Bormann and others 1994):

- both science and society are shaped by underlying values and assumptions
- management actions can be beneficial
- ecosystem processes are inherently difficult to predict
- the entire system must be managed in its context

A new forest land management system is couched in terms of a model that "focuses on carefully defining objectives by iteratively 'lacing' together societal values with knowledge of the ecological capacity of the ecosystem, and openly and effectively passing information between different geographic scales" (Bormann and others 1994, 13). Information is construed as a primary resource, the free flow of which can enhance organizational effectiveness and efficiency. Relating societal demands to ecosystem capacity is considered essential for assessing sustainability; to this end, a calculation procedure is introduced as a means of dealing with conflicts between local, regional, and national interests. The authors further propose that "an impartial, recognized authority is needed to implement the procedure to calculate ecosystem management for sustainability, and to see that the process of conflict resolution proceeds effectively" (Bormann and others 1994, 53).

More public attempts to pin down the meaning of ecosystem management have also been undertaken. The Keystone Center is a nonprofit public policy and education organization headquartered in Keystone, Colorado. Early in 1995 the Center assembled a group of fifty individuals representing diverse interests to explore the meaning and utility of ecosystem management, particularly at the community level. The deliberations and findings of a series of plenary sessions and regional meetings are summarized in a final report issued in late 1996 (Keystone Center 1996). Ecosystem management is characterized as a process of reconciliation: "A collaborative process that strives to reconcile the promotion of economic opportunities and livable communities with the conservation of ecological integrity and biodiversity" (Keystone Center 1996, chap. 1). The eight steps for implementing an ecosystem approach are very similar to those listed in Box 4–2. Adaptive management—structuring initiatives as experiments—is advocated as a way to cope with inherent uncertainty. An 'active' mode is recommended, one in which several alternatives are simultaneously pursued; this approach would seem to fly in the face of time-honored experimental practice, resulting in an information-rich decision environment (as noted in the report) but also a very ambiguous one. Scientists are cast in a central decision-support role: "Wise decisions are supported by credible, objective, unbiased, relevant, and timely information that is widely available, easily accessible, and usable" (Keystone Center 1996, chap. 3).

Chapter five of the Keystone report is dedicated to collaborative decision-making, and includes a wide-ranging prescription for effective collaborative processes:

- clearly define the roles and authorities of participants
- build trust and promote fairness
- promote leadership that nurtures safety, trust, and creativity
- encourage a collaborative attitude
- try to maintain participant continuity
- address time and resource limitations
- address cultural differences and power imbalances
- build accountability into the process (varying degrees of formality)
- build organizational commitment (this may require internal changes)
- aim for consensus if feasible (but there may be statutory constraints)
- strive for early results and accomplishments to forestall disenchantment or undue frustration
- link decision making (i.e. planning) and implementation
- establish and enforce ground rules that clarify roles and procedures
- use nonpartisan facilitators
- run efficient meetings
- promote skill development with respect to group dynamics or other necessary areas of expertise

The final chapter of the report deals with implementation issues. Great stock is placed in market-based incentives to encourage ecosystem management; agency budgeting practices, various statutory restrictions, and scientific support are also highlighted as areas needing improvement or reform. The general tenor of the report does not depart significantly from that of strategies purveyed by mainstream officialdom. Ecosystem management is declared to be “a new way of doing business” that can help breathe life into traditional multiple-use and sustained yield principles.

The U.S. MAB Human-Dominated Systems Directorate is sponsoring case study work on ecosystem management in south Florida, where water management practices have significantly altered the Everglades. Working groups comprising scientists (social and natural) and regional managers have developed a number of regional scenarios to explore the prospects for ecological and societal sustainability (Harwell 1997). A couple of lessons were drawn. Assembling an interdisciplinary team of scientists and decision makers of diverse affiliations expedited the necessary integrative work, and a GIS-based database facilitated the merging of disparate data sets and the rendering of graphical representations. Yet although a shared scientific vision was readily articulated, other stakeholders played little role in the process—evidently the Human-Dominated Systems Directorate felt disinclined to contemplate any sort of process for community participation:

> However, we found that the analyses could initially be performed, and solutions proposed, only by an appropriate scientific group that does not purport to represent the diversity of stakeholders in the region. By developing ideas in an open, scientific forum without agency or political constraints, much of the contentious debate typical of regional environmental issues could be bypassed. (Harwell 1997, 510)

The word 'community' is flung about with considerable abandon. What exactly does it mean? At least three types of communities seem pertinent to ecosystem management: communities of *place*, communities of *identity*, and communities of *interests* (Duane 1997); of these, it is place and interests that usually clash, and reconciling them is a political challenge that traditional management approaches are not up to. Duane points out that even if an appropriate institutional context can be established—one based on collaborative planning, for example—'social capital' is still required to resolve any of several types of conflicts:

- cognitive conflicts rooted in different understandings
- value conflicts manifest as disputes over goals
- interest conflicts that signal an inequitable distribution of costs and benefits
- relationship conflicts that bring differing emotional motivations to the fore

Resolving these becomes more likely if horizontal networks of civic engagement, rather than vertical networks of administrative control, can be used to build trust and cooperation. As Duane puts it: "*Information* does not resolve social conflicts; *people* do" (1997, 775).

There is also much interest in community-based ecosystem approaches in Canada. A handbook prepared under the Fraser River Action Plan (Grant 1997) outlines a process based on the four-step CCME framework (Figure 4–1). The suggested characteristics of a successful convenor group have much in common with those cited above in the discussion of the Keystone Dialogue group. The activities of the Salmon River Watershed Roundtable are used to convey some of the practical aspects of developing an action plan. Interestingly, a community initiative is construed primarily in terms of business planning: vision setting, an implementation strategy, milestones, option scenarios, quality assurance, communications strategies, cultural attributes, and similar corporatist phraseology anchor the approach.

Given the proliferation of terms, definitions, and interpretations surrounding ecosystem management, there have been no few attempts at conceptual clarification. Grumbine (1994) reviewed the academic literature to distill ten dominant themes (Box 4–3).

Box 4–3
Ten dominant themes of ecosystem management (*Source*: Grumbine 1994)

1. *hierarchical context*—seeking connections between biological levels of organization
2. *ecological boundaries*—working across jurisdictions
3. *ecological integrity*—protecting the patterns and processes that maintain biodiversity
4. *data collection*—doing more research and promoting better data management
5. *monitoring*—tracking the results of management actions
6. *adaptive management*—emphasizing experimentation and learning
7. *interagency cooperation*—integrating conflicting goals and mandates
8. *organizational change*—altering structures, norms, and power relationships
9. *humans embedded in nature*—acknowledging reciprocal influences
10. *values*—recognizing how they frame management goals

Grumbine sees ecosystem management as a response to the current "biodiversity crisis", and notes a divergence between academic and agency visions of what the management implications might be: the former tend to emphasize the scientific aspects of protecting ecosystem integrity, while the latter are more beholden to mission statements and steer clear of contemplating substantive organizational changes. Setting clear goals is widely considered to be critical to success, but the degree of anthropocentrism is a point of debate. Grumbine believes that many stewardship models suffer from concentrating on *efficient* management rather than on *sufficient* management, and from paying too little attention to the sociopolitical dimensions of change.

In a sequel written several years later, Grumbine (1997) revisits the themes he put forth in order to convey a few pragmatic lessons and to highlight ongoing dilemmas. He notes the ambiguity that continues to cloak ecosystem management and chalks it up to several factors:

- the politics surrounding attempts to define any new concept
- the attendant shift to a new way of thinking that places problems in larger contexts
- the difficulty of thinking contextually
- a fondness for narrow problem definitions and "quick fixes"

Grumbine is struck by the energy for change displayed by managers at the grassroots: "Resource professionals everywhere are waking up to the fact that they are not so much a technical elite as they are facilitators in a large-scale societal conversation about conservation" (1997, 46). But strategic maneuvering within the upper echelons of government agencies threaten to derail these nascent efforts, and hostile law-makers in the U.S. Congress have also undercut the legal basis for ecosystem management (which, according to Grumbine, is necessary if it is to survive infancy).

Noting the lack of agreement concerning the scope and significance of ecosystem management, the Ecological Society of America struck a committee to sort matters out. The committee offered a wide-ranging prescription in their report (Box 4–4). The report stressed the need for effective dialogue between managers and researchers, and admitted that stakeholder interactions represent one of the greatest challenges to implementation; yet the committee had little to say about stakeholder participation beyond issuing the usual call for public education.

Box 4–4

Ecosystem management according to the Ecological Society of America (1996)

- strive for intergenerational sustainability
- express measurable goals in terms of the "desired future behaviors" of ecosystem components and processes
- adopt sound ecological principles that emphasize processes and interconnections
- recognize that complexity and diversity confer resistance and resilience; uncertainty cannot be completely eliminated
- consider the ecosystem components and processes that transcend management boundaries
- include the larger context—there is no single appropriate scale for management
- acknowledge the role of humans by identifying and engaging stakeholders in planning activities
- recognize that knowledge is incomplete—construe management strategies as hypotheses to be objectively tested

An assessment of ecosystem management activities in the Pacific Northwest concluded that the situation was out of control: "No one knows and there is no way to determine whether the money spent on ecosystem management research is achieving stated public management goals" (Berry and others 1998, 69). Noting experiences elsewhere, the review group (comprised of academics) had little hope that elaborate planning procedures would offer a remedy:

> Ritualistic, top-down actions supported by 'objective analysis' and 'facts' become tools in a contest to exert or regain control over 'unreasonable' or 'uninformed' opponents. Under the circumstances, admission of error, openness, and a willingness to embrace uncertainty in the interest of learning all receive little play or even attention. (Berry and others 1998, 71)

The group recommended that an independent Board for Ecosystem Management Research—endowed with an explicit mandate—be established to coordinate all research in the Pacific Northwest and 'tweak' institutional arrangements (e.g. by means of policy, funding, technical guidelines, incentives). This model amounts to the near-privatization of ecosystem research in order to break the “hammerlock” held by federal agencies: “This proposal should enhance research innovation at the same time as it promotes both organizational efficiency and overall effectiveness” (Berry and others 1998, 78). It’s difficult to imagine that yet another layer of bureaucracy will address the concerns expressed by the review group, or avoid the slide into top-down ritual that they roundly denigrate.

It is a widely held assumption that clearer goals are needed before ecosystem management can be genuinely implemented. Brunner and Clark (1997) deny that the clarification of goals can help to resolve political differences; they see the term ‘ecosystem management’ as a potent symbol that prompts reflection and clears space for collective deliberation, arguing that “clear and specific but premature goal definitions would reduce the adaptability of ecosystem management as an evolutionary process” (1997, 51). Nor do Brunner and Clark think much of the prospects for constructing a better scientific foundation using the paradigms of ‘hard’ science, suggesting that the uniqueness, diversity, and open contexts encountered outside the laboratory will undermine such efforts. Instead, they favor prototyping strategies that encourage innovation, diffusion, and adaptation. These processes, together with independent appraisals, can accelerate improvement and help disseminate *de facto* standards of good practice.

This section provided a high-altitude flight over the contested terrain of ecosystem management. The majority of proposed frameworks appear to be dedicated to making the practice of environmental management better, faster, and cheaper. Through the haze of competing interpretations, one thing seems clear: it poses many challenges to existing institutions. Incomplete or scattered knowledge, discordant natural and jurisdictional boundaries, interagency cooperation, public participation, and other conundrums resist bureaucratic specification. But enough with policy prescriptions. How about on-the-ground experiences? Many groups in the Great Lakes region have been engaged in applying ecosystem approaches for more than twenty years under the umbrella of the Great Lakes Water Quality Agreement, a Canada-U.S. accord intended to safeguard the integrity of waters throughout the basin. The next section briefly examines what lessons have been drawn.

4.2 Around the Great Lakes

The stated purpose of the 1978 Great Lakes Water Quality Agreement is "to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem" (International Joint Commission 1997, Article II); this statement is generally interpreted as urging the adoption of an ecosystem approach. Twenty years later there is still much work to be done, as only one of forty-three areas of concern has been delisted.

Given the richness of the institutional milieu in the Great Lakes basin, governance issues—and the difficulties they can present—have been the focus of considerable attention over the years. Francis (1986) described the exhaustion of the "grand design ideal", a demise that has sparked efforts to create public constituencies and to cultivate interorganizational relations that could invigorate the 'middle ground' of society; he noted that such developments still confront the challenge of reconciling institutions with ecosystems, an undertaking that is perhaps impaired by existing legal and policy frameworks.

Adopting a more analytical stance, Donahue (1988) reviewed the structural and programmatic characteristics of four prominent multi-jurisdictional, resource-based organizations: the International Joint Commission, the Great Lakes Commission, the Great Lakes Fishery Commission, and the Council of Great Lakes Governors. Considerations of political feasibility lead Donahue to favor fine-tuning over large-scale reform. Nevertheless, he suggested that the generally broad mandates provide ample room for an ecosystem approach, but cautioned that any innovation will wither in the absence of political will.

Jurisdictional affairs are also found wanting by Caldwell in his account of environmental governance around the Great Lakes, where he notes that "the political and economic arrangements in modern industrial society were neither designed nor intended to deal with large-scale systemic environmental problems" (1994, 28). Institutional reform proceeds haltingly in the face of discordant policies and conservative, short-term thinking. MacKenzie (1996) also points to shortcomings in the policy process, and posits three prerequisites for ecosystem management (Table 4–1).

Table 4–1 Prerequisites for ecosystem-based management (*Source*: MacKenzie 1996, Table 2-1)

Prerequisite	Features
Participation of appropriate actors	✔ intergovernmental ✔ interdisciplinary
Development of a mutually agreed upon decision making process	✔ flexible mechanisms ✔ common objectives ✔ iterative dispute resolution
Legitimacy	✔ political support ✔ public participation ✔ ample funding

Hartig and his colleagues (1998) recently reviewed experiences with remedial action plans (RAPs) around the Great Lakes and distilled a number of lessons. They argue the need for a transition from traditional 'command-and-control' management strategies to more cooperative, bottom-up approaches that empower local stakeholders—a shift that challenges many government agencies. Another lesson drawn by the authors is that measurable results help to sustain commitment. Eight principles for the successful implementation of ecosystem-based management are proffered (Hartig et al. 1998):

- broad-based stakeholder involvement from the very beginning to encourage local ownership of the process
- the commitment of top leaders to a consensus-based process
- agreement on information needs to support decision-making
- a strategic framework to establish priorities and assure continuous improvement
- human resource development to foster cooperative learning and promote sense of place
- monitoring to assess progress
- evaluation and feedback concerning the effectiveness of management actions
- gauging stakeholder satisfaction in order to address disappointments, confusion, or apathy

Several lakewide strategies are being prepared to support the Agreement and complement the site-specific remedial action plans. The Lake Superior Binational Program, established in

September 1991, is at the most advanced stage of development. The program has two main components: a zero-discharge demonstration program for persistent toxic and bioaccumulative substances, plus a suite of ecosystem objectives to restore and protect the Lake Superior basin (Ontario Ministry of Environment and Energy 1993). The first component figures in the Lake Superior Lakewide Management Plan, which shall also address the beneficial use impairments identified by the International Joint Commission (presented in Box 3–2). The ecosystem objectives encompass a broad range of issues organized under five main categories (Lake Superior Work Group 1995):

- aquatic communities
- terrestrial wildlife
- habitat
- human health
- sustainability

The objectives maintain that aquatic and terrestrial communities should be diverse, self-regulating, and representative of historical conditions; human uses should not impair productive ecosystem functions, and anthropogenic contaminants should not pose a health risk. Furthermore, human uses should not significantly degrade Lake Superior ecosystems (or adjacent ones). The basic objectives are further elaborated in a series of sub-objectives that culminate in a set of indicators for assessing the health of the basin and for guiding management activities[2].

In a report to the Great Lakes Science Advisory Board Allen, Bandurski, and King (1993) urged close attention to issues of *scale* and *type* (i.e. the defining criteria that foreground certain aspects of a material system) in delineating the boundaries of ecological systems; such decisions are sensitive to purpose: “For a given purpose, there are more and less effective ways to specify the system” (1993, 7). In marked contrast to most other accounts, flexibility of thought and action—with a view to encouraging open dialogue among stakeholders—is the hallmark of the contextual approach outlined in the report. Considerable emphasis is placed on devising potent questions and exploring problem definitions, rather than on proclaiming authoritative goals or end-points. Indeed, the authors recommend Soft Systems

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[2] Additional information (including publications) about the Lake Superior Binational Program is available online at <http://www.cciw.ca/glimr/lakes/superior/>.

Methodology as an appropriate way of operationalizing many of their ideas. Inquiries conducted in such a manner are somewhat removed from the usual imperatives to expedite command-and-control functions, and are more likely to unfold in the interstices of existing institutional arrangements. This suggests a different picture of science in the public realm, one where scientists are not the only arbiters of their work.

Despite the shortcomings of the "grand design ideal" (Francis 1986), the resurgence of lakewide strategies suggests that it still finds support among many planners and resource managers. It seems to be mainly academic commentators who bemoan the 'command-and-control' mindset and proclaim a need for processes to support cooperative learning. It would seem that wider stakeholder processes are indeed making some headway under the banner of "partnership". But what sorts of partnerships are envisioned? Is it simply a matter of placing more chairs around the table while leaving the menu intact, with science still the main course?

4.3 The etiquette of inquiry: Banquet or buffet?

Institutional arrangements and public participation apparently remain stumbling blocks for those who profess to favor an ecosystem approach. Norton (1998) declares that we lack a paradigm for integrated environmental management and contends that the language we use is inadequate to establish meaningful dialogue among ecologists, policy makers, and the public. The 'false images' of the wholly rational decision maker and of value-neutral science do little to alleviate the communication problem.

> The belief that nature is, or can be, measured and described before one decides what is important—the serial view—is a dangerous illusion. It is an illusion because it assumes falsely that science can be without perspective and scale, and that it can be complete or finished prior to action; it is dangerous because the illusion of prior omniscience predisposes managers and scientists to undervalue learning, social and technical, as a reason to pursue policies. (Norton 1998, 358)

Cortner and others (1996) see ecosystem management as a mainly political undertaking and strip away any pretense of value-neutrality:

> Ecosystem management can thus be understood as a social movement designed to embrace a new philosophical basis for resource management. It calls for changes in how we approach nature, science, and politics and will require changes in behavior by institutions and individuals. It will affect values such as democracy, free enterprise, and the rights of citizens. (Cortner and others 1996, 7)

If one grants that ecosystem initiatives possess a political dimension, how does science enter the fray? Many observers of debates over environmental issues have examined the role of science in framing problem situations. Wynne (1996) argues that the cultural and institutional forms of science profoundly shape the interaction between scientific expertise and lay-publics; rather than focusing exclusively on the cognitive dimension of this interaction (e.g. educating an 'ignorant' public), he urges that attention also be paid to trustworthiness and credibility—these factors exert a major influence on the uptake of scientific messages. Wynne supports his position by describing the interplay between expert and lay understandings of the impacts of radioactive fallout (from the Chernobyl accident) on sheep farming in the Lake District of northern England. Mistrust of authorities and experts was rampant. By Wynne's account the scientific perspective—articulated according to what he called the "scientific-bureaucratic cultural idiom"—suffered from a lack of reflexivity: "Its credibility was influenced not so much by what it said directly and explicitly, as in the way it was institutionally and intellectually organized, including lack of recognition of its cultural and institutional biases—its own tacit social body language" (Wynne 1996, 38). Wynne identifies a number of factors which seemed to affect the credibility of scientific claims (Box 4–5).

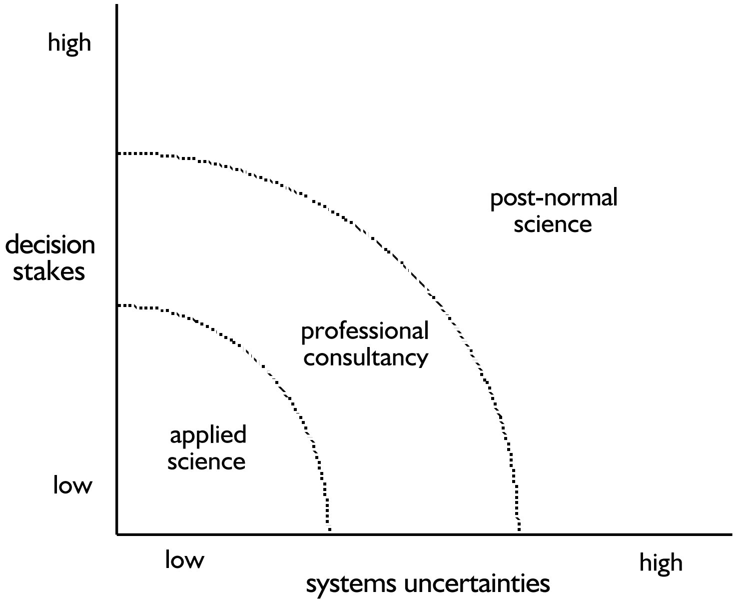
Yearley (1996) examines how environmental and conservation groups such as Greenpeace harness scientific expertise. Although such expertise promotes good relations with official agencies and yields financial benefits (e.g. through grants and contracts), media publicity and legal scrutiny can quickly undermine technical processes and blur the boundaries demarcating 'good' science. As Yearley notes: "Anybody who hoped for a straightforward and harmonious relationship between scientific understanding of ecological issues and agreement on the practical steps to be taken will have been disappointed" (1996, 174).

Box 4–5
Lay criteria for judging scientific claims (Source: Wynne 1996, Table 1.1)

- Does the scientific knowledge *work*?
- Do scientific *claims* pay attention to other available knowledge?
- Does scientific *practice* pay attention to other available knowledge?
- Is the *form* of the knowledge as well as the content recognizable?
- Are scientists open to criticism?
- What are the social and institutional affiliations of experts?
- What issue 'overspill' exists in lay experience?

Many critiques of science-citizen relations center on the mode of knowledge production—how claims are authorized and legitimated. Funtowicz and Ravetz (1994) distinguish three varieties of policy-related research by considering the epistemological and ethical dimensions of environmental problems (Figure 4–3).

Figure 4–3
Varieties of problem-solving strategies (*Source*: Funtowicz and Ravetz 1994, Fig. 1)



Applied science is mission-oriented research that is affirmed by a peer community and the mandating body. Professional consulting entails more personal judgment and is evaluated in light of accepted standards of practice and client needs. Post-normal science encompasses stakeholders who actively participate in the problem-solving process, thereby constituting what Funtowicz and Ravetz call an "extended peer community". The choice of language is a little curious—the phrases 'post-normal science' and 'extended peer community' are sufficiently ambiguous that their implications are far from obvious. I'll consider each in turn.

Puzzle-solving lies at the heart of Kuhn's conception of 'normal' science. A puzzle, assumed to have a solution, becomes the object of canonical inquiry conducted using accepted methods so as to refine and extend a paradigm—research consists of theoretical and experimental "mopping up", as Kuhn put it (1970, 5)[3]. A paradigm, understood as a guiding theory, is the possession of a mature scientific community that Kuhn likens to a somewhat esoteric language community with a distaste for novelty: "For most people translation is a threatening process, and it is entirely foreign to normal science" (1970, 203). So by my reading, post-normal science entails the rejection of canonical inquiry (i.e. no privileged framework) and highlights a need to translate concerns and information among the members of the extended peer community. But given the likely diversity of participants, in what sense can they be regarded as 'peers'? Presumably stakeholders would collectively engage in some kind of refereeing process, but Funotowicz and Ravetz provide no hints about what this would look like. Oxley (1997) took up the idea of post-normal science in considering the prospects for involving members of the local community in decision-making concerned with the conservation of a natural area near Kitchener, Ontario. Adopting a museological perspective on educational programming, she suggested using photographic exhibits as a forum for exploring public perceptions and instilling a sense of place. Oxley took the idea of an extended peer community further than most, but two things strike me: the very designation of a 'post-normal science' seems to imply that there is indeed a homogeneous enterprise called 'science', and that Kuhn's description of its 'normal' form captures its essence. Both of these suppositions can be disputed.

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[3] I know, it's almost a cliché to cite the *Structure* these days, but it spurred a lot of paradigm-talk.

The tensions between expertise and participation are especially palpable in the search for ways to enact ecosystem management (or sustainable development, for that matter). On the one hand, stakeholder involvement is almost universally urged; yet on the other, such a move flies in the face of corporate good sense—it threatens to disrupt techniques that aim to achieve effective and efficient decision-making. As a mode of governance, technocracy poses some significant challenges for citizen involvement in matters of environmental policy.

In a widely cited work, Lee (1993) analyzed the interplay of science and policy in the U.S. Pacific Northwest, where hydroelectric power generation along the Columbia River and its tributaries has devastated wild salmon stocks. He advocates a blend of adaptive management and 'bounded conflict' as way to undertake social learning over time scales of biological significance.

> Adaptive management—the compass—is an idealistic application of science to policy that can produce reliable knowledge from unavoidable errors. Bounded conflict—the gyroscope—is a pragmatic application of politics that protects the adaptive process by disciplining the discord of unavoided error. (Lee 1993, 11)

Lee proposes a pragmatic approach to *civic science* that has four rules: (1) use crises to encourage double-loop learning that reexamines premises and goals; (2) take advantage of disorder and slack—don't become enamored of fixed timetables; (3) be skeptical of the value of information—it makes sense to explore as many hypotheses as possible, including those of significance to managers; and (4) be patient (1993, 177). While Lee's portrayal of civic science includes technical and social components, he insists that science must be insulated from politically sensitive questions so as to preserve technical efficiency:

> Social learning works best when it produces good science: controlled experimentation, replication of surprising and important results, skepticism about cognitive biases in the conclusions reached—the elements of technically sound, efficient learning. Exercising political pragmatism in defending these ideals is therefore crucial to civic science (1993, 172–173).

The picture that emerges here is one predicated on a fairly conventional division of labor in which the 'social' rallies to defend the 'technical' core against meddlesome attacks by political detractors; such a strategy would help to bolster the legitimacy of experimentation and lower the costs of error. At root, this seems to be a fairly technocratic conception of the science-policy nexus that gives science pride of place at the center of the table.

That both technical and social judgments play a role in shaping knowledge and policy is a prominent theme in recent science and technology studies. Irwin (1995) argues that studies of risk evaluation challenge the assumption that scientific appraisal is central and everything else is just a distracting sideshow. A more symmetrical treatment of science and its publics indicates that "the science we get will reflect the social priorities and audience constructions of its sponsors" (Irwin 1995, 51). He goes on to summarize three major policy responses to environmental problems:

- expert assessments built around the independent, 'objective' judgments of scientific advisors
- public forums that permit a more open consideration of social and technological options
- pragmatic approaches that are less formalized, emphasizing flexibility and 'sensible judgment'

Irwin points out some limitations of each approach. Expert assessments tend to invoke science as a legitimating device to forestall external challenges and thereby facilitate closure; this tactic tends to downplay uncertainty and obscure social or economic concerns. Public forums can become 'ritualistic' if open discussion commences only after the issues have already been framed and structured. In the interest of remaining readily practicable, pragmatic approaches can stifle wider discussion concerning priorities and constraints. 'Science Shop' activities in Europe provide promising examples of innovative science-citizen relations, but Irwin notes that such activities suffer from not fitting easily into the structure of contemporary science; there are few academic rewards for participating, and lay perspectives don't always lend themselves to theoretical treatment. Civic-mindedness in science calls for a certain flexibility and openness that is at odds with the classic scientific spirit that has evolved over the last four centuries or so. Irwin's vision of a 'citizen science' is outlined in Box 4–6.

Box 4–6
Basic attributes of a 'citizen science'
(*Source*: Irwin 1995)

- engages with lay understandings
- acknowledges a plurality of knowledge forms and avoids imposing a unitary consensus
- approaches 'problem situations' without falling into established academic categories
- recognizes the uncertainties, limitations, and strengths of applying science to everyday life
- is institutionally flexible and open to change

Scientific practices have changed profoundly throughout the twentieth century. The Second World War in particular had a drastic impact, mobilizing natural and social scientists to work on applied research projects devoted to the war effort. Redner (1987) sees the Manhattan Project as the most potent symbol of the transition to large-scale, state-funded research subject to bureaucratic oversight. What he dubs 'World' science exhibits a number of distinguishing features that reflect new patterns of knowledge production:

- *technification*—instrumentation and technique assume crucial importance for disciplinary development
- *formalization*—mathematical description and computation become the hallmarks of what is properly scientific
- *abstraction*—theoretical concepts become increasingly removed from concrete human experience (often proceeding in tandem with professionalization)
- *problem-solving*—a preoccupation with readily solvable (i.e. restricted) problems reinforces the concern for productivity and intensifies the need for bureaucratic management
- *finalization*—the application of research techniques becomes externally directed to serve national, industrial, or societal needs

Redner argues that cognitive commitments and authority structures are interlocked in scientific disciplines. Well-formed disciplines can be seen as monopolistic establishments that deny resources and accreditation to 'outsiders' (1987, 118).

A comparative analysis of scientific fields helps to illuminate the many ways in which intellectual work is organized and controlled. Whitley takes the intellectual field to be the primary locus of knowledge production; intellectual fields are conceived as "relatively well-bounded and distinct social organizations which control and direct the conduct of research on particular topics in different ways through the ability of their leaders to allocate rewards according to the merits of intellectual contributions" (Whitley 1984, 7).

Whitley focuses on two aspects of scientific work in order to characterize major differences between fields: the degree of mutual dependence between researchers, and the degree of task uncertainty involved in producing or evaluating knowledge claims. By defining the organizational structure in terms of these two primary dimensions, Whitley distinguishes seven types of scientific fields (Box 4–7).

Box 4–7

A typology of scientific fields (*Source*: Whitley 1984)

A. *fragmented adhocracies* treat commonsense objects and are marked by considerable intellectual variety and fluidity (e.g. management studies)
B. *polycentric oligarchies* are organized into competing schools centered on leaders who control access to journals and employment opportunities (e.g. continental European ecology)
C. *partitioned bureaucracies* are highly rule governed and tend to value theoretical elaboration over empirical work, yet leave some room for 'deviance' in the applied periphery (e.g. economics)
D. *professional adhocracies* admit a variety of influences, but tend to produce specific empirical knowledge by linking conceptual approaches to particular skills (e.g. engineering, biomedical sciences)
E. *polycentric professions* employ relatively standardized skills and procedures in different research programmes (e.g. experimental physiology)
F. *technologically integrated bureaucracies* are coordinated through research technology that serves to link theory, method, and phenomena (e.g. modern chemistry)
G. *conceptually integrated bureaucracies* value theoretical coordination and strive to fit the goals of subgroups into a 'unified cognitive order' (e.g. modern physics)

Whitley's typology highlights the diversity of circumstances under which science is practiced. Kuhn's 'normal' science can be recognized as a conceptually integrated bureaucracy that reflects the authority structure of modern physics. The point is that this is not the only model for organizing scientific work. Contextual factors also play a role in shaping how the intellectual work gets done. Some of these influences—such as reputational autonomy, control over access to critical resources, and audience structure—vary significantly across the seven types Whitley identified (Table 4–2).

Table 4–2
Contextual factors across scientific fields (*Source*: Whitley 1984, Table 6.1)

Type	Reputational autonomy over setting			Concentration of control over access to resources		audience structure	
from Box 4–7	*performance standards*	*significance standards*	*problem definition*	*horizontal*	*vertical*	*variety*	*equivalence*
A	low	low	low	low	low	high	high
B	medium	medium	low	medium	high	high	medium
C	high	high–c* low–p*	high–c low–p	high–c medium–p	medium	medium	low
D	high	low	medium	low	low	high	medium
E	high	medium	high	medium	high	medium	medium
F	high	high	high	low	high	low	medium
G	high	high	high	high	high	low	low

* the symbols –c and –p denote the core and periphery of a partitioned bureaucracy, respectively

This brief foray into the workings of the scientific establishment points out a few of the obstacles that lay in the way of attempts to render the boundaries of science more permeable. What, then, are the implications for revitalizing science–citizen relations, for assaying some sort of 'citizen science'? It seems that the notion of an extended peer community is an idealistic one, given the authority relations that prevail in established scientific disciplines. Notwithstanding the current clamor for more 'relevant' research, individual scientists lack incentives to address pressing public concerns or are even penalized for doing so.

The peer-review system discourages innovation. Self-interest inclines scientists to restrict the ability of clients to criticize performance standards; and lay influences invariably frustrate attempts to achieve the cognitive order that permits the evaluation of intellectual contributions. Entrenched norms such as these would presumably have to be replaced, circumvented, or even overthrown but Funtowicz and Ravetz remain silent on the matter. If post-normal science is read as a low-key critique of technocratic governance, then merely calling for more open dialogue seems idealistic, and it leaves off where the real work must begin. Transcending managerial biases and reforming the politics of professional expertise requires more than methodological elaboration. Shackley, Wynne, and Waterton (1996) express reservations about vigorous 'methodologizing' that leaves existing institutional arrangements out of the problem frame, thereby inhibiting reflexivity:

> The ever-present danger is that the methodologizing tendency will merely offer the prospect to existing institutional forms of adapting to/coping with complexity, without any serious questioning of their own practices, or of the changing world in which they are operating. (Shackley, Wynne, and Waterton 1996, 217)

The schema advanced by Funtowicz and Ravetz (i.e. pure/applied science→professional consulting→post-normal science) implies a gradual widening of the audience engaged in judging the quality of scientific work: from peers, to clients, to stakeholders. Yet sweeping stakeholders into the affair marks a profound departure from the centuries-old process of exclusion initiated by the first scientific societies in the 17th century. It's difficult to see the post-normal practitioner as a scientist in the classical sense. Perhaps the designation 'post-Newtonian' or 'post-Cartesian' science might be more apt, if one takes science to mean the methodical production of knowledge; its etiquette of inquiry is more akin to the informality of a buffet than the ceremony of a state banquet.

4.4 Science in the interstices

Ravetz (1971) has argued in support of the craft character of scientific work and commented extensively upon the increasing interpenetration of science and industry; he indulged in a little speculation concerning the emergence of a more self-conscious and activist 'critical science' directed by "true intellectuals rather than a technical intelligentsia" (1971, 427). However, Ravetz saw little need for any sort of rapprochement between scientists and their general publics:

> In the last resort, there are no direct means whereby anyone outside the world of science can exercise quality control on science. The products of the craft work of scientists are intelligible, and valuable, only to other scientists. And although they relate to the external world, their value as well as their meaning is governed by the judgements of men, those particular men who enjoy this esoteric activity. (Ravetz 1971, 287)

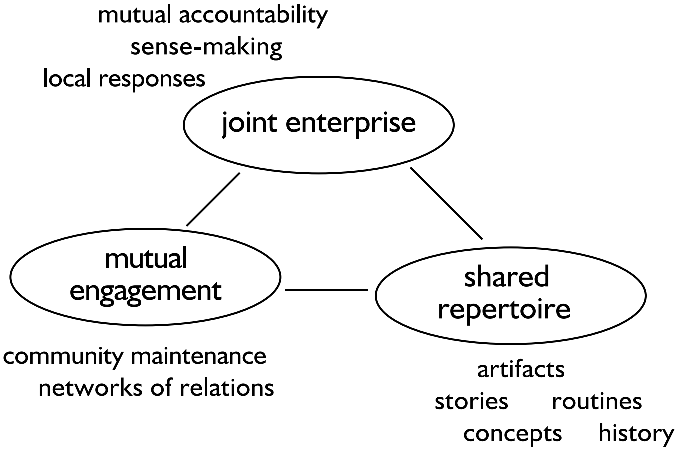
The basic notion here is one of science as an elite enclave of intellectuals. So what has changed this state of affairs? According to Funtowicz and Ravetz, a growing awareness of global environmental issues—an awareness that collapses the traditional fact/value distinction and threatens a 'legitimation crisis'. Science undertaken in the post-normal mode shucks the pretense of disinterested scholarship, but where does it leave us? It seems to offer no powerful rejoinder to the question posed by Fischer (1990, 35) in his critique of technocracy: "Can we, in short, build a meaningful system of participatory decision processes in the age of technology and expertise?" The abstract formulations and proposed methodological elaborations of post-normal science—its "intellectual tools"—appear to skate over some deep tensions such as that existing between expertise and democracy, and that between efficiency and participation.

Post-normal science, civic science, and other visions for merging science with public policy seem to entail a more collaborative model of expertise, one that engages with complexity and acknowledges the legitimacy of multiple perspectives. This would require reshaping the role of the expert in order to integrate expertise and participation such that the exercise of the former doesn't automatically preclude the latter. Advocacy research is one model, but Fischer argues that it is often adversarial, with experts becoming hired guns for competing interests. In addition, the elitist tenets of professionalism (e.g. the presumed autonomy of the expert) usually bend effort towards resolving policy issues, not developing an ongoing community process (1990, 350). Fischer considers the 'politics of expertise' to be especially problematic for the development of a more participatory mode of research; by his account, infusing mainstream disciplines with new values is a project with intellectual and political dimensions. An alternative model should have procedural and methodological ground rules to structure inquiry:

> In specific procedural terms, it is essential to examine systematically the institutional and intellectual conditions that support the successful use of participatory inquiring systems. In particular, we need to develop systematic rules for structuring collaborative problem posing, expert-client discourse, and social learning. (Fischer 1990, 377)

The real trick, of course, is to avoid both the vagaries of inquiry that lacks sufficient structure and the rigidity that attends an overabundance of structure. Echoing Wenger (1998), the paramount design task is to achieve a judicious combination of participation and reification so as to compensate for their respective shortcomings; that is, correcting the severe imbalances that can hinder the negotiation of shared meaning. Excessive fluidity can impair coordination and alignment. Excessive rigidity can frustrate attempts to probe blockages to inquiry or to uncover divergent assumptions. A well-tempered process of deliberation heeds those dimensions of practice that are the wellspring of community coherence (Figure 4–4).

Figure 4–4
Practice as a source of community coherence (*Source*: Wenger 1998, Fig. 2.1)



Schön (1983) delved into the epistemology of professional practice and pointed to the positivist origins of the technical rationality that dominates the institutional contexts of professional life. Technical rationality extols problem *solving* and ignores problem *setting*, an emphasis that creates difficulties in situations lacking fixed and unambiguous ends (i.e. those that do not admit a 'calculus of decision'). Schön developed the idea of reflection-in-action, a process in which the dichotomies maintained by technical rationality (means/ends, research/practice, knowing/doing) are dissolved. The inquirer functions as an agent-experient rather than as a spectator-manipulator. The reflective practitioner enters into a relationship with clients or stakeholders that departs from the traditional one of "mystery and mastery". Pondering the contours of reflective practice

> leads us to recognize that for both the professional and the counterprofessional, special knowledge is embedded in evaluative frames which bear the stamp of human values and interests. It also leads us to recognize that the scope of technical expertise is limited by situations of uncertainty, instability, uniqueness, and conflict. When research-based theories and techniques are inapplicable, the professional cannot legitimately claim to be expert, but only to be especially well prepared to reflect-in-action. (Schön 1983, 345)

Ordinary bureaucratic settings are unlikely to embrace reflective practice, according to Schön—confusion and uncertainty threaten to disrupt their smooth functioning. An accommodating institution must meet several 'extraordinary' conditions (1983, 338):

- place a high priority on flexible procedures
- permit divergent responses
- accept qualitative assessments of complex processes
- disperse responsibility for judgment and action
- attend to conflicting values and purposes

The organizational characteristics of a civically-minded science are discerned more clearly in light of Whitley's typology. If it is to be more than an education or public relations exercise (i.e. a forum for damage- and spin-control), any science that embraces vernacular interests is likely to resemble a fragmented adhocracy, perhaps tending toward a polycentric oligarchy or a professional adhocracy as methodologies solidify. Ironically, these more permeable organizational types may be favored by the continuing industrialization of science and the full flowering of post-industrialism. Gibbons and others (1996) apply the nondescript label 'Mode 2' to an emerging form of knowledge production that is transdisciplinary, heterarchical, and carried out in diverse settings. But this trend reflects no democratizing impulse; rather, increasing international competition in business and industry is driving firms to commercialize knowledge by establishing partnerships centered on specialized applications.

The sort of citizen science envisioned by Irwin—or even the post-normal science advocated by Funtowicz and Ravetz—currently lacks an institutional basis and can be practiced, if at all, only in the interstices of existing institutions. Hence the designation 'interstitial science' may not be out of place; one of its basic tasks is to promote what Heifetz, in his study of leadership (1994), has called *adaptive work*:

> Adaptive work consists of the learning required to address conflicts in the values people hold, or to diminish the gap between the values people stand for and the reality they face. Adaptive work requires a change in values, beliefs, or behavior. The exposure and orchestration of conflict—internal contradictions—within individuals and constituencies provide the leverage for mobilizing people to learn new ways. (Heifetz 1994, 22)

Heifetz points out that our predilection for easy answers—not searching questions—reinforces an aversion to engaging in adaptive work that might be distressing. He describes a number of capabilities needed for mobilizing adaptive work (Box 4–8).

Box 4–8
Mobilizing adaptive work (*Source*: Heifetz 1994)

- *providing a holding environment* to contain and channel stresses
- *directing attention* so as to head off a search for technical 'solutions' to an adaptive problem
- *framing issues* and managing information in order to lay bare the key challenge(s)
- *orchestrating* conflicting perspectives so that learning can occur
- *choosing* the decision-making process according to the type and severity of the problem, level of social resilience, etc.

The activities that mobilize adaptive work are a far cry from the usual exhortations to set goals, establish measurable objectives, and placate stakeholders—such work does not come easily to most organizations. Seen as information processing systems, organizations are somewhat handicapped when it comes to reflective inquiry. Since most organizations are created in order to fulfil a mandate or to accomplish particular tasks, there arises a certain tension between acting in accord with operational principles and revising—or dropping—those principles in the face of 'hostile' evidence. Dery has described organizations as epistemologically closed systems wherein inquiry is subordinated to performance: "Error prevention is more important than detection and correction. And to design and organize for error prevention is to already know what is not an error" (Dery 1990, 38). Hence organizations are best regarded as performance systems that impose powerful constraints on data selection, not as learning systems suffused with the spirit of experimentation. Instead of insisting that organizations embody an unbearable tension, it may be more fruitful to consider the prospects for building an infrastructure for learning at some supra-organizational level. But this is not institution building on a grand scale; to paraphrase Dery (1990), it's about reconfiguring the social context of justification in order to generate some focused stress—let's call it bounded dissent—that compels scrutiny of problem frames. One can liken the effort to setting the stage, not writing the script.

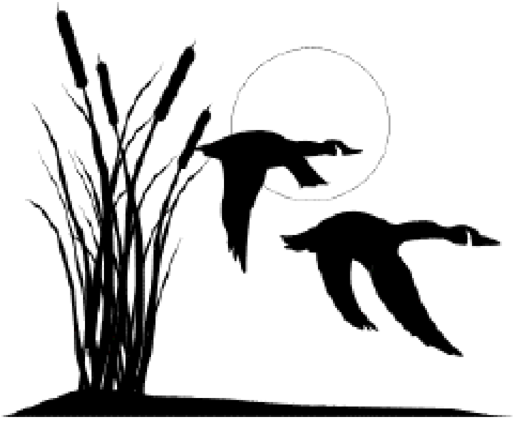
Before pressing on, a brief review of some key ideas presented in this chapter is in order. Of the many prescriptions for ecosystem management reviewed here, the vast majority place great stock in carefully defining goals, objectives, and deliverables—these are the GODs of the EMAN pantheon; few modern managers would dare to work without them. All very well if you are beholden to a mandate, which can be looked upon as a guillotine poised to behead the poor folk who don't measure up. But flowcharts, milestones, benchmarks, and the rest have the unfortunate tendency of smothering the very creativity, cooperation, and adaptability that almost everyone agrees is essential to the ecosystem approach. So we face a bit of a conundrum, for there is no institutional basis for practicing ecosystem management in shifting contexts. The challenge we face is one of seeking and maintaining the middle ground between learning and performing, between diversity and cohesion, between the absence of structure on the one hand and overweening superstructure on the other. In short, we lack a suitable infrastructure for learning.

The Long Point World Biosphere Reserve, like most biosphere reserves, harbors a diversity of concerns and local arrangements that do not hinge on an official mandate. The apparatus of strategic management planning, with its concern for minimizing error and maximizing efficiency, is not an appropriate way to conceive of the creation of a regional environmental information network. Mintzberg (1994) sees planning as fundamentally conservative in that plans tend to perpetuate existing categories, opting for stability over adaptability:

> Formally planned change of the kind we are suggesting tends to have three essential characteristics: (a) it is incremental rather than quantum, (b) it is generic rather than creative, and (c) it is oriented to the short term rather than the long term. (Mintzberg 1994, 176)

What needs to be ‘managed’ is the diversity of human problem setters and erstwhile problem solvers, not the world at large. Fostering cooperation and coordinating perspectives is tantamount to building Schön’s ‘extraordinary’ institution—one which makes room for reflective practice.

Chapter five turns to the issue of boundaries. Many boundaries figure in the discourses surrounding ecosystem management: the boundary between science and policy; boundaries between academic disciplines; demarcations that set apart administrative jurisdictions; and boundaries delineating ecosystems. As a result, practicing any sort of an ecosystem approach requires some adroit boundary work in order to manage the tension between heterogeneity and cooperation.



Chapter 5

Boundary business

> Thus the order and regularity in the appearances, which we entitle *nature*, we ourselves introduce. We could never find them in appearances, had we not ourselves, or the nature of our mind, originally set them there.
>
> Immanuel Kant,
> *Critique of Pure Reason*

5.1 Contested borders

We put a lot of work into establishing and maintaining boundaries, be they physical, institutional, ideological, or cognitive; the act of defining them has important practical implications. The intermingling of boundaries and belief systems determines access, power, and legitimacy (Michael 1995). So it behooves anyone bent on practicing an ecosystem approach to delve into the 'natural history' of boundaries, especially in heterogeneous settings peopled by groups holding diverse interests, skills, and expectations. Integrated monitoring entails the creation, use, and maintenance of what Bannon and Bødker (1997) have labeled a *common information space* within which cooperative work is performed. While they introduced the concept in order to investigate the dialectical aspects of computer-supported cooperative work (CSCW), it also seems appropriate for discussing the distributed, decentralized, and asynchronous handling of environmental information. Bannon and Bødker insist that a common information space is not just a repository of shared databases, but also encompasses the interpretation work required to construct shared meanings; its dialectical character is exemplified by the tension between the need for openness (i.e. ongoing debate) and closure (i.e. portable artefacts that can 'travel' between communities). Hence a common information space is a plastic construct that spans organizational boundaries.

Boundary delineation drives to the very heart of what it means to define an ecosystem, and attitudes about doing it vary. In particular, the degree of arbitrariness accorded a posited boundary reflects the character and strength of ontological commitments. Previous chapters have contrasted essentialist and constructivist attitudes, and this distinction will serve here as well. Whereas essentialists cleave to purportedly necessary and invariant criteria, constructivists regard universal demarcation criteria with some skepticism. For example, Gieryn (1995) takes constructivism "out of the lab" and argues that the science/non-science divide itself is a flexible one that has been contested for centuries through diligent boundary work:

> Boundary-work occurs as people contend for, legitimate, or challenge the cognitive authority of science—and the credibility, prestige, power, and material resources that attend such a privileged position. Pragmatic demarcations of science from non-science are driven by a social interest in claiming, expanding, protecting, monopolizing, usurping, denying, or restricting the cognitive authority of science. (Gieryn 1995, 405)

I don't wish to linger too long on such high ground, but it's important to appreciate the significance of boundaries in environmental monitoring. First, integrated monitoring requires that diverse groups of actors cooperate in collecting, sharing, and interpreting environmental data. Many borders are challenged and refined as these groups strive to legitimate their activities, secure the resources they need, and engage in collective sense-making. Within a biosphere reserve the participation of scientific experts, agency staff, knowledgeable amateurs, and interested volunteers intensifies border traffic. Second, there have been many attempts to implement spatial ecosystem frameworks, usually in the interest of using a geographic information system. However, viewing an ecosystem as a fixed spatial object is not entirely straightforward. One researcher states with assurance: "We recognize all natural ecosystems by differences in climatic regime. Climate, as a source of energy and moisture, acts as the primary control for the ecosystem" (Bailey 1996, 157); yet this ecologist chides us: "So do not stand on your dignity about the real existence of any boundary; it is in your mind" (Canny 1981, 2). When it comes to interpreting environmental data, lines on a map should not be taken for granted. The supposition that an ecosystem can be conceived as a purely spatial object is fraught with pitfalls. Section 5.2 will introduce some of these difficulties.

That natural and human boundaries are often incongruent is another source of vexation. Ankersen and Hamann (1996) recount efforts to redress the incongruence between jurisdictional and biotic boundaries in Florida. They consider the 'boundary conundrum'—manifested by non-conforming geographical and institutional boundaries—to be the most perplexing dimension of ecosystem management, given the juxtaposition of open ecological systems with relatively rigid human institutions. The problem is that the impulse to designate ecoregions, watersheds, or the like as management units is unlikely to proceed smoothly in the absence of accompanying institutional realignments. As Ankersen and Hamann note, statutory directives, agency missions, turf battles, and other assorted "historical baggage" can easily stymie attempts to reform boundaries. Far-reaching overhauls can also engender considerable suspicion. Fitzsimmons (1994) argues that ecosystem management augurs the expansion of the federal regulatory regime (thereby threatening economic growth and private property rights—a classic American objection), and suggests that ecosystems lack sufficient precision and stability to guide management actions. Contested ideologies aside, this last point may be well taken and could pose a challenge to agencies organized along traditional bureaucratic lines.

Boundaries are vexing because ecosystems are open systems: they exchange matter and energy with their surroundings. Canny (1981) propounds a number of boundary properties that are commonplace in open systems (Box 5–1).

Box 5–1
Some properties of boundaries in open systems (*Source*: Canny 1981)

- boundaries appear and multiply spontaneously (e.g. dissipative structures)
- external energy destroys boundaries—its rate of application influences the degree of heterogeneity
- a boundary contains the record of the interactions across it, but the degree of evanescence varies
- interaction across a boundary favors the side with higher variety—the boundary expands at the expense of the low-variety space

Our fondness for drawing lines on a map collapses ecosystem interactions onto the horizontal plane, but strong interactions are quite rare here; strong interactions are often radially directed under the influence of gravity and light—horizontal patterns may be incidental to vertical exchanges (Canny 1981). A strong interaction presumably reflects a strong gradient. But ecological gradients are often 'fuzzy' rather than sharp, a circumstance that can confound conventional map-based analyses. Identifying robust boundaries is the linchpin of any analysis; a number of systems ecologists have floated ideas about how to go about doing this.

5.2 In search of robust boundaries

Maps work best when they depict 'exact' objects whose spatial attributes are fixed and unambiguous (e.g. buildings, census districts, coastlines). But even then they are a flexible medium of communication, as Monmonier points out: "If any single caveat can alert map users to their unhealthy but widespread naïveté, it is that *a single map is but one of an indefinitely large number of maps that might be produced for the same situation or from the same data*" (1991, 2). Unfortunately, the healthy skepticism that Monmonier recommends is hard to find among people (not a minority by any means) who equate an environmental information system with a geographic information system. The fluidity of ecosystem boundaries belies the common assumption that they can be mapped in a straightforward way.

Appendix A describes some of the difficulties associated with viewing ecosystems as spatial units; it introduces the *modifiable areal unit problem*, a complication that arises when spatial analysis is sensitive to scale and aggregation effects. A modifiable areal unit is one that is arbitrarily bounded in space—this generally means that the selected boundaries have little significance with respect to the process(es) under investigation. For example, when studying the population dynamics of pine martens a watershed is a modifiable areal unit unless a marten somehow 'sees' watershed boundaries. Some implications of using geographic information systems for ecological applications are also considered. In particular, the *exact object model*—that assumes boundaries are crisp and precisely defined—is found wanting. Database researchers are only in the early stages of devising ways to handle *vague* spatial objects.

So if a purely spatial definition of ecosystems is problematic, where can one turn for succor? The basic ideas of hierarchy theory have found much support among ecologists. Most biological systems display several levels of organization: the classic ordering of *cell—organism—population—community—ecosystem—landscape* is a widely recognized scheme. For landscape ecologists in particular, notions of hierarchy and scale are directly relevant. King (1991) described a landscape as a nested hierarchy where lower levels are characterized by smaller spatial extents and higher-frequency behaviors. Higher levels are associated with larger spatial scales and low-frequency behavior (i.e. slow turnover times).

O'Neill and his colleagues assert that system identification is essentially arbitrary, that a system is a human construction (O'Neill and others 1986, 38). Yet in considering the thermodynamic theory of dissipative systems, they suggest that hierarchical structures are commonplace in open, evolving systems. They add: "It does not appear that we are artificially imposing the hierarchical structure for the convenience of explanation" (1986, 121). There seems to be a little gerrymandering going on concerning the ontological status of perceived hierarchies in natural systems, a point raised earlier in Chapter 2.

The condition of nestedness or containment is a special case, not a general one. While nested systems appear obviously hierarchical, Allen and Hoekstra (1992) point out that there are many examples of non-nested hierarchies in ecological systems (e.g. food chains and pecking orders). If one relaxes the nestedness criterion, the most important criteria for ordering levels are frequency and constraint. The essential idea here is that ecosystems are not easily delimited by fixed spatial boundaries. If ecosystems are defined in terms of interactions and pathways, then material and energy cycles become key to understanding their dynamics: "Ecosystems can be seen more powerfully as sequences of events rather than as things in a place. These events are the transformations of matter and energy that occur as the ecosystem does its work. Ecosystems are process-oriented and more easily seen as temporally rather than spatially ordered" (Allen and Hoekstra 1992, 100).

If most relevant pathways are not spatially fixed, how are boundaries defined? Natural surfaces—robust boundaries—are distinguished when one observes discontinuous changes in process rates; a steep rate gradient betokens heterogeneity (Allen and Starr 1982, 87). Now, a robust boundary may well coincide with some distinctive landscape feature. If drainage patterns are of interest, then a watershed constitutes a non-modifiable unit for the purpose of investigation—its border reflects a bona fide boundary, as there is an abrupt change in the pattern at the watershed boundary.

However, a watershed may not be a suitable unit of analysis for every application. Wiens noted that objects and scales that comport easily with our own habits of perception offer no assurance that they also shape the 'ecological neighborhoods' of other organisms: "We need nonarbitrary, operational ways of defining and detecting scales" (1989, 391). Wiens opined that if scale-dependency is continuous—such that domains of scale cannot be readily identified—then generalizations will be hard to come by.

The key point here is that the spatial aspects of an ecosystem may be only incidental to its functional aspects. Allen and Hoekstra explain their reasoning this way:

> We are so insistent on resisting a spatial definition of ecosystems because that definition excludes many aspects of ecosystems that simply do not fit the landscape neatly. The ecosystem is a much richer concept than just some meteorology, soil, and animals tacked onto patches of vegetation (Allen and Hoekstra 1992, 99).

The modifiable areal unit problem can give rise to spurious relationships in the context of environmental data analysis. The issue highlights the difficulties of supposing that ecosystems can be straightforwardly conceived as mappable entities. The question one must ask is: Do the adopted boundaries represent a non-modifiable unit for present purposes? If not, then the task is to identify a more 'natural' surface, keeping in mind that meaningful areal units may not map perfectly onto fixed features of the landscape. But there is no general agreement on this matter. King (1993) asserts that natural scales—identified by considering system interactions and media properties—tend to coincide with tangible features such as watersheds. This statement may say more about our predilection for focusing on the tangible aspects of ecosystems, rather than about how such features are integral to system organization. Wiens espouses a broader outlook: "Proper analysis requires that the scale of our measurements and that of the organisms' responses fall within the same domain" (Wiens 1989, 394).

If sensitivity to scale-related matters is a good idea, what are the practical implications? Allen, Bandurski, and King (1993) reject the notion of an all-purpose set of criteria for parsing ecosystems.

Considerations of *scale* and *type* are basic to the ecosystem approach they outline. Scale pertains to the grain (in both space and time) and extent of an observation set. Type refers to the criteria employed to distinguish the system of interest in light of specific questions (e.g. a lake basin can be viewed as a geomorphic entity, as habitat for benthic organisms, or as a fishing ground). Taken together these choices constitute a frame of observation or perspective that distinguishes foreground from background (i.e. extracts phenomena from noumena); this dependency on perspective is often underappreciated or overlooked entirely. Allen, Bandurski, and King see this dependency as a warrant for flexibility of thought and action, a warrant for identifying non-traditional boundaries that may be relevant to an issue under investigation.

By itself, adept analysis within a particular observation frame will only get you so far. The congruence—or lack thereof—between different frames also demands attention. For a monitoring initiative to be a genuinely integrated affair, there remain the twin issues of merging disparate data sets and of forging links with other communities of practice. Thus connections must be established on at least two levels; the following sections look at these in turn.

5.3 Combining disparate data sets

Coordinating the activities of participants is vital in any effort to integrate data drawn from different groups and agencies. A considerable degree of collaboration is called for in many programs, particularly with regard to sharing data. Such cooperation does not arise spontaneously in the face of bureaucratic and political forces that are inclined to jealously protect organizational mandates. Ecological phenomena heed few jurisdictional boundaries, so data sharing between groups or agencies is a prerequisite for any concerted integration effort. Challenges arise both within and between organizations collecting environmental data. Evans (1994) identified a number of circumstances that can either promote or inhibit data sharing:

- proprietary data interests or 'turf battles' (inhibit)
- bureaucratic inertia (inhibits)
- the presence of a motivated 'champion' (promotes)

- assorted legal and economic issues: information construed as property; the availability of government subsidies, etc. (these can promote or inhibit depending upon one's commitments)

Other factors can also make data integration an arduous task. The reward system for academic researchers neither encourages data sharing between projects nor commends close attention to documenting data characteristics. With regard to metadata requirements, one recommendation that emerged from a review of selected case studies called for the mandatory production of metadata for every study whose data might be used for interdisciplinary research (National Research Council 1995a, 109). The recommendation stipulates that metadata should include a description of the study design, data collection protocols, quality control procedures, preliminary processing, and other information that would permit someone who is not intimately familiar with the data set to use it in an informed manner. Ideally the user could even backtrack to earlier versions of the data, if necessary.

Michener and others (1997) recently examined the benefits and costs associated with developing metadata for the ecological sciences. Recognizing that cross-scale synthesis and integrated modeling become almost impossible to do if metadata are unavailable or incomplete, the group proposed five categories of ecological metadata descriptors (Box 5–2). Rich metadata content facilitates secondary use of a data set by those unfamiliar with it, and ensures that a the data can be interpreted—or reinterpreted—at a later date (e.g. the '20-year test').

Quite a number of GIS implementation studies carried out within organizations have highlighted several common difficulties. A British study (Campbell and Masser 1992) surveyed 514 local authorities in Great Britain in 1991. The organizational issues that were cited as most problematic included: lack of technical experience in GIS; poor communication between specialists and users; and lack of support from senior staff. These issues are probably germane to any data integration activity. The changes wrought by introducing new data handling procedures are not often thought through, even though they can profoundly alter roles and responsibilities within an organization. Interorganizational data sharing can be a very tough nut to crack. This is understandable, given that most integrated monitoring programs call upon the resources of many groups within a very rich institutional milieu. But often there are no compelling nuclei around which information can condense.

Box 5–2

Classes of ecological metadata descriptors (*Source*: Michener and others 1997, Table 1)

I Data set descriptors

A. title or theme
B. identification codes or accession number
C. abstract & principal investigator(s)
D. keywords

II Research origin descriptors

A. description of overall project (e.g. objectives, funding)
B. description of specific subprojects (e.g. site description, experimental design, research methods, personnel)

III Data set status and accessibility

A. status (e.g. last update, data verification)
B. accessibility (e.g. storage medium, proprietary restrictions, costs)

IV Data structural descriptors

A. data set file (e.g. size, format, header information, authentication procedures)
B. variables (e.g. definition, units of measurement, data type, data format)
C. anomalies (e.g. calibration errors)

V Supplemental descriptors

A. data acquisition methods
B. quality control procedures
C. related materials (e.g. maps, notebooks, comments)
D. software & data processing algorithms
E. archiving procedures
F. publications and results
G. history of data set usage

Ecosystem management can be very loosely interpreted, but it generally denotes activities whose purview transcends a single discipline, medium, or scale; it is a multi-organizational endeavor, and some measure of cooperation among participating groups is essential. It is illuminating to consider the results of a recent survey of 105 sites in the U.S. that practice some form of cooperative ecosystem management (Yaffee and others 1996). Collaboration and public support were cited by about 60% of the cases as factors facilitating progress. Opposition from critics and lack of resources were the biggest obstacles (50% and 44% of cases, respectively). The most prevalent piece of advice offered by respondents was to involve all stakeholders at an early stage. The use of flexible management strategies was another common recommendation.

In combining disparate environmental data sets the erstwhile analyst (synthesyst?) confronts a number of challenges possessing both theoretical and organizational dimensions. Modifiable areal units are more the rule than the exception in ecological systems. Concepts from hierarchy theory suggest that dynamic natural phenomena are not fruitfully considered to be solely spatial phenomena that can be unambiguously delineated on a single map. The implications for using a GIS as an 'integration tool' are significant, yet there doesn't seem to be widespread recognition of the potential pitfalls (at least among applied practitioners). Appendix A introduces some of the difficulties that arise when an exact object model—predicated on crisp, unambiguous boundaries—are applied to vague ecological objects whose boundaries are fuzzy at best.

Insofar as there is no 'correct' scale for analysis, attending to the difficulties of integrating different types of data requires a good understanding of the data characteristics and of the underlying scientific assumptions; these 'built-in' features of data

> mean that data interfacing involves more than just combining the tangible aspects of the data, such as formats and data values. It also necessarily involves identifying, understanding, and accommodating the assumptions, perspectives, value judgments, and decisions inherent in each data set. In simpler terms, all data sets cannot be all things to all people. (National Research Council 1995a, 89)

Similarity judgments (i.e. notions about homogeneity or exchangeability) play an important role in deciding when and how to combine data from different sources (National Research Council 1992, sec. 4.1). These judgments are usually packed into modeling assumptions, sometimes explicitly, but more often not. Unpacking them, looking 'under the hood' so to speak, is a task more likely to occur when divergent problem frames collide (i.e. the knocking and pinging that augurs misaligned assumptions and expectations). Providing support for attempts to reconcile perspectives—which entails debating, translating, and negotiating—is a necessary component of any monitoring initiative that involves multiple communities of practice.

5.4 Connecting communities of practice

Integrated monitoring unfolds in heterogeneous settings that require diverse groups of actors to cooperate in collecting, sharing, and interpreting environmental data. Most boundary work takes place at the margin of a domain. If cooperative arrangements are called for, the meeting of professional or cultural domains is often mediated by 'boundary objects' at the margin: these are ideas, things, or processes that people in different domains can "get behind" in order to facilitate their joint work (Gieryn 1995). Gieryn's usage of the concept owes much to Susan Leigh Star's writings on the nature of an understanding that can straddle multiple viewpoints. Star studied the artificial intelligence research community in some detail through much of the 1980s and was struck by the open character of heterogeneous problem solving; in a critique of asocial models of such activity, Star (1989) proposed *boundary objects* as a resource for partly reconciling different perspectives:

> Boundary objects are objects that are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use, and become strongly structured in individual-site use. (Star 1989, 46)

Boundary object sit 'between' actors and provide referents for cooperative activity. Star identified several prominent types of boundary objects:

- *repositories* (e.g. a library or museum)
- *ideal types* that aid communication (e.g. taxonomies, diagrams, and atlases)

- *terrain with coincident boundaries* but different contents (e.g. a common geographic unit represented using different criteria or types of maps)
- *forms and labels* that standardize the collection and dissemination of information

While the types listed above are quite abstract, a number of historical case studies provide more concrete examples. Star and Griesemer (1989) provide a cogent account of boundary work in their study of the Museum of Vertebrate Zoology at the University of California, Berkeley. During the early decades of this century many allies were recruited in the course of establishing and running the new museum. Cooperation is essential in order to pursue scientific research that involves the efforts of scientists, curators, amateur collectors, patrons, university administrators, and government officials. Figure 5–1 depicts the major boundary objects in play. The museum's success is ascribed to two factors: the standardization of methods for collecting, preserving, labeling, and taking field notes; and the production of boundary objects that helped to maintain coherence across different perspectives.

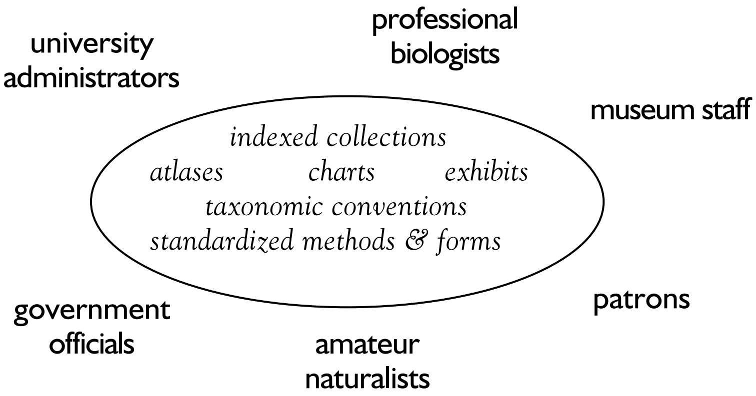


Figure 5–1
Boundary objects in play at the Museum of Vertebrate Zoology, Berkeley (*Source*: Star and Griesemer 1989)

Adopting a somewhat ecological approach to laboratory work, Fujimura (1992) considers how collective action is managed across social worlds. She argues that boundary objects are too plastic, too malleable to permit the stabilization of 'facts' and the recruitment of allies as described by Latour (1987). Instead, the more specific concept of a *standardized package* is proposed to allow for a greater degree of fact stabilization. A package defines a conceptual and technical workspace representing an amalgam of theory and method. Fujimura traces the rise of oncogene theory, with its standardized techniques of molecular genetics, to substantiate her claims. For phenomena amenable to technical treatment (i.e. laboratory manipulation), a standardized package may be just the thing to complement the articulation work that boundary objects support. But I don't expect to see standardized packages for environmental monitoring any time soon—natural systems in the wild are not so easily boxed.

It might strike the reader that all this talk about creating boundary objects and mobilizing adaptive work verges on institutional design, and in a weak sense this is the case. By this I mean that institutional realignments unfold "on the fly", not according to some grand strategy. Linder and Peters (1995) contrast two traditions of institutional design: decisionist and dialogical; the first favors global rationality (e.g. universal standards) and is averse to politics, whereas the latter embraces local rationality and emphasizes shared discourse. The preferred modes of addressing governance and design issues are summarized in Table 5–1.

Table 5–1
Two traditions of institutional design (*Source*: Linder and Peters 1995, 155)

	Decisionist tradition	Dialogic tradition
Governance	*Elite choice-making*	*Discursive steering*
Design	*Expert formulation*	*Forums for reasoned argument*

The attitudes to design that I wish to encourage are more attuned to the dialogic tradition than the decisionist one. Foremost is a concern with shaping a well-tempered process of deliberation that is not too firmly wedded to technocratic norms. Furthermore, the role of the designer is not that of a detached outsider imparting certified, objective knowledge from on high: "In its stead, the designer is cast in a minor role, setting a larger process into motion rather than controlling it. Rather than engineer, the designer is animateur" (Linder and Peters 1995, 157).

The significance of dialogue or argument in policy and planning has also been stressed by others. An alternative logic of inquiry that departs from the norms of instrumental rationality has been dubbed the 'argumentative turn' by some policy analysts. Dryzek (1993) summarizes the turn against objectivist discourse—even qualifying it as an intellectual movement—and points to the inadequacies of purely analycentric techniques in the rough-and-tumble world of politics.

> The essence of judgment and decision becomes not the automatic application of rules or algorithms but a process of deliberation which weighs beliefs, principles, and actions under conditions of multiple frames for the interpretation and evaluation of the world (Dryzek 1993, 214).

Dryzek seeks a rational basis for comparing frames, lest a situation slide into "anything goes" relativism (the ghost of Feyerabend, again). He urges that frames be used in a forensic manner as sources of argument to test the mettle of proffered claims and to counter 'distortions'. Open communication and unrestricted (albeit competent) participation undergird defensible policy analysis conducted according to the canons of discursive democracy—a mode of deliberation that entails unfettered inquiry and "a selective radicalization of scientific principles" (1993, 229).

What is a frame? An interpretive frame serves to distinguish foreground from background; in Kantian terms it sifts phenomena from raw noumena. The notion of a *cognitive grid* conveys the sense in which I understand the concept. No one can attend to the totality of 'facts' that bear on a given situation or circumstance, and not all facts are created equal—some are deemed more meaningful than others in light of particular assumptions, interests, and capabilities. The exploration of alternative frames is intrinsic to the dialogic tradition; chapter six will pursue the implications of this interplay in more detail.

The transparency of public inquiry advocated by Dryzek is hard to imagine, but the centrality of dialogue cannot be ignored. Schön and Rein (1994) distinguish two types of interpretive frames that figure in policy discourse: rhetorical frames that aim to persuade or cajole, and action frames that inform practice (e.g. laws, sanctions, procedures). In considering the prospects for communicating reliably across conflicting frames, the authors suggest that no model of idealized discourse provides a satisfactory basis for *frame reflection*; they propose a view of policy making couched in terms of a design rationality that highlights learning within a social process where “the designer discovers unanticipated patterns, relationships, and possibilities, which may inform further designing” (Schön and Rein 1994, 85).

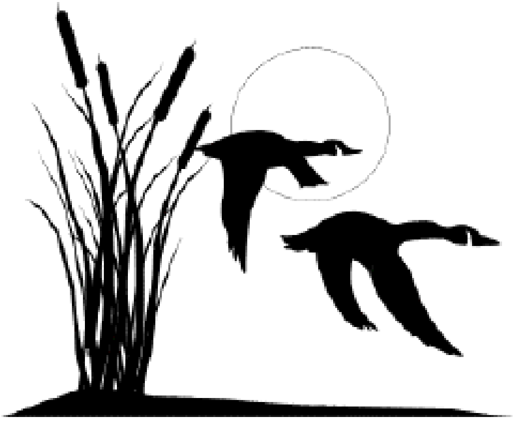
Disparate interests and powers make for a rich and varied design process that admits cooperation, competition, debate, and perhaps even litigation. For Schön and Rein the quality of discourse is a central concern as actors seek control over the form, meaning, and use of policy objects that function as “messages”, the meanings of which are constructed by stakeholders in the larger environment. Reliable communication, which is deemed essential to reflective inquiry, rests upon the ability to test how messages are interpreted. Co-design is one strategy for undertaking frame reflection; it may involve (Schön and Rein 1994, 171):

- reframing the problem, perhaps through a shift to other metaphors
- probing blockages to inquiry
- seeking to understand the policy object and its various interpretations

Reflective inquiry of the sort described by Schön and Rein doesn’t arise spontaneously—it must be consciously courted, especially in the face of complexity and ambiguity. In heterogeneous and distributed settings, building bridges is a required skill. Wenger (1998) points out that processes of reification and participation can create connections through *boundary objects* and *brokering*: the boundary objects help to bridge disjoint forms of participation by providing means of organizing interconnections; brokers introduce elements of one practice into another, thereby providing new possibilities for meaning. The astute designer does not neglect boundary relations. As Wenger puts it: "Connecting the communities involved, understanding practices, and managing boundaries become fundamental design tasks" (Wenger 1998, 108).

The principal message of this chapter is simply this: boundaries are worth paying attention to. To design an initiative for integrated monitoring is to design boundary objects that can help to bridge multiple perspectives and provide support for managing the tension between heterogeneity and cohesion. Unfortunately, not many frameworks dare to countenance the ‘soft underbelly’ of integrated monitoring: the need for supporting adaptive work that connects diverse communities of practice. The OMNR framework described by Boyle (1998) is an exception in this regard (see Figure 3–4), but it remains ensconced in a managerial ethos (not surprising, given that the client was a provincial agency) that is not entirely in keeping with the spirit of the biosphere reserve concept. An ecosystem approach that strives to heed community aspirations in the spirit of participatory design might be more appropriate.

The singular strength of the OMNR framework is that it is both technical and social: it conjoins discussion about public issues with the scientific deliberations. But to my mind the label 'analysis' does not do justice to the sheer scrappiness intrinsic to this marriage. There is much analyzing taking place, to be sure, but there is also debating, translating, and negotiating. It is not an entirely orderly affair. I prefer to merge the stages labeled as 'analysis' and 'synthesis' in Figure 3–4 and call it *sense-making*: attempting to reconcile multiple and conflicting interpretations in the face of equivocality and confusion. Chapter six—the capstone of Part I—describes the nature of sense-making.



Chapter 6

From decision-making to sense-making

In order to achieve the organisation of society most favourable to the progress of the sciences and the prosperity of industry, it is necessary to give spiritual power to the scientists, and administration of temporal power to the industrials.

Henri Saint-Simon,
Du système industriel

6.1 The decisionist temper

Providing support for managerial decision-making is widely touted as *the* raison d'être of environmental monitoring programs; the mindset and the metaphors underlying this rationale warrant a closer look. It should now be clear that the constructivist position I adopt takes exception to blithe assumptions about how people collect, interpret and use environmental data. In reference to the design and deployment of information technology Coyne (1995) notes the ready slippage into talk of goal-setting, arguing that the three-fold model of analysis, synthesis, and evaluation stems from the hypothesis testing model of science: "In the same way that logic works toward proving a theorem, or a scientific experiment is set up to confirm (or refute) a hypothesis, design begins with a problem to be solved or a goal to be accomplished" (Coyne 1995, 220). But when a situation is messy and ill-defined, the knee-jerk application of rigidly structured design methods may not be the best move.

Struck by the widespread interest in decision-making among politicians and bureaucrats, Shklar examined the "decisionist temper" and claimed that it is animated by an aversion to rules steeped in convention, myth, or ideology:

> Decisionism, however, has a vast appeal, precisely because the vision of a limited number of political actors engaged in making calculated choices among clearly conceived alternatives is an essential basis for any theory that wishes to reduce international complexities to systematic, diagrammatic form. (Shklar 1964, 13)

Given that moments of decisive choice are unusual in matters of public policy, she doubts that such an outlook is very relevant to routine, non-crisis situations. But the powerful allure of a goal-oriented rationality in industrial society cannot be denied. From this perspective the fractious, ponderous deliberations of public policy making are seen to impede the exercise of reason and the direct application of scientific knowledge.

In discussing constraints on action, Majone bemoans the common tendency "to explain policy outcomes exclusively as the result of the deliberate actions of powerful individuals and groups" (1989, 75). He feels that this sort of reasoning produces a technocratic, over-intellectualized version of decision-making. There are several well-known critiques directed at the decisionist biases of synoptic rational planning. For example, Lindblom (1959) argued that the "superhuman" demands of the rational-comprehensive approach—that insists on clear objectives and comprehensive means-end analysis—are impossible to meet when dealing with complex policy issues; he noted that incremental, mutual adjustment among interest groups, or "muddling through", tends to be the most common mode of policy-making. March and Olsen (1979) advanced their 'garbage-can' model to suggest that a choice situation is often richly ambiguous, allows a variety of decision styles, and admits multiple interpretations: "At any point in time a choice will be interpreted by different groups of actors in the light of their own problems" (March and Olsen 1979, 376). A decision process can become separated from decision outcomes when symbolic functions (e.g. affirming beliefs or values) become salient; in this case, actual outcomes are beside the point.

Albæk (1995) contends that many decision models overestimate the importance of their basic premises: the rational perspective overvalues power and ignores the political aspects of decisions. The conflict-bargaining perspective overlooks the non-instrumental contributions of specialized knowledge. And the garbage-can view surrenders too much to chance. He rejects pure and simple categories and echoes Majone's (1989) emphasis on the role of argumentation in politico-administrative decision-making. Given that science also entails discussion based on reasoned argument, it is quite natural that research results become the object of debate: "It is really just a matter of the debate on research being carried on among a wider public than the research community" (Albæk 1995, 92). The most influential contributions of research are often those that restructure discourses of action by reorganizing concepts and clarifying views; in this way research can support—but almost never dominate—public reflection.

> Utopian ideas of an enlightened despotism of the experts, or of the disappearance of conflicts of interest if only the good argument were allowed to convince in a free dialogue, may at best be heroically attractive, but do not have much to do with reality. (Albæk 1995, 96).

The sprawling literature on management theory is dominated by the tenets of synoptic rationality—library shelves are laden with tomes concerned with mathematical analyses of decision-making and human behavior. Simon (1960) construed 'managing' to be synonymous with 'decision-making' and distinguished three stages of decision-making: the *intelligence phase* in which the environment is scanned for problematic situations; the *design phase*, involving the development and analysis of possible course of action; and the *choice phase*, where a particular course of action is selected. Not far beneath Simon's schema lies a mechanical trope: "We can think of white-collar organizations as factories for processing information" (1960, 5).

The computation metaphor has a long reach. Organizations are widely conceived as information-processing networks, an outlook popularized by Simon and his colleagues at Carnegie and given impetus by the growing use of computers in the 1950s and 1960s. The vocabulary of information technology has evolved over the decades as it penetrated the management literature: from electronic data processing, to management information systems, to decision-support systems, to expert systems. Our time has been nominated the *Information Age*, and the information economy is eagerly anticipated right across the political spectrum. In an influential book, Daniel Bell declared that the social framework of Western society is changing: "What counts is not raw muscle power, or energy, but information" (1973, 127). Information is deemed the central resource in a post-industrial economy based on services, and knowledge becomes the source of innovation and the basis for formulating public policy. For Bell, science is the defining ethos of post-industrial society.

To be adept at handling information while rendering timely decisions is to demonstrate managerial prowess. Yet to suppose that decision-makers are pure information processors ignores all the hard work that precedes those sporadic moments of decision. Boland presents five 'fantasies' of information (Box 6–1) that he argues promulgate the fallacy of scientism and deny the significance of interpersonal dialogue in the search for meaning: "The search for meaning is a continuous search that is never completely or finally realized. Meaning is always in doubt and needs to be reaccomplished" (Boland 1987, 366). In Boland's view the yearning for a technologically-based order is pernicious to the extent that it deflects attention from the quality of the dialogue that contributes to processes of sense-making.

Box 6–1
Five fantasies of information (*Source*: Boland 1987)

- *Information is structured data*—this denies the importance of language as a medium for understanding the world
- *An organization is information*—this perpetuates the rationalist assertion that knowledge precedes action
- *Information is power*—this inflates the promise of order and control
- *Information is intelligence*—this disembodies and objectifies human intelligence
- *Information is perfectible*—this anchors design activity in the optimality criteria of information economics

Monitoring initiatives and their associated information systems are generally promoted under the rubric of decision-support. The basic rationale is that more and better information makes for more efficient and effective management. “We anticipate the emergence of ‘scientific information management’ as a discipline with both a management and a research component, emphasizing the timely and effective transformation of data into information and knowledge for scientists, managers, policy makers and the public” (Stafford, Brunt, and Michener 1994, 15). Hammond and others (1983), however, have noted many fundamental obstacles to the use of scientific information in public policy making. They sorted constraints and limitations into three categories: situational, cognitive, and scientific (Table 6–1).

Table 6–1
Limitations on the use of scientific information in policy making (*Source*: Hammond and others 1983)

Situational	Cognitive	Scientific
• facts and values are ambiguous • scientific statements are ordinarily probabilistic • political considerations (e.g. reluctance to admit failure)	• choosing among competing claims requires the exercise of judgment, not just analysis • adversarial processes in the public domain render scientific claims unstable • we are prone to information overload	• experiments are often impossible to perform • generalization of scientific claims to new settings is often difficult • scientific knowledge is uncertain and incomplete

Dahlbom and Mathiassen (1993) ponder whether the value of information has been overrated in keeping with the five "pet ideas" of positivism: objective observation; explanation and prediction; general knowledge of empirical laws; hypothesis testing; and physicalism. Such rational and technical ideals are far removed from the vagaries and ambiguities of organizational life.

> Out task is not simply to design good information systems for a fictitious, ideally rational organization, but to design information systems for real, irrational organizations. In order to do this, it is not enough to simply define information as a resource that it is our task to organize the supply of. We must also understand the multiple roles played by information in organizations. (Dahlbom and Mathiassen 1993, 24)

Feldman and March (1981) provide many examples that illustrate how the link between decisions and information use is usually weaker than generally supposed. For instance, most people tend to collect more information than they can reasonably expect to use and end up wallowing in an ocean of data: "At the same time, they appear to be constantly needing or requesting more information, or complaining about inadequacies in information" (Feldman and March 1981, 174). Instead of seeing this state of affairs as emblematic of perverse behavior, Feldman and March highlight the significance of social norms in shaping information use. By their account, the concept of intelligent choice is a central ideological construct of modern western civilization that encourages the conspicuous consumption of information as a demonstration of competence and legitimacy. If organizations are viewed as performance-oriented systems (Dery 1990), then a preoccupation with optimizing performance will give short shrift to the appreciation of complexity and ambiguity. Dery goes further, arguing that we rely heavily on "administrative institutions that are at once suspicious of and equipped to reject the new" (1990, 128). Overcoming or working around such impediments to change requires an infrastructure that does not value performance at the expense of learning.

6.2 From goal-seeking to appreciation

Sir Geoffrey Vickers denied the easy separation of fact and value in public affairs and introduced the notion of an *appreciative system* that he characterized as "an artifact, an unique interpretive screen, yielding one among many possible ways of interpreting and valuing experience" (Vickers 1965, 69). Vickers' ideas have been taken up by quite a number of researchers and practitioners in the UK systems community working in the soft systems tradition. In the early 1970s Peter Checkland initiated an action research programme at the University of Lancaster with the aim of developing a way of thinking about ill-structured problem situations in the 'real world'. Finding the techniques of traditional systems engineering poorly suited for situations that do not admit a precise specification of objectives, he articulated a systems-based approach for clarifying the purposes of 'soft' human activity systems (Checkland 1981). The methodology evolved to encompass seven stages that hinge on a *root definition*, a concise description that expresses the core transformation of the system of interest. The elements of a well-formed root definition are denoted by the mnemonic CATWOE (Box 6-2).

Box 6–2
The elements of a well-formed root definition (*Source*: Checkland 1981)

Customers: beneficiaries or victims affected by the activities of the system

Actors: agents within the system who carry out the main activities, especially the main transformation

Transformation process: the core purpose of the system, given by the conversion of a defined input into a defined output

Weltanschauung: a framework or image that renders a particular root definition meaningful

Ownership: those who oversee system activities

Environmental constraints: external features taken as 'givens'

Conceptual models based on the root definition are used to structure discussion concerning desirable and feasible changes in structures, procedures, or attitudes. Checkland considers learning, not optimization, to be the core concern of soft systems methodology (SSM). In surveying the sociological implications of applying the methodology, he places it in the phenomenological tradition and establishes a link to Vickers' ideas by construing the methodology as a way of discovering and changing the appreciative settings of the relevant actors.

In a subsequent account of 'mature' SSM the original seven stages are rolled into two interacting streams of inquiry: a *logic-driven* stream that develops models (primary task- or issue-based) of some transformation process; and a *cultural* stream that examines the sociopolitical aspects of intervention, often with the aid of "rich pictures" that represent problem situations (Checkland and Scholes 1990). While earlier writings on SSM sometimes referred to its epistemological role, Checkland and Scholes take especial care to clarify the notion of 'system' that underlies its application: "Systemicity is shifted from the world to the process of enquiry into the world: 'the system' is no longer some part of the world which is to be engineered or optimized, 'the system' is the process of enquiry itself" (1990, 277).

By providing a means of understanding how people attribute meaning to their perceptions of the world, soft systems methodology can potentially contribute to the creation of information systems that serve particular human activity systems. Checkland and Holwell (1998) assess this potential while undertaking a bit of "conceptual cleansing" aimed at dispelling some of the confusion surrounding the organizational context of information systems. Noting that many information systems development (ISD) methodologies tend to pay scant attention to organizational analysis, Checkland and Holwell offer a richer conception to suggest how information is created by people as they attribute meaning to selected facts in particular contexts (Figure 6–1). Checkland coined the word 'capta' to denote those facts elicited by a particular appreciative setting. Considered in its full richness, the road from 'data' to 'knowledge' is a long and rocky one.

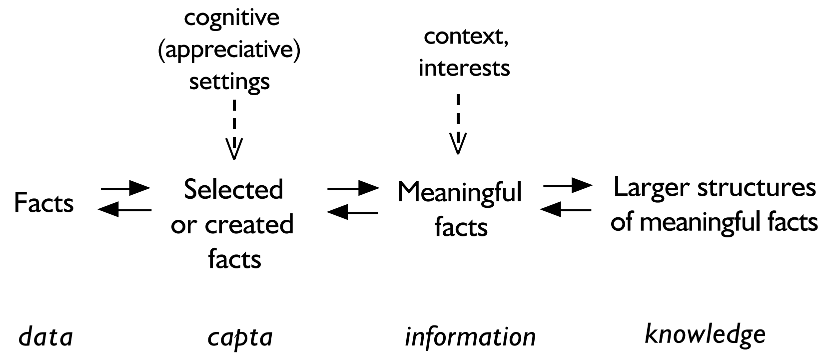
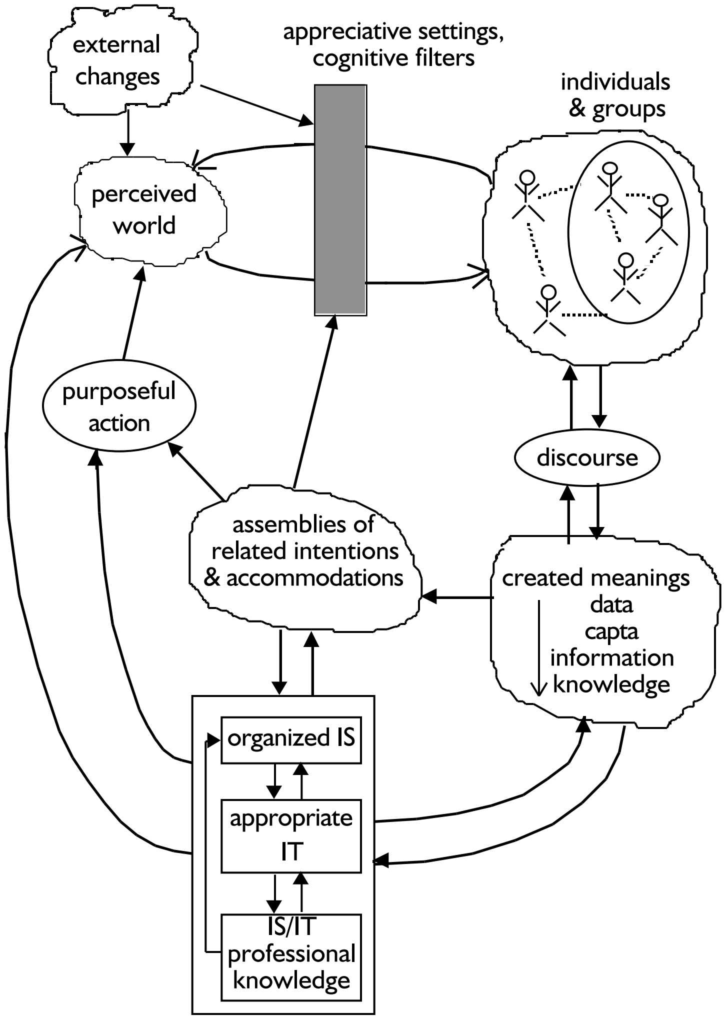


Figure 6–1
From data to knowledge (*Source*: Checkland and Holwell 1998, Fig. 4.1)

In an organizational context, the bare process outlined in Figure 6–1 is embedded within a human activity system. The 'process for organization meanings' (POM) model illustrates how the deployment of appropriate information technology (IT) can help support purposeful action on the part of individuals and groups in the organization (Figure 6–2).

Figure 6–2
The POM model
(*Source*:Checkland and Holwell 1998, Fig. 7.7)



A number of other researchers have turned to soft systems methodology in developing information systems to support organizational activities. Lewis (1994) argues that the conventional engineering view ignores social and political factors and tends to document only the formal, officially sanctioned activities of the organization. The creation of a genuine information system—conceived as a multifarious social artefact—requires some understanding of the cognitive frameworks or filters that function within a given setting. Lewis presents a model of decision-making behavior that incorporates Vickers' notion of an appreciative system (Figure 6–3). Building upon Checkland's work, Lewis identifies three general elements of organized inquiry: a *framework of ideas* that is applied through a *methodology* in order to investigate some *application area*.

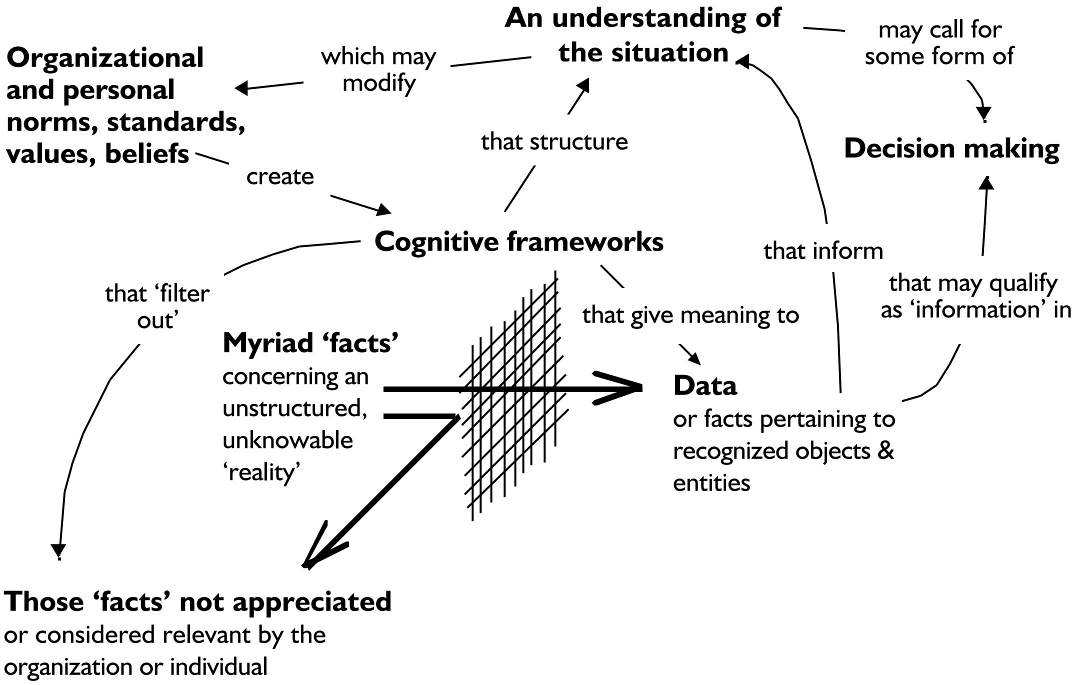


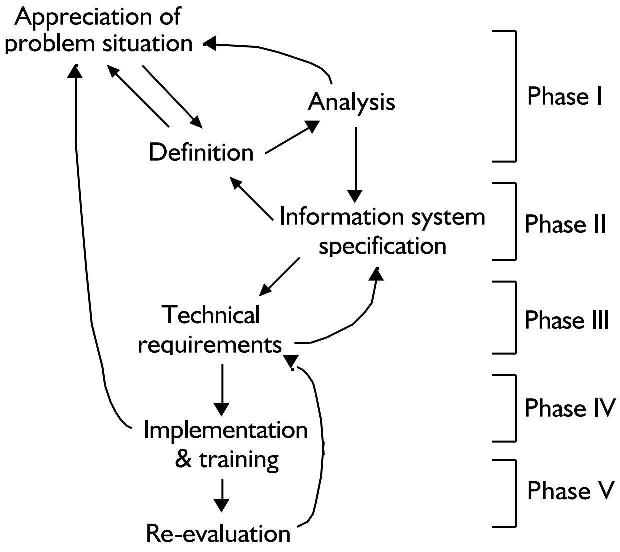
Figure 6–3
An appreciative system as a cognitive filter (*Source*: Lewis 1994, Fig. 5.5)

The intellectual framework encompasses philosophical assumptions, ethical values, a body of accepted facts, and perhaps even a mythology (i.e. untestable beliefs). The methodology offers prescriptions or guidelines for using particular methods and techniques. The application area stipulates where inquiry is directed. Lewis focuses on data modeling using an interpretive approach to elicit the cognitive categories required to make sense of a particular system definition. The approach he describes is grounded in the recognition that an information system worthy of the name cannot be designed without heeding the social, historical, and political factors that influence existing business processes.

Client-led design is an idea that has surfaced in the IS literature as an alternative to the structured, datalogical approaches that dominate the field. The University of Paisley in Scotland is at the center of this work, which is also rooted in soft systems thinking but strives to meld the 'hard' requirements of engineering a computer-based product with the 'soft' aspects of organizational culture. This design approach embeds the specification of technical requirements within a soft systems framework. Miles (1988) argues that such an embedding offers better prospects for sustaining a collaborative relationship between information users and specialists, compared to grafting a 'soft' feasibility study onto the front end of some other structured analysis technique. But more expansive thinking can be a hard sell: "Its price is that it draws technical experts into broader considerations—arguably an advantage but something often resisted by the experts. It also takes as given that organisational problems are prime with respect to technical ones" (Miles 1988, 59).

Stowell and West (1994) describe an iterative sequence of five phases that places the information systems analyst in a facilitating role (Figure 6–4). The basic philosophical orientation is one of *interpretivism*: the acquisition and use of 'facts' is seen to be socially shaped by human actors, and decision-making is thought to be more about maintaining relationships than about optimizing performance.

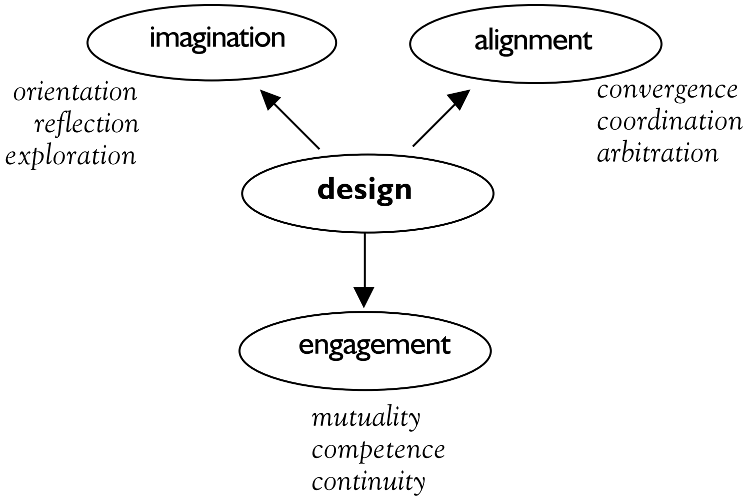
Figure 6–4
A framework for client-led design
(*Source*: Stowell and West 1994, Fig. 2.4)



Crowe, Beeby, and Gammack bring matters of organizational culture to the fore in their account of client-led design: "We should thus think of managing *for* multiple realities, instead of managing in spite of multiple realities" (1996, 122). The supposition that there is a straightforward correspondence between objects in the physical world and mental symbols is rejected as inadequate. The trio advocate a flexible, evolutionary approach to IS provision that permits client groups to dynamically revise their information constructions, which then serve as 'conversation pieces' or epistemological devices to support continuous learning.

Conversation is intrinsic to design. Buchanan (1995) sees design as a basically indeterminate, humanistic enterprise with a rhetorical dimension: "Deliberation in design yields arguments: the plans, proposals, sketches, models, and prototypes which are presented by designers as the basis for understanding, practical action, or production (Buchanan 1995, 46). This view of design is in marked contrast to the dominant information-processing metaphor (also a mainstay of cognitive science) that leaves little room for problem setting and the negotiation of meaning. Wenger also highlights the social dimensions of design, with an emphasis on building learning communities: "The challenge of design, then, is to support the work of engagement, imagination, and alignment" (Wenger 1998, 237). Figure 6–5 summarizes the tripartite framework that Wenger recommends as an aid for thinking about how well a specific design attends to learning tasks.

Figure 6–5
Infrastructures of learning (*Source*: Wenger 1998, Fig. 10.2)



Each of the three modes Wenger identifies calls for different kinds of work, but it is in combining these modes so as to maintain vital tensions that learning communities are built. *Engagement* requires the ability to contribute to the negotiation of meaning and the development of shared practices, but if it becomes too insular or ingrained it shuts out other viewpoints and stifles change. The exercise of *imagination* requires license to explore, take risks, and entertain new images or connections; however, if it becomes too disconnected from concrete happenings—or simply projects stereotypes—it runs the risk of failing to yield potent new understandings to guide action. *Alignment* requires sharable artefacts or boundary objects that congeal experience and serve as centers of coordination; but when its pursuit becomes too stringent, too rule-bound, it can devolve into empty ritual and curtail flexibility of thought and action.

Attending to all of these trade-offs can be a fairly delicate undertaking, one almost impossible to carry out in a hostile environment. By 'hostile' I mean an environment that shuns risk, abhors complexity, penalizes error, extols efficient performance, and values consistency. Does this sound like the average bureaucracy? Not to be unduly harsh, most organizations are bent on performing, not learning (Dery 1990). So perhaps the best place to attempt to build the capacity for (social) learning is not within organizations but at a higher, supraorganizational level—to attend to the social context of justification, as Dery puts it. And here, seeking some sort of rapprochement among multiple and competing interpretations of a problematic situation—or achieving any interpretation at all—is the stuff of sense-making, not decision-making.

6.3 The nature of sense-making

Learning is a prominent theme in discussions about sustainability and ecosystem management. Many commentators bemoan how infrequently it occurs, and call for better means of supporting social learning. What is such a learning system supposed to accomplish? The default aim is to provide answers, but Michael (1995) feels that efforts dedicated to this end can actually undermine a genuine learning stance by promoting what he calls "organizational and stakeholder rigidification", a reluctance to see 'facts' in a different light. In turbulent times learning must occasionally deviate from the norm and reperceive or reinterpret confusing situations. As Michael notes, learning can be a risky business subject to sociocultural, emotional, and cognitive constraints—our minds are infused with myths, habits, and biases that can unconsciously obstruct learning. He offers a few suggestions for creating an environment more conducive to learning in support of ecological management (Box 6–3).

Box 6–3

Designing for learning
(*Source*: Michael 1995)

- use the metaphoric power of language to reframe issues and actions
- use myth reinforcement to encourage a learning attitude
- acknowledge uncertainty and embrace errors
- minimize the sense of vulnerability that change engenders
- use facilitators rather than chairpersons—an appreciation of group dynamics can ease frustrations
- introduce training of group process skills
- provide short-term rewards to sustain learning
- become educators to reinforce the learning mode
- use crises as learning occasions

The traditional (even if overly simple) distinction between structured and unstructured problem situations has implications for the type of learning appropriate to each circumstance. Simon (1960) referred to *non-programmed* and *programmed* decisions: the former are concerned with devising strategies and setting goals, whereas the latter involve the execution of repetitive and routine operations. Even so, perhaps the label 'unstructured decision' is an oxymoron—does someone actually engage in decision-making (i.e. selecting one of several well specified alternatives) when conditions are ambiguous, even incoherent? Not really. Weick and Meader (1993) canvassed research on group support systems and noted the traditional emphasis on problem solving and decision-making. They argue that a crucial stage tends to be overlooked, namely, how people come to frame circumstances as problems in the first place: "The omission is a pervasive Western bias that reflects our preoccupation with decisions and answers, rather than with interpretations and questions" (1993, 230–231). Individuals can be seen to engage in *sense-making*, not decision-making, when they are trying to wrest meaning from an equivocal situation. As Weick and Meader point out, to label a discomfiting situation a 'problem' is only one option—for some it might be an enigma to ignore, a dilemma to dissolve, or an opportunity to exploit. From this perspective, decision-making can proceed only after a shared interpretation of causation and preferences has emerged. Figure 6–6 suggests the context of the two modes of deliberation.

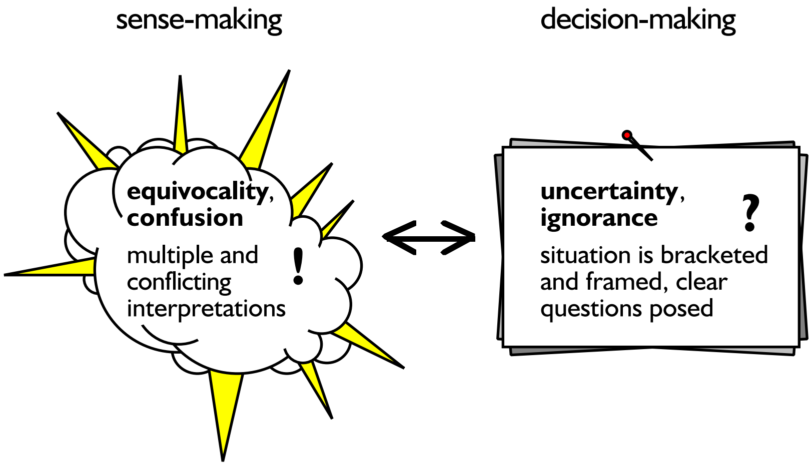


Figure 6–6
Sense-making vs. decision-making

Weick and Meader distinguish uncertainty from equivocality: uncertainty can usually be tackled by acquiring more information through analysis, whereas equivocality is dispelled through the construction of a shared interpretation—additional information may be of little help. According to Weick (1995), sense-making is more about invention than discovery; it is spurred by ‘shocks’ or interruptions, and it is a social activity that seeks to establish plausible and coherent constructions that can guide and coordinate action in a world replete with multiple meanings. Successful sense-making depends on adequately preserving flow and continuity: “Content that is rich in dynamics, process imagery, verbs, possibilities, and unfolding narratives should represent flows more plausibly and accurately than does content that is dominated by statics, structures, nouns, the impractical, and lists” (Weick 1995, 108).

Westley (1995) construes planning (somewhat generously) as a “technology for sense-making” that intervenes between knowledge and action, reducing equivocality so that choice becomes possible. Strong paradigms and ideologies favor action but tend to reject uncongenial information, a predicament that exemplifies the difficulty of striking a balance between change and continuity. The challenge for institutional design is no small one: “It is clear that for adaptive management to succeed, organizations must find sense-making processes that *simultaneously* open the organization to new stimuli and provide strong action generation" (Westley 1995, 400). While this search may run up against formidable obstacles within a modern bureaucracy, altering interorganizational arrangements holds considerable promise. Westley suggests that cultivating a diversity of interorganizational forms is important for maintaining responsiveness to ongoing change.

The organizational challenge that Westley describes was referred to by Miller (1993) as the "Icarus paradox" of competitive advantage. Over time the concentration and dedication that a successful organization evokes tend to reinforce simplistic fixations that eventually pave the way to decline: "Cultures, systems, processes, and world views will become too monolithic to allow organizations to embrace and adapt to the complex currents of their settings" (1993, 118). A range of managerial and cultural factors interact to shut out nonconformist views and conflicting data, instilling a bias for single-loop learning (i.e. goal attainment) at the expense of a more searching double-loop learning that reassesses the standards and goals of the organization. Self examination is usually only triggered by a crisis. In effect, escalating simplicity sacrifices requisite variety.

It has been recognized that learning can occur on different levels: task-based learning seeks improvements in efficiency and effectiveness in order to enhance performance; goal-based learning revises objectives in order to adapt to changing circumstances. This basic characterization of different learning modes is described at length by Argyris and Schön (1978), who see organizational learning as a dialectical process: "Organizational learning occurs when individuals, acting from their images and maps, detect a match or mismatch of outcome to expectation which confirms or disconfirms organizational theory-in-use" (1978, 19). But according to Argyris and Schön, most people in our (Western) society are 'programmed' with what they call Model I theories-in-use that inhibit double-loop learning. Individuals using Model II theories-in-use are more inclined to surface norms and assumptions (Table 6–2).

If an organization is thought to embody a working model of a theory (a dubious proposition in some circumstances), then Argyris and Schön's learning schema can be applied to models of adaptive management. Lee (1993) does this in arguing that adaptive management can be understood as a way to build double-loop learning into the routines of an organization. The conceptual framework of an organization is ideally revised in light of disconfirming evidence, but Lee appreciates that this rationalist vision must be softened in the face of the conflict that is likely to erupt when the basic operating theory is brought into question.

Table 6–2
Governing variables of personal theories-of-action (*Source*: Argyris and Schön 1978)

Model I theory-in-use	Model II theory-in-use
• define goals and try to achieve them • maximize winning and minimize losing • minimize the expression of negative feelings • be rational	• valid information—advocacy coupled with inquiry • free and informed choice—joint control, public testing • internal commitment • learning-oriented norms

But there's a curious asymmetry as Lee moves from organizational learning to social learning: he wishes to sequester civic science and protect it from the turbulence of social learning, arguing that its lessons should not require double-loop learning: "From a political standpoint civic science should be often a source of solutions, sometimes a source of single-loop learning, and never a challenge to legitimacy. Prudent politicians will not proceed in any other way" (1993, 166). By Lee's account, civic scientists speak truth to power. He prefers an indirect linkage between science and policy aims, and stresses the need for political pragmatism in order to husband scarce political support:

> A prudent scientist looks to the long run in dealing with surprises that are tied to policy. First, a scientist's political capital is his or her reputation; in that respect, both good and bad news must be reported in a timely fashion, or else the scientist's ability to make further credible contributions will be jeopardized. Second, the time scale of politics is shorter than that of scholarly publication; often a year or more passes between submission of an article and its appearance in print. Timely warnings can take most of the sting out of public disclosure of surprise. (Lee 1993, 167)

While Lee issues the warning that civic science should not precipitate double-loop learning, he really seems to want to head off *triple-loop* learning that scrutinizes broader institutional arrangements. Flood and Romm (1996) used the phrase triple-loop learning in identifying three modes of learning that center on the how, what, and why of managing organizational affairs. In the context of organizational design, interventions are aptly guided by an overall awareness of the issues and dilemmas that span three arenas of discourse:

- Are we doing things right? → single-loop learning (How?)
- Are we doing the right things? → double-loop learning (What?)
- Is rightness buttressed by mightiness, or vice versa? → triple-loop learning (Why?)

Single-loop learning involves task-oriented, means-end thinking. Double-loop learning problematizes the definition of ends and means, and sets new ones through open debate. Triple-loop learning is propelled by a concern with power-knowledge dynamics. Diversity management is the leitmotif of Flood and Romm's metatheory of choice-making—they want to sustain a spirit of reflexivity that keeps interventions from sliding into either "imperialism" or "stumble-in-the-dark pragmatism":

> The purpose of reflexivity is to question in deliberate fashion the relevance and consideredness of unchallenged yet favoured points of view. It enables and prepares theoreticians and interventionists for the enriching process of confronting alternatives. Reflexivity is indeed a means by which disciplines are able to retain and encourage diversity and tension. (Flood and Romm 1996, 34)

The approach articulated by Flood and Romm draws heavily on critical systems thinking and reflects a commitment to complementarism and emancipation. The practical implications are organized around three issue areas that demarcate different arenas of discourse: design, debate, and power relations. Learning within the respective arenas is motivated by the following aspirations:

- to enhance the *relevance* of design activity
- to enhance the *consideredness* of decision-making
- to enhance the *astuteness* of moral deliberation

What does triple-loop learning look like in practice? A brief example may help to illustrate the prospects for systemic learning in an organizational context. To this end a little thought experiment is in order, one which takes a fictitious environmental agency as its focus (Figure 6–7).

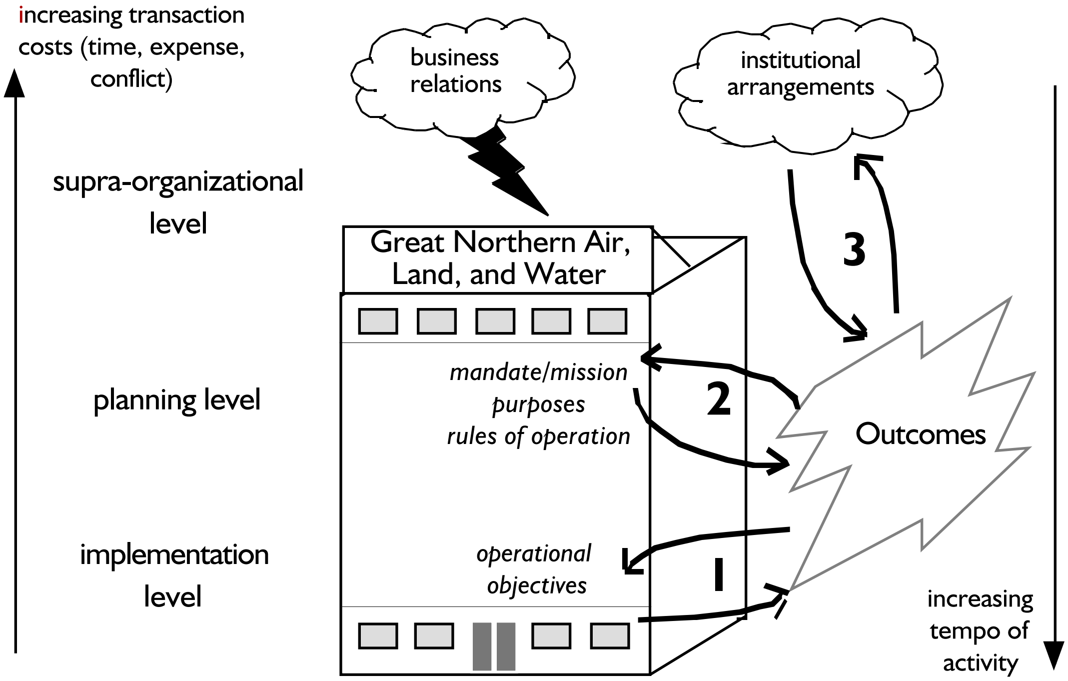


Figure 6–7
Triple-loop learning in an organizational context

The agency, 'Great Northern Air, Land, and Water' engages in single-loop learning at the implementation level as it strives to accomplish its operational objectives. Double-loop learning at the planning level involves rethinking the agency's purposes and rules of operation. Triple-loop learning at the supra-organizational level entails reshaping institutional arrangements or business relations. There are a couple of things to note here. First, there are costs associated with maintaining a capacity to shuttle between the three centers of learning, and these costs become increasingly burdensome: time, expense, and conflict all increase in moving to higher orders of learning. Second, the tempo of activity at the operational level favors quick decisions that take expressed goals for granted. All this means that social learning is a profoundly difficult undertaking that is difficult to generate at the organizational level and may not be amenable to strategic programming.

I'm inclined to map Flood and Romm's arenas of discourse onto Wenger's three infrastructures of learning (see Figure 6–5). My motivation for doing this comes down to 'level of analysis': despite overlapping concerns, Flood and Romm keep to the strategic high ground of organizational design, whereas Wenger focuses more palpably on communities of practice. The exercise of imagination promises to bolster the relevance of a design process that must wrestle with multiple perspectives (how?); securing (partial) alignment draws diverse participants into debate about the scope and character of the joint enterprise (what?); and fostering engagement implicates power relations, incentives, and the manner in which participants contribute (why?). While still an abstraction, community of practice comes closest to conveying a sense of where the action associated with integrated environmental monitoring is concentrated. Monitoring activity is not vested in a single monolithic organization within a biosphere reserve—it is distributed, decentralized, and multifarious.

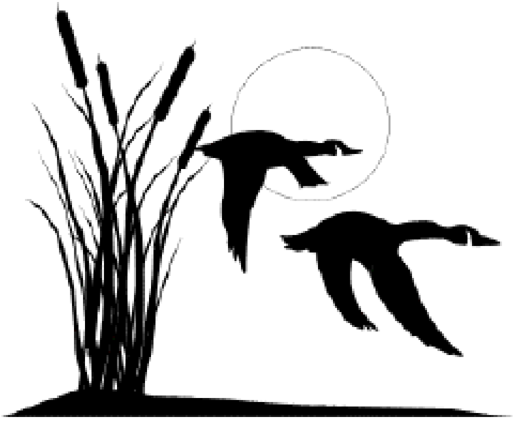
The type of learning that Michael (1995) urges—that which yields useful questions rather than glib answers—seems to fit more comfortably under the heading of sense-making than decision-making. And sense-making also comports easily with the interpretivist outlook of soft systems methodology. The task then becomes one of designing an appreciative system to support sense-making.

Well, this concludes the Grand Tour. It's time to recapitulate some of the key ideas that have been developed thus far. I hope I have convinced the reader of two main points. Firstly, that integrated environmental monitoring under an ecosystem approach incorporates a tangle of scientific, social, and even political issues that are not easily teased apart; monitoring in this mode is not usefully conceived as a purely technical exercise for scientific experts. Secondly, that a purely managerial framework—predicated on fixed, measurable goals and standard procedures—fares poorly in the absence of a formal mandate. Such a framework cannot do justice to the diversity of local concerns and arrangements found within a biosphere reserve. Furthermore, fostering alignment, engagement, and imagination are not design tasks that can be readily accomplished through administrative fiat or the use of highly structured methods. A design process conceived in the tradition of soft systems thinking might offer a viable alternative for building "infrastructures of learning".

What are the methodological implications of the design approach advocated here? It is certainly more exploratory and less rigid than traditional structured methods, and it recognizes that there are both technical and social dimensions to how people use—or fail to use—environmental information. But rather than grafting social considerations onto a technically-conceived method in order to incorporate a 'user' perspective, the design process embeds technical elements within a wider social framework; such an approach seems more appropriate for messy, ill-structured situations that cry out for sense-making. Here are some ancillary points that will inform what follows:

- a well-tempered process of inquiry/design aims for a judicious mix of participation and reification
- boundary objects can help to bridge multiple perspectives and provide support for managing the tension between heterogeneity and cooperation
- it's important to heed the 'soft underbelly' of integrated monitoring: the need for mobilizing adaptive work that connects diverse communities of practice
- in situations of equivocality and confusion, deliberations center more on trying to make sense, not make decisions

The second part of this thesis will outline the elements of a locally-sensible framework for monitoring practice that primarily supports sense-making, not decision-making; it does this by crafting a set of 'boundary objects' that undergirds the definition of an issue-based relevant system and functions as a sort of 'resource kit' for addressing various aspects of integrated monitoring. The design process aims to facilitate learning, not control; to generate searching questions, not final solutions. The case study explores the prospects for integrated monitoring in the Long Point World Biosphere Reserve located on the north shore of Lake Erie, Ontario.



Chapter 7

The Long Point World Biosphere Reserve

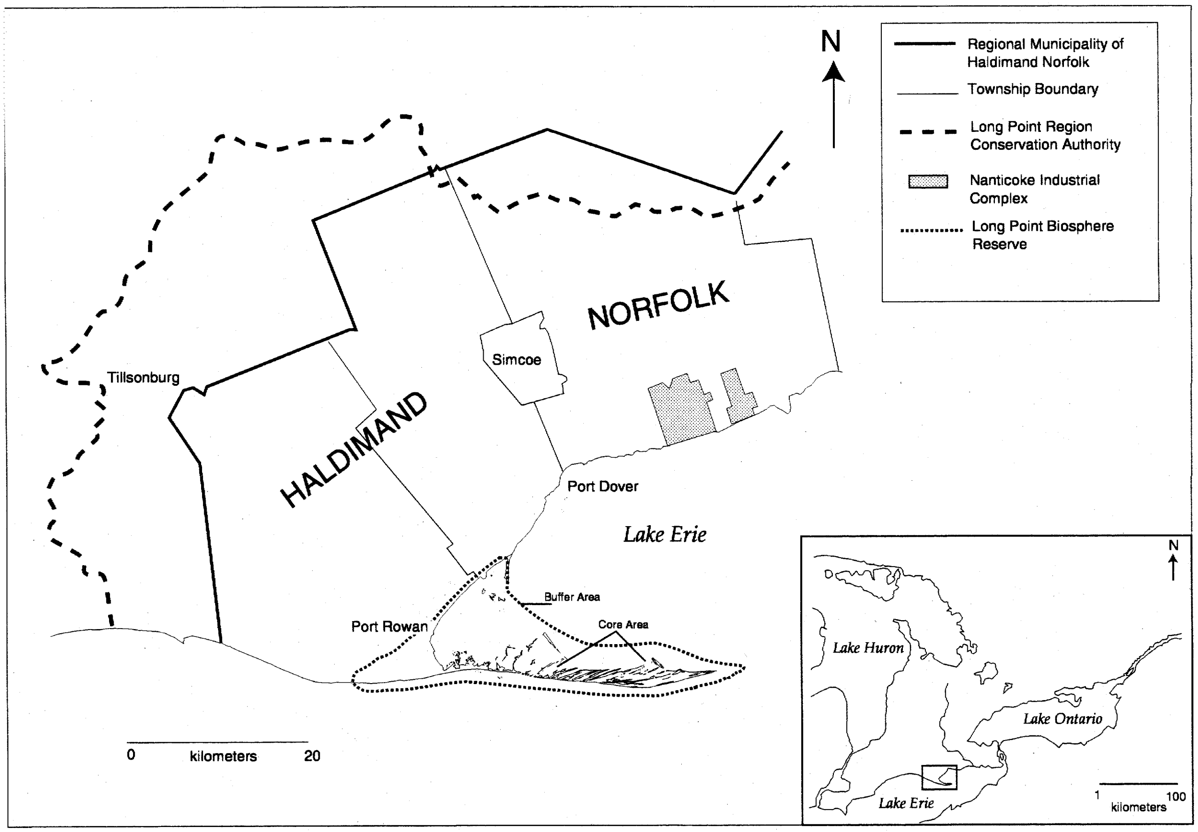
What seems to be needed now is some method to assess how well we're doing in maintaining the things we value and need the most.

Jeff Robinson,
Port Rowan Good News
(December 1997)

7.1 The biosphere reserve concept

Long Point is a barrier spit on the north shore of Lake Erie that extends more than 40km eastward from the mainland (Figure 7–1). The barrier complex—the largest in the Great Lakes—is nourished by sediments eroded from sandy bluffs located up to 95km to the west (Davidson-Arnott and Fisher 1992). The spit shelters the extensive wetland areas that lie behind the barrier complex. Long Point Bay is an important stopover for migratory waterfowl in North America, and it has been identified as a priority area for habitat management under the North American Waterfowl Management Plan of the Eastern Habitat Joint Venture (Petrie 1998).

Figure 7–1
The Long Point area
(Reprinted, by permission, from Nelson and others 1996, Fig. 1)



The ecological significance of the area has been extensively described over the years and has garnered international recognition. In 1982 Long Point was designated a Wetland of International Importance under the Ramsar Convention on Wetlands, and in 1986 the barrier system and adjacent lands were designated a World Biosphere Reserve under the UNESCO/Man and the Biosphere (UNESCO/MAB) Programme[1]. The *Long Point Environmental Folio* was published in 1996 by the Heritage Resources Centre at the University of Waterloo; its sixteen chapters provide summaries of regional geomorphology, historical economies, sport and commercial fisheries, waterfowl, water quality, shoreline processes, and more. The general intent of the document is to make information about the local environment more readily accessible and understandable to the general public.

Biosphere-related activities are coordinated by the Long Point World Biosphere Reserve Foundation (henceforth the Foundation), a non-profit group of volunteers that is broadly representative of stakeholders in the region. The Foundation was incorporated in 1992 with the basic purpose of promoting the preservation and protection of all areas within the biosphere reserve. Three subsidiary aims support this general purpose (Box 7–1).

Box 7–1
The aims of the Foundation (*Source*: Long Point World Biosphere Reserve Foundation 1994, 10)

- educating and informing people about the biosphere reserve, including its history, features, and significance
- supporting and promoting research and monitoring within the reserve, and disseminating such findings to the general public
- fostering an understanding of local economic, natural, and cultural features, and promoting an open exchange of ideas about them

The statutory framework document promulgated by UNESCO conveys the basic thrust of the global network: biosphere reserves should strive “to explore and demonstrate approaches to conservation and development on a regional scale” (UNESCO 1998, Article 3). The *Seville Strategy* was approved in 1995 as a means of expanding and improving the global network. A number of goals, objectives, and recommendations were put forth (Box 7–2). Recommendations for implementation are also included in

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[1] For more information about the UNESCO/MAB programme, see <http://www.unesco.org/mab/home.htm>. The secretariat of the Ramsar Convention on Wetlands maintains a web site at <http://www.ramsar.org/>.

the strategy, and these are sorted according to the most appropriate level of action (i.e. international, national, and individual reserve).

Box 7–2
Goals and objectives of the 'Seville Strategy' (*Source*: UNESCO 1996)

I Use biosphere reserves to conserve natural and cultural diversity

I.1 Improve the coverage of natural and cultural biodiversity by means of the global network
I.2 Integrate biosphere reserves into conservation planning

II Utilize biosphere reserves as models of land management and of approaches to sustainable development

II.1 Secure the support and involvement of local people
II.2 Ensure better harmonization and interaction among the different zones of the biosphere reserve
II.3 Integrate biosphere reserves into regional planning

III Use biosphere reserves for research, monitoring, education and training

III.1 Improve knowledge of the interactions between humans and the biosphere
III.2 Improve monitoring activities
III.3 Improve education, public awareness and involvement
III.4 Improve training for specialists and managers

IV Implement the biosphere reserve concept

IV.1 Integrate the functions of biosphere reserves
IV.2 Strengthen the global network of biosphere reserves

The MAB Programme has its roots in a recommendation adopted at a 1968 conference bearing the incongruous title 'Intergovernmental Conference of Experts on the Scientific Basis for Rational Use and Conservation of the Resources of the Biosphere'. According to one organizer, this Biosphere Conference is notable for declaring—for the first time—that "the utilization and the conservation of our land and water resources should go hand-in-hand rather than in opposition, and that interdisciplinary scientific approaches should be promoted to achieve this aim" (Batisse 1993, 108). A series of coordinating meetings culminated in the launch of the MAB Programme in 1971 with the aim of promoting research into problems of resource management spanning a broad range of biogeographic settings and human settlement patterns.

The activities of the MAB Programme are overseen by the International Coordinating Council (ICC), a multinational group that usually meets every two years. At the first session of the ICC in November 1971, the general objective of the Programme was set out:

> The general objective of the Programme is to develop the basis within the natural and social sciences for the rational use and conservation of the resources of the biosphere and for the improvement of the global relationship between man and the environment; to predict the consequences of today's actions on tomorrow's world and thereby to increase man's ability to manage efficiently the natural resources of the biosphere. (UNESCO 1972, 7)

The biosphere reserve network was established in 1976 to provide a geographic focus for the Programme. There are currently more than 350 reserves in almost 90 countries around the world. Canada has six established biosphere reserves (Table 7–1), and there are a handful of other nominations at an advanced stage of preparation.

Table 7–1
Biosphere reserves in Canada (*Source*: Francis 1991)

Name	Date designated	Area / ha
Mont St Hilaire (PQ)	Apr 1978	5 500
Waterton (AB)	May 1979	52 000
Long Point (ON)	Apr 1986	26 300
Riding Mountain (MB)	Apr 1986	297 800
Charlevoix (PQ)	Nov 1988	448 000
Niagara Escarpment (ON)	Feb 1990	207 000

An 'Action Plan for Biosphere Reserves' followed on the heels of the first biosphere reserve congress convened in Minsk in 1983[2]. Biosphere reserves were promoted as venues for applying the principles of the 1980 *World Conservation Strategy*:

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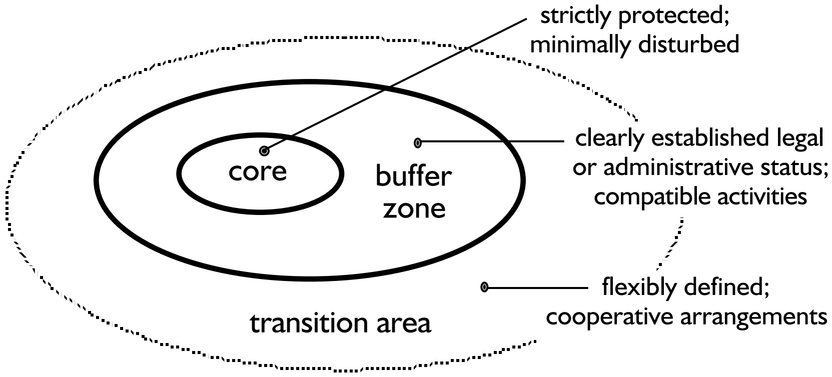
[2] The proceedings were published by UNESCO in 1984 under the title *Conservation, Science and Society*.

> Biosphere reserves are protected areas of representative terrestrial and coastal environments which have been internationally recognized for their value in conservation and in providing the scientific knowledge, skills and human values to support sustainable development. (UNESCO 1984, 12)

At the eighth session of the ICC in 1984, two advisory panels were established: the 'General Scientific Advisory Panel' and the 'Scientific Advisory Panel on Biosphere Reserves'. The panels issued reports that redirected MAB research and refined the biosphere reserve concept to better reflect the 1984 action plan. Both reports are summarized in annexes to the final report of the ninth session of the ICC (UNESCO 1987). The panel reports precipitated some significant restructuring of the Programme. In referring to the report of the General Scientific Advisory Panel, a member of the Council commented that the advisors "are asking us to change our theme to one of Man *in* the Biosphere instead of Man *and* the Biosphere" (UNESCO 1987, 15).

The advisory panel on biosphere reserves recognized the difficulties that attend the management of buffer zones, such as how the imposition of land use restrictions can hinder voluntary cooperation. While continuing to assert the primacy of conservation, the panel urged a shift toward increased local involvement. A 'transition area' or 'zone of cooperation' replaced what was originally referred to as the outer buffer zone. The transition area ideally provides support for appropriate planning and sustainable resource development practices (Figure 7–2).

Figure 7–2
Zonation of a biosphere reserve (*Source*: UNESCO 1987, Annex 6)



The 1984 Action Plan stipulated several functions of biosphere reserves including conservation, research, monitoring, education, training, and cooperation at local to international levels (UNESCO 1984). In the panel's report these functions were subsumed under three main areas of concern: conservation, logistic support, and development (Figure 7–3). A functioning biosphere reserve displays all three functions, but the relative importance can vary over time and between reserves. The Panel urged all MAB National Committees to heed the Action Plan and to help maintain the international Biosphere Reserve Information System.

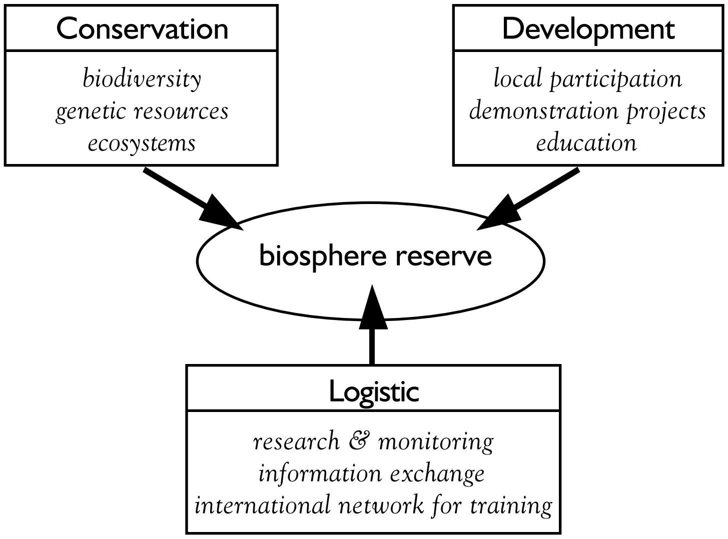


Figure 7–3
Three main concerns of a biosphere reserve (*Source*: UNESCO 1987, Annex 6)

The managerial overtones that shaped the first Action Plan persist in the Seville Strategy: "In sum, biosphere reserves should preserve and generate natural and cultural values through management that is scientifically correct, culturally creative and operationally sustainable" (UNESCO 1996, 6). The UNCED agreements and *Agenda 21* now provide much of the underlying motivation and rationale at the international level—the MAB 'wagon' has been hitched to the UNCED 'horse'. During the twelfth session of the ICC, it was argued that the MAB Programme is "pre-adapted" to respond to the challenges of UNCED. Five priority research themes were identified in the Medium Term Plan for the period 1996 to 2001 (UNESCO 1993):

- conserving biological diversity and ecological processes

- exploring approaches to land use planning and the sustainable management of resources
- formulating and communicating policy-related information on sustainable resource management
- building up institutional capacities for land use planning and sustainable resource management
- contributing to the Global Terrestrial Observing System (GTOS)

While there is no shortage of strategy documents, published case studies of on-the-ground experiences are rarer; this lack is being addressed as more people pay attention to the local responses to designation. Solecki (1994) placed the biosphere reserve concept within the tradition of rational planning and described some of the impacts of designation on local communities in the United States. He urged that regional planners become more aware of the "political and social realities" of rural communities and cited some typical difficulties:

- fear over loss of local autonomy
- lack of local political commitment
- insufficient administrative capacity
- poor coordination among agencies operating in the area

In a review of integrated conservation-development projects (ICDPs, including biosphere reserves) in developing countries, Wells and Brandon (1993) noted the growing interest in community-based initiatives and concluded that the designation as a biosphere reserve has only rarely influenced prevailing management approaches; the concept has not yet penetrated deeply into the minds of resource managers accustomed to jurisdictional neatness and the pursuit of performance objectives. Local involvement and interagency cooperation are major stumbling blocks. The establishment of a buffer zone also seems to be problematic in most ICDP-like initiatives, as a mandate to manage buffer areas is unusual. Effective local participation (Box 7–3) is hindered by a number of factors rooted in bureaucratic demands for efficient and accountable performance:

- authority structures that inhibit participation
- a demand to produce early, tangible results (the cultivation of participatory processes can require at least a decade of effort)
- neglect of the local socioeconomic context

Box 7–3
Five dimensions of local participation (*Source*: Wells and Brandon 1993)

- information-gathering
- consultation during the design or implementation phases of an initiative (or both)
- decision-making
- initiating action and identifying new needs
- evaluation and lesson-drawing

Price (1996) traced the evolution of the biosphere reserve concept over the last twenty-five years and noted a shift in emphasis from the 1970s to the mid 1990s: the Seville Strategy firmly places people *in* biosphere reserves. Local participation is now widely considered to be essential to a functioning biosphere reserve; this growing recognition bodes well for initiatives that adhere to principles of participatory design. But success is far from guaranteed. Institutional support for local participation is generally weak and, as I labored to show in Part I, integrated monitoring requires that diverse communities of practice become sufficiently aligned that cooperative action is feasible—achieving this (partial) alignment has both technical and social aspects that must not be neglected if a useful and relevant monitoring initiative is to emerge.

7.2 Monitoring in Long Point Country

A considerable amount of monitoring takes place in and around Long Point. A compilation of monitoring initiatives completed in May 1996 identified almost 60 programs undertaken by three levels of government and several non-government groups (Table 7–2). Like most mail surveys, this one probably underestimated the level of monitoring effort (the sampling frame was not described). Still, the diversity of activity is quite striking: aerial insect monitoring, beach water quality, an economic base study, forest inventories, waterfowl migration, marsh monitoring, and more. Of the 47 ongoing programs listed in the report, 26 are overseen by federal or provincial agencies, 7 by regional or municipal authorities, and 14 by non-government or industry groups. Most of the monitoring initiatives can thus be seen to issue from an official mandate.

Table 7–2 Some of the organizations engaged in monitoring around Long Point (*Source*: Poff 1996)

Federal/provincial agencies
Canadian Wildlife Service
Canadian Forest Service
Department of Fisheries and Oceans
Ontario Ministry of Environment
Ontario Ministry of Natural Resources
Regional/municipal authorities
Regional Municipality of Haldiman-Norfolk
Haldiman-Norfolk Health Department
Long Point Region Conservation Authority
Non-government groups
Long Point Bird Observatory
Ducks Unlimited
Long Point World Biosphere Reserve Foundation

An integrating framework is conspicuously absent, but this is not too surprising: the institutional milieu around Long Point is quite rich, and no one has an overarching responsibility to engage in integrated monitoring. There are no compelling nuclei around which data collection can be organized; existing administrative arrangements have not favored the construction of boundary objects. It was noted more than a decade ago that the degree of fragmentation has frustrated the development of shared perspectives:

> If a means could be found to introduce a larger perspective and have it incorporated into institutional arrangements, it would at least provide a forum where communication could be improved, gaps in programs and policy could be gradually filled, and the fragmented parts of the many program activities could be brought together in a more coherent manner. (Francis and others 1985, 80–81)

The intent of the 1996 monitoring assessment report was to provide a summary of *who* is monitoring *what*, presumably as a prelude to bolstering the logistic function of the biosphere reserve: "The desire is to explore what else might be done to round out or strengthen monitoring activities in the region" (Poff 1996, i). The obvious question is then: How do we go about doing this? A

Community Action Plan (CAP) was produced in 1994 under the auspices of the Long Point World Biosphere Reserve Foundation. The CAP articulated a number of community goals sorted into five general thematic categories (Box 7–4).

Box 7–4

Goals of the 1994 Community Action Plan (*Source*: Long Point World Biosphere Reserve Foundation 1994)

1. **Renewable resources and natural areas**
   - Protect and improve fish and wildlife habitat
   - Prevent further spread of exotic invasive species
   - Protect and restore biodiversity
   - Promote sustainable use of our renewable resources
   - Encourage scientific research pertaining to sustainable use of natural resources in Long Point Country
2. **Water quality and quantity**
   - Reduce water consumption
   - Reduce sewage pollution
   - Restore water quality and a healthy environment in and around water courses and Long Point Bay
   - Reduce human activities that contribute to erosion
3. **Education and communication**
   - Make more information about Long Point Country available to all levels of the community
   - Foster appreciation of the uniqueness of Long Point Country
   - Improve communication and coordination between community groups, supporting agencies, and local government as they work together to maintain and improve the environment
   - Promote commercial opportunities that bring revenue to the Long Point Bay area without jeopardizing its environmental integrity and biodiversity
4. **Energy and non-renewable resources**
   - Make our homes and businesses energy-efficient
   - Promote conservation of our non-renewable resources
5. **Waste management and toxic contaminants**
   - Eliminate the use and discharge of toxic contaminants from our homes
   - Reduce household garbage
   - Clean up garbage in marshes and parks, on beaches and shorelines, and along streams and roads

A range of monitoring activities were proposed under the heading of ‘Education and Communication’ (e.g. the preparation of an annual “State of the Bay” report, the effects of fluctuating water levels, factors affecting sediment transport). There are implicit concerns and aspirations that seem to underlie many of the project ideas—perhaps these can anchor the design of a monitoring initiative.

When I embarked upon this case study I noted three aspirations that seemed to motivate much of the thinking about monitoring in the region:

- trying to draw together the far-flung monitoring work already underway around Long Point
- reporting to the community about the status of local ecosystems
- breathing life into the biosphere reserve concept

However, there were no definite notions about how to proceed. People who were intimately familiar with monitoring in the neighboring Niagara Escarpment Biosphere Reserve shared their experiences, but there was a general feeling that what was needed was an approach tailored to the interests and concerns of Long Point Country; this was a desideratum I remained mindful of throughout the process.

7.3 Conducting the case study

A single case-study approach was adopted in keeping with the exploratory nature of this research and the sensibilities of soft systems thinking. Yin (1989, 23) defined a case study as an empirical inquiry that:

- investigates a phenomenon or a set of events within its real-life context
- lacks clear boundaries between the phenomenon of interest and its context
- draws on multiple sources of evidence

Long Point presents an interesting case study for several reasons. The biosphere reserve designation is more than a decade old, so the concept has secured a measure of public credibility, (to see a municipal official distributing souvenir pins commemorating the designation is one indicator!). The Community Action Plan is a noteworthy document, and while it is overtly conservationist in tone, this is probably due to the nature of the process that produced it. Community input was solicited mainly through two public meetings that perhaps attracted people more inclined to support and participate in environmental projects. Even if it's not clear that the objectives of the Action Plan speak loudly to all (or most) segments of the community, it does appear that local participation is not an alien prospect in the region.

The absence of an formal mandate is another consideration. There are disadvantages and advantages to working without a formal mandate. It can be more difficult to marshal the necessary resources and expertise to get things done, and establishing legitimacy requires extra effort. On the other hand, there is more room to be creative and experimental; the stakes are lower and the error costs tend to be not too high. Indeed, one can look upon a mandate as a guillotine poised to behead the poor folk who don't measure up. Relatively speaking, Long Point represents a sort of 'guillotine-free' zone.

Two streams of inquiry were pursued: interviews were conducted concurrently with my participation in a series of workshops and meetings that addressed monitoring activities in the region. Ethics approval for the interview part of the study was obtained from the Office of Human Research and Animal Care at the University of Waterloo. I was invited to participate in the workshops, where my role was mainly to offer advice and support. My observations and notes of these meetings, along with summaries if they were available, provided a record of these proceedings.

The interviews were undertaken in order to acquire some understanding of the issues surrounding the first two research questions posed in Box 1–3; these questions are concerned with the patterns and expectations underlying the collection and exchange of environmental data in the region. Interview participants were deliberately selected according to their affiliation: federal/provincial agency, regional/municipal authority, or non-government group; this 'stratified purposeful' sample yielded a good cross-section of interests. Each interview lasted 30–45 minutes and was audiotaped. A semi-structured format was adopted in order to encourage the participant to offer as rich a description as possible of his or her work. Appendix B provides samples of the information letter provided to all interview participants, along with copies of the interview guide and the consent form.

I participated in a series of four meetings held between April 1997 and June 1998; these meetings provided considerable insight bearing on the last two questions in Box 1–3 that focus on the design of a locally-sensible framework within a heterogeneous setting. Table 7–3 indicates the principal topics that were discussed at the four sessions. Early in the process it was clear to many participants that the community goals put forth in the Community Action Plan were "sectoral" or "effects-oriented" in scope, and did not really reflect an ecosystem approach. This concern was raised at the indicators workshop (12 April 1997), but an alternative conceptual framework was not considered at this point. One thing was clear: no single agency or organization could do it all—integrated monitoring would be an intrinsically collaborative venture involving several levels of government and non-government groups.

It was obvious from the beginning that there was no cogent rallying point—the design process required some way to structure discussion. I was not at this point thinking consciously in terms of constructing 'boundary objects', but the need for something of the sort (I was trying to discern 'rallying points') lead me to search the literature for ideas; much of chapters five and six stemmed from that search. The first session was ostensibly convened to propose indicators to measure progress toward the goals of the Community Action Plan. Several people favored an ecological or "science-based" approach, but one local resident (a retired biologist no less) warned against trying to monitor too much. Like most indicator exercises, this one wrestled with the question: What comes first—a list of indicators or a systemic framework? The issue remained unresolved, but it struck me that without some sort of structuring framework we were throwing a lot of indicators 'into the pot'.

Monitoring questions had been effectively used to focus the framework developed to assess cumulative effects along the Niagara Escarpment (MacViro Consultants 1995). The possibility of proceeding along similar lines at Long Point was explored during the next two meetings (15–16 May 1998). I introduced a metaphoric conception of integrated monitoring (an 'orchard' metaphor—it is described in more detail in chapter eight) to facilitate communication and to encourage different perspectives on what monitoring involves. My intent was to suggest an 'organic' alternative to the 'mechanical' design process that tends to dominate in a managerial context.

Table 7–3
Major topics discussed during the workshop series

Date	Location	Convenor	Major topics of discussion
12 Apr 97	CWS field station, Big Creek National Wildlife Area	Environment Canada, Ecological Monitoring Coordinating Office	• indicators to measure progress toward the goals of the Community Action Plan (CAP) • the desirability of an ecosystem approach • the proposed Canadian Biosphere Reserve Association
15 May 98	Backus Heritage Education Centre, Port Rowan	Long Point World Biosphere Reserve Foundation	• prospects for building on past work (e.g. '93 stress workshop, '94 CAP) • review of the cumulative effects monitoring framework for the Niagara Escarpment • advantages of forming a monitoring advisory committee to play a coordinating role
16 May 98	Simcoe	Long Point World Biosphere Reserve Foundation	• 'orchard' metaphor introduced as a communication aid • using public issues and aspirations as a basis for integrated monitoring • 'Long Point Country Monitoring Framework' conceived as a community-based initiative, not a planning tool
24 Jun 98	Backus Heritage Education Centre, Port Rowan	Long Point World Biosphere Reserve Foundation	• presentation outlining the prospects for designing an integration framework • devising sets of monitoring questions pertaining to the to issue categories expressed in the CAP—establishing a focus for monitoring and data integration

Metaphors can often be seen to underlie the ways we think and act; for example, battlefield metaphors permeate much strategic planning (e.g. achieving objectives, discerning threats, navigating mine fields, gathering intelligence). Some recent approaches to designing information systems look upon metaphors as a potent resource: they can help confer clarity, render abstract concepts more concrete, and favor particular styles of participation (Kendall and Kendall 1993). But every metaphor is multifaceted; Kendall and Kendall warn that an 'alien' metaphor should be introduced with caution. Metaphorical thinking encourages play with perspectives, and such play can help stimulate learning (Dahlbom and Mathiassen 1993).

At this point one of the principal organizers firmly identified the design initiative as a community-based project, not as a potential tool for regional planning; this position simply reflects the fact that neither the participants nor the Foundation have any authority to engage in planning. An open meeting was then scheduled (24 June 1998) to solicit input from interested members of the public and to set up community and scientific advisory groups. In an invitation letter the President of the Foundation introduced the project this way:

> The Long Point World Biosphere Reserve Foundation is developing a "Long Point Country Monitoring Framework (LPCMF)". Beginning with issues identified at the community level this framework will: help direct and focus current and future monitoring/research initiatives undertaken by the local community, university researchers, and government agencies and lead to a reporting system that will help answer the community's concerns about environmental issues. (Poff 1998)

The five theme areas of the Community Action Plan (see Box 7–4) provided a starting point for the deliberations at the June meeting. Translating the goals into specific questions for monitoring proved to be not an easy thing to do—there was considerable uncertainty about the attributes of a well-posed monitoring question, and the goals themselves seemed too general (i.e. insufficiently pointed) to be really useful in establishing a focus. It struck me that the CAP document by itself might not provide an exclusive basis for designing a monitoring framework conceived in terms of an ecosystem approach; it is aggregated to such a level that it is a little too diffuse, and there is little sense of connectedness among the goal statements. However, the document does provide a record of public concerns and it did figure in many of the discussions. Some participants clearly felt that the effort invested in the plan should not to be swept aside.

The extent to which a proposed monitoring framework meshes with the community action plan—whether it be a direct extension or more peripheral—was not openly discussed. Unfortunately, a follow-up to the last meeting in June was canceled, and indeed the design process might be fairly described as being "dead in the water"—but not sunk—at this time. The abrupt withdrawal of a key individual, an energetic 'local champion', has left the process in limbo for the moment. Like most community initiatives, this project has proceeded by fits and starts. Some months may pass before proceedings resume. It is hoped that the ideas developed in this thesis will provide direction for future discussions, stimulate debate, and help to structure the design process both at Long Point and in other non-managerial contexts.

A few words about methodology are in order. I drew on soft systems thinking to conceptualize my role in the design process, but for a number of reasons I made no attempt to foist the methodology upon the working groups. First, soft systems methodology and client-led design are usually practiced in the context of a contractual arrangement centered on a professional-client relationship. I was reluctant to enter into such a relationship lest I became mired in the position of proclaiming "the right way" to go about designing an integration framework—thereby shutting down the creative impulse in other participants (remember: designer as animateur, not architect). Second, soft systems approaches evolved in organizational settings where mission statements can be fairly readily articulated; direct application can become unwieldy when working with a heterogeneous assemblage of folk outside of an 'organizational box', so to speak.

In sum, the situation was too inchoate, too fluid in the early stages to admit a pre-defined sequence of analytical steps. Furthermore, I wanted to preserve the exploratory nature of the deliberations and let the participants establish a rapport. My deportment was not far removed from that urged by Guba and Lincoln (1989) in their account of *fourth generation evaluation*: a marriage of responsive focusing and constructivism that "solicits and honors the inputs from the many stakeholders and affords them a measure of control over the nature of the evaluation activity" (1989, 184). Some of the impressions I picked up along the way are summarized in the following section.

7.4 Some impressions

The interviews that were conducted in parallel with the design sessions yielded a few insights and confirmed some suspicions gleaned from other observations and documents. Most noteworthy is that the 'zone of cooperation' beyond the buffer zone is rather quiescent—there is relatively little cooperation to speak of. It is also apparent that the biosphere reserve designation is still young in institutional terms and has yet to make much of an impact on either monitoring or local governance. Many monitoring programs predate the designation (by several decades in some cases) and are intended to serve organizational interests; the designation is largely invisible to existing mandates. Furthermore, in the minds of many people it is unclear what a biosphere reserve means to the region—there are few rallying points. One respondent favorably cited the Community Action Plan as an example of a project that provided some focus for discussion and presented the community with an opportunity for self-evaluation. It may be that the abstractness of the biosphere reserve concept is an impediment to wider local awareness and participation. Box 7–5 summarizes some general impressions.

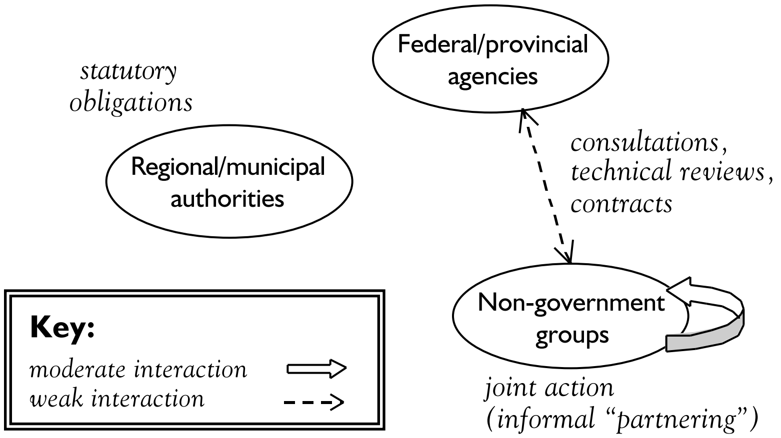
Box 7–5
Some noteworthy findings from the interviews

- unless a monitoring initiative is explicitly biosphere-related (i.e. sponsored by the Foundation), it is not greatly influenced by the designation
- the biosphere reserve designation does not loom large in the thinking of regional planners—it currently lacks jurisdictional significance
- there is little interaction among monitoring groups, and data sharing is infrequent—there is no coordinating apparatus or mechanism to exchange information
- integration would be valuable, but everyone labors under resource constraints (e.g. staffing, money, time); this is a circumstance unlikely to change in the near future
- data management gets short shrift—not much attention is paid to metadata issues

Any sort of integrated monitoring must start with an appreciation of the nature and scope of interactions among monitoring groups; the interviews helped with this. Figure 7–4 is a simple diagram that illustrates the intensity of interaction inferred from the interviews. The term 'interaction' broadly denotes many kinds of dealings: from joint planning, to resource exchanges, to consultations. The intensity of interaction reflects the frequency or degree of commitment. What emerges is a very rough picture of how environmental information flows in the region.

Volunteers are the lifeblood of non-government organizations (NGOs), and those groups engaged in monitoring around Long Point are no exception. As one program manager declared: "Without them, the programs are dead". The large volunteer base of NGOs, coupled with their scattered sources of funding (e.g. membership dues, corporate and private donations, fund raising, government contributions, foundation grants) makes for a rich variety of interactions among them. Shared constraints compel NGOs to form partnerships (an oft-cited word) in order to get things done. Government agencies are also periodically involved with non-government groups through the tendering of contracts, technical reviews, and consultations.

Figure 7–4
Interactions among monitoring groups



What is quite striking is the relative isolation of regional and municipal authorities. "We don't interact with them at all", stated one member of an environmental NGO. I would ascribe this state of affairs to the fact that regional municipalities seem to be almost totally beholden to their mandates: statutory obligations (especially planning responsibilities), coupled with scarce resources, tend to squeeze out all else. A regional planner remarked that since the biosphere reserve does not fall under the jurisdiction of any municipality, it receives recognition but little direct attention. Mandates also loom large in the operations of federal and provincial agencies. Commenting upon the ambit of agency monitoring programs around Long Point, one staff member observed: "They're all management-related—there's not any curiosity-based research there".

It would appear that the designation currently exerts little pull in the region. But this state of affairs should not be construed as a failing. A fully functional biosphere reserve is an ideal that marks a profound departure from conventional practices—its realization may well require decades of patient work. Many of the people I interviewed mentioned the value of the designation in helping to raise awareness and attract funding, so for the most part the biosphere reserve concept remains, well, conceptual. It would be an exaggeration to say that the biosphere reserve has penetrated deeply into the public consciousness in the region. I encountered residents of the cottage community on Long Point who wore puzzled frowns when I referred to the biosphere reserve. The Foundation has evidently taken pains to maintain a fairly low profile over the years. Occasional joking about the condition of the sign on the waterfront at Port Rowan that proclaims the designation allude to the delicate task of establishing credibility and maintaining a modicum of public support.

Prevailing interactions among monitoring groups tellingly indicate the absence of any compelling centers of coordination or 'condensation nuclei'[3]. As I saw it one of the basic tasks of the design exercise was to draw together people holding disparate interests and expertise while remaining sensitive to local circumstances. However, the limited means of groups engaged in monitoring around the region calls for some restraint—laying out a sweeping initiative that requires resources that are in short supply is a recipe for frustration and, ultimately, failure. One interview respondent mentioned that an integration effort would be valuable, but recommended starting out at a small scale by addressing a few specific questions. Another respondent remarked that too many people are collecting data that is never used: "If you're going to collect data, you should always have a reason for collecting it, and you should always have a plan for making it public". Given the degree of disarticulation in the region, the

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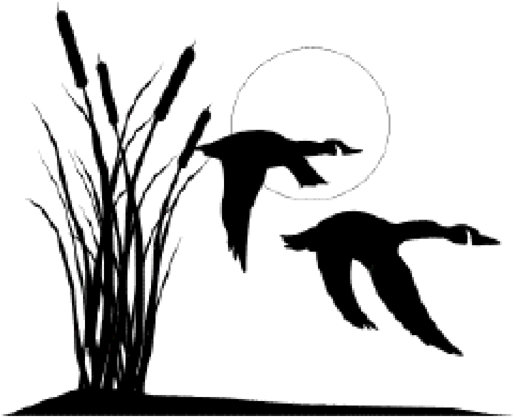
[3] I employ another little trope here—condensation nuclei are atmospheric particles around which water vapor condenses to form precipitation.

notion of a boundary object provides a handle for grappling with integration issues, and a place to start.

The next chapter attempts to wed the two concepts of sense-making and boundary object in the guise of a sense-making portfolio—an ensemble of charts and diagrams centered on a public issue and aspiration. A few general design criteria inform the creation of a sense-making portfolio: these arose over the course of deliberation as desirable features of a community-based monitoring initiative; they refer to the attributes of what I took to calling a locally-sensible framework for monitoring practice. In particular, a locally sensible initiative should:

- support community aspirations
- make room for volunteer contributions
- recognize the multiscale character of natural processes and human activities
- focus and direct attention



Chapter 8

Creating a sense-making portfolio

The desire is to explore what else might be done to round out or strengthen monitoring activities in the region.

Christine Poff,
Long Point Area Monitoring
Assessment Project

8.1 Sense-making by design

The development of an integrated monitoring initiative is being conducted in a spirit of cooperative design rooted in the soft systems tradition. The initiative ultimately looks forward to establishing some sort of environmental information system, say the 'Long Point Country Environmental Information Network' (my own unofficial label). An outlook that I have encouraged is informed by the recognition that most monitoring activity unfolds against a backdrop of ambiguity where the crucial task is trying to make sense, not decisions. Indeed, at the last public meeting one of the principal organizers was quick to declare that the project should not be seen as contributing to a management plan. Consequently, more emphasis was placed upon problem setting rather than problem solving. In his writings Vickers declined to take problem setting for granted and introduced the notion of *appreciation* that takes concerns, not problems, as prime. An appreciative system serves to guide action, mediate communication, and make life bearable: "It is thus a mental construct, partly subjective, largely intersubjective, that is, based on a shared subjective judgment, and constantly challenged or confirmed by experience" (Vickers 1983, 55).

As argued in chapter six, many ideas from soft systems thinking bear on this initiative. A number of information systems practitioners have drawn on Vickers' notions to articulate fairly sophisticated models of organizational decision-making (Checkland and Holwell 1998; Lewis 1994; Stowell and West 1994). These models highlight the interpretive aspects of meaning attribution. Appreciation entails filtering myriad 'facts' through a cognitive framework that imbues them with relevance: "We cannot therefore talk of *the data* required for making a particular decision but only the data which a particular appreciation of the world deems as being required" (Lewis 1994, 99). The appreciative setting can be grasped by constructing notional models that serve as epistemological devices to support a learning process.

Sense-making is thus the grounding theme. A sense-making portfolio is presented as a way of linking cognition and action, a way of articulating a plausible account of current understanding that is more a depiction of the state-of-knowledge than of the state-of-the-world (even if one grants the possibility of grasping the latter, the two can be far, far apart); at its core lies a system definition in the form of a data frame that sets up a figure–ground relationship (by bracketing or framing a situation) used to explore a particular issue. Weick (1995) downplays the significance of accuracy and argues that sense-making is mainly concerned with achieving plausibility, coherence, and reasonableness—it is about invention, not discovery. So what is necessary in sense-making?

> The answer is, something that preserves plausibility and coherence, something that is reasonable and memorable, something that embodies past experience and expectations, something that resonates with other people, something that can be constructed retrospectively but also can be used prospectively, something that captures both feeling and thought, something that allows for embellishment to fit current oddities, something that is fun to construct. In short, what is necessary in sensemaking is a good story. (Weick 1995, 60-61)

Story telling is intrinsic to sense-making. Knowledge, assumptions, beliefs, and expectations are often brought to light through narrative accounts of actions or events. And narratives play an epistemic role by establishing coherence and significance—they help to frame interesting questions and serve to qualify what counts as an intelligible answer (Rouse 1996, 160). Bruner (1990) asserts that human experiences are typically framed in a narrative form, and he sees them as “especially viable instruments for social negotiations” (Bruner 1990, 55).

When articulating a narrative the trick is to stop short of a ‘master’ narrative that homogenizes local diversity (e.g. access to resources, power, expertise) and accommodates only one rationality grounded in a sacrosanct logic proclaimed by a voice “from nowhere”. Narratives—and the metaphors they invoke—are subject to stabilizing and destabilizing influences; like any construction a narrative may be extended, reconstructed, or even deconstructed. Narratives, then, are grist for sense-making.

The sport fishery of Long Point Bay is taken up as an example to illustrate what a sense-making portfolio might look like. The creation of a portfolio entails the identification of processes or activities that are germane to a particular aspiration; it attempts to integrate the *how* of monitoring with the *why* and *what* in as transparent a manner as possible. One can also view it as a sort of 'resource kit' for thinking about related aspects of monitoring work such as data modeling, data sharing, and indicator development.

The reader should bear in mind that what follows is largely a product of my own effort and has not yet been subjected to extensive public testing—it remains very much in a 'beta' stage of development. Community-based initiatives tend to unfold at their own pace, and this one remains far from getting down to the fine details of implementation. But it is important to provide tangible examples that can fuel future deliberations. The portfolio represents *one* way to quicken many of the ideas introduced in Part I of this thesis. As such, it is intended to be suggestive, not authoritative.

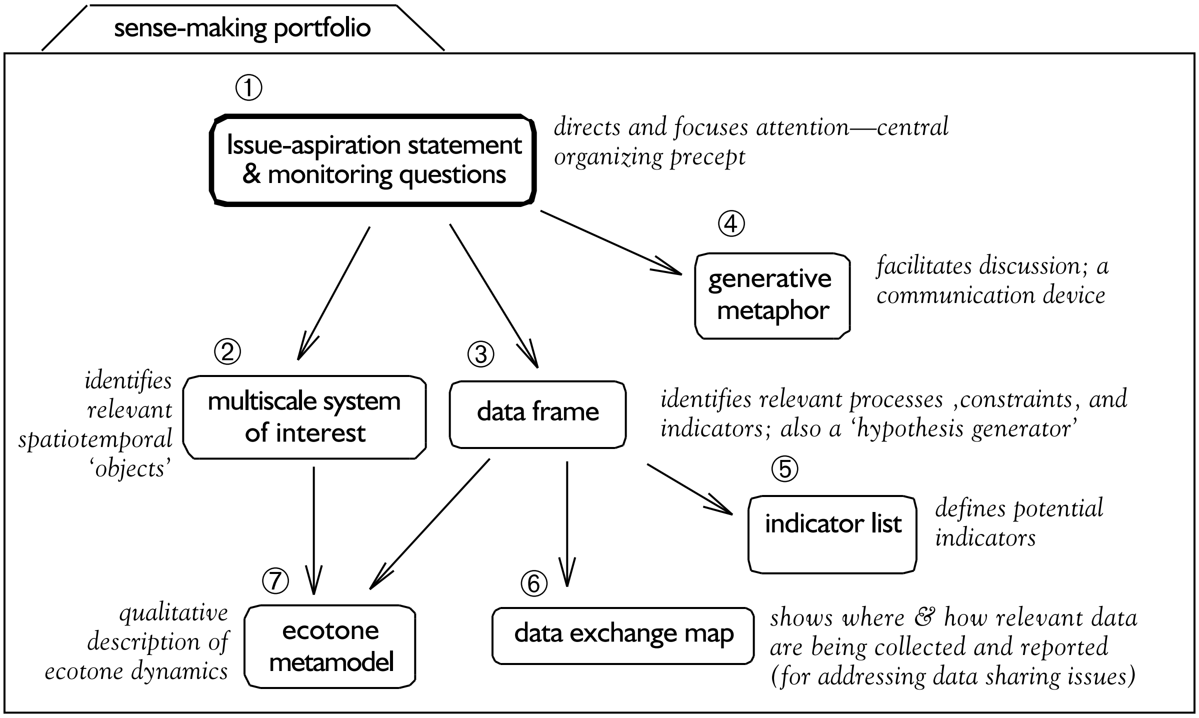
8.2 The elements of a sense-making portfolio

The central object of design activity is a portfolio that supports a sense-making process; it comprises a set of 'living' documents that are modified as part of an open process of continuous learning. In effect they serve as boundary objects that different groups can use to negotiate shared meanings and to coordinate their monitoring work. There is a heavy emphasis on visual devices that can be readily conceived and disseminated. Drawing is intrinsic to many design exercises, and diagrams of all sorts are used to support systems thinking (this probably reflects an engineering heritage). Stowell and West (1994, 62) have cited four major benefits of producing good systems diagrams: they help to crystallize thinking, aid communication, provide documentation, and enable 'walkthroughs' of problematic or confusing situations. Figure 8–1 presents the elements of a sense-making portfolio. A portfolio consists of a set of condensed visual aids intended to help structure discussion about various aspects of integrated monitoring; its elaboration entails both participation and reification. Figure 8–1 is not meant to imply that there is a rigid development sequence that invariably progresses from items one to seven. It should be clear, however, that an issue-aspiration statement anchors the design and plays a role roughly analogous to that of a root definition in soft systems methodology. Each element will be briefly introduced before turning to a more concrete example in the next section.

issue-aspiration statement

The issue–aspiration statement is fundamental to the portfolio: it directs attention and promotes cognitive bracketing (i.e. the setting up of figure and ground). The statement constitutes the central organizing precept—the 'why' of monitoring—and expresses a vision that should be sufficiently pointed that it can provide a focus for monitoring. Vague, fuzzy declarations are of little help. An expressed aspiration together with a set of monitoring questions provide a handle for identifying relevant processes, thereby helping to articulate what is called an "issue-based relevant system" in soft systems methodology. An issue-aspiration statement should not be regarded as a root definition, for it does not necessarily express the transformation of a particular entity (Checkland and Scholes 1990). The statement conveys a public concern, not the core purpose of some human activity system.

Figure 8–1
Elements of a sense-making portfolio



multiscale system-of- interest

A multi–level account starts with recognizing that context is important in understanding complex systems. But the levels are not given *a priori*—they are relative to the questions posed by a positioned observer, and reflect particular definitional criteria (Ahl and Allen 1996). In keeping with a basic rule of thumb in hierarchy theory, three levels are distinguished: an upper level

(L+) that provides a context for the focal level processes (L), plus a lower level (L–) that can perhaps shed light on the dynamics of interest (Allen and Hoekstra 1992). Salthe (1985) proposed a triadic schema in which focal-level dynamics are fed by initiating conditions from the lower level and constrained by boundary conditions impinging from the upper level. The notation is easily extended to encompass further levels: L++, L-- , and so forth (I prefer to avoid labels such as L–2 or L+2 in order to discourage any implication of 'quantization' or pre-givenness).

That a region can be conceived as a mosaic of patches is a basic tenet of landscape ecology. Mosaics and gradients are the two forms of spatial heterogeneity most studied by landscape ecologists to understand the interplay of natural and human processes (Forman 1995). Patch boundaries delineate relative discontinuities in the rates of observed processes (e.g. a thermocline). Furthermore, patchiness is scale-dependent (Wiens 1989). For each level, spatiotemporal objects can be roughly defined in terms of particular core processes, thereby specifying the type of system being defined. But take note: there is no fanciful assumption here that identified objects are *exact objects* possessing crisp, well-defined boundaries. Most ecological boundaries are fuzzy and dynamic, exemplifying *vague objects*. Indeed, there is no presumption that the system-of-interest is comprised of genuine spatial objects 'out there'. Objects are depicted using dashed lines to emphasize their fuzzy character and to discourage the tendency to 'fix' solid lines and thereby reify spatial objects. Tentative boundaries should invite attempts to redraw them in light of a revised understanding.

data frame & indicator list

The data frame singles out processes at each level that are considered to be most relevant in light of current knowledge, and points out important linkages among them; these linkages may be constraint or modifying relations. Potential observables or indicators pertaining to the processes of interest are identified and categorized according to how well developed their associated protocols are. *Tier I* (core) indicators are routinely measured and have well-developed protocols. *Tier II* (pilot) indicators are employed in demonstration projects and have somewhat developed protocols. *Tier III* (research) indicators have considerable potential but remain undeveloped. A similar categorization scheme was used in an exercise to develop policy performance indicators for the Ontario Ministry of Natural Resources (Boyle 1998). While the data frame presents a generalized synthesis of scientific research and local knowledge, it should not be looked upon as an authoritative model of how the world works. The data frame provides a 'conversation piece' in the soft systems sense—it serves its purpose to the extent that it prompts ongoing discussion and debate.

generative metaphor

Metaphors often undergird the naming and framing of a situation. According to Schön and Rein (1994), a metaphoric capability is intrinsic to competent policy design. While engaged in design activity it becomes important to discuss and reflect on proposed work. Metaphors—understanding one thing in terms of another—can encourage this by portraying an activity or issue in a new way. Metaphors are *generative* to the extent that they yield new perceptions, explanations, or inventions (Schön 1993). Metaphoric design invokes new concepts, restructures perceptions, invites different interpretations, and thus lends itself to problem setting (Madsen 1989). For example, I employed the image of an orchard as a metaphoric vehicle to portray environmental monitoring in a different light and to encourage a wider appreciation of what is involved. The main purpose of doing so was to redirect the impulse to see monitoring as a purely technocratic initiative undertaken for and by accredited professionals in pursuit of a particular mandate.

Kendall and Kendall (1993) described nine main metaphors that permeate the design of information systems: game, machine, journey, jungle, family, zoo, society, war, and organism; these metaphors were then mapped onto commonly used development methodologies. By this account, most structured methodologies are partial to machine images (and soft systems methodology is conducted in a 'zoo'). Commenting upon the evident paucity of organic metaphors, the authors opined that "the organism metaphor requires a great deal of flexibility and adaptability to flourish" (Kendall and Kendall 1993, 161). The organic metaphor of an orchard was introduced to encourage a more flexible outlook and to highlight some important aspects of design work:

- design is not something undertaken once and for all—it is an ongoing and evolutionary process (e.g. new branches bud and others get pruned as understanding evolves)

- a bare list of indicators does not adequately convey a sense of connectedness; it constitutes little more than a jumbled heap or 'compost pile' that generates much heat
- a monitoring initiative has its vulnerabilities: it can wither due to lack of nutrients, it can be attacked by pests, or it can be fatally struck by lightning from above!

The metaphor I introduced portrays an orchard of aspirations rooted in a substrate of public issues (Figure 8–2); it was generally well received—this local resonance may reflect the significance of forested areas in the region. A corridor reforestation project was one of the Foundation's recent flagship projects, and biodiversity monitoring plots set up in several Carolinian forest tracts (according to the SI/MAB protocols developed with the support of the Smithsonian Institution) are important in local educational programs.

Figure 8–2
An organic metaphor for integrated monitoring

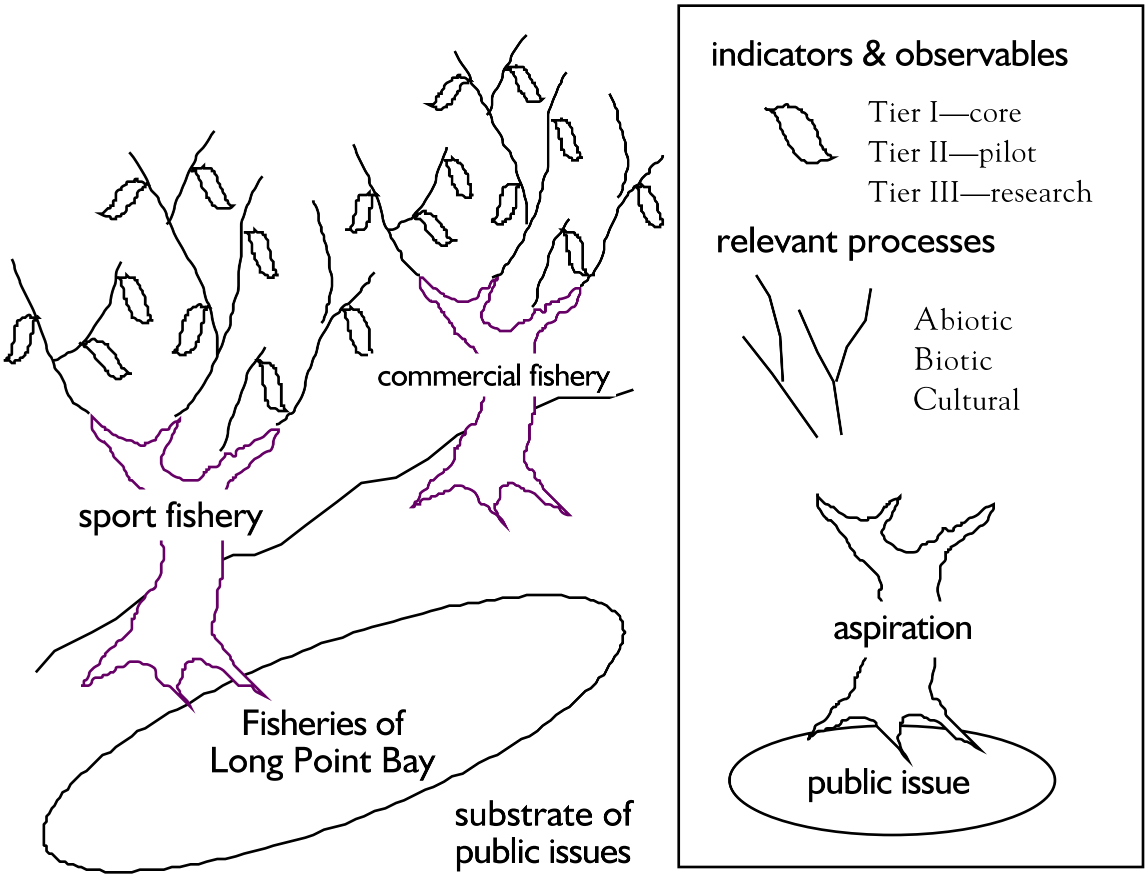


Figure 8-2 vividly suggests how the elements of an integration scheme are fitted together in the course of defining an issue-based relevant system. A given public issue is coupled to a pointed aspiration that leads to the identification of natural processes and human activities deemed relevant to the issue under consideration. Indicators are then selected to track the pertinent abiotic, biotic, and cultural processes; the following section uses the nearshore sport fishery to illustrate this process.

data sharing

When different groups in different organizations are collecting environmental data, sharing that data becomes essential in any kind of integration effort. It's important to know who is collecting relevant data sets and how the data are acquired, stored, and reported. A data exchange 'map' provides a starting point for working out suitable arrangements and for devising metadata ('data about data') that provide a potential user with information about the characteristics of a particular data set.

ecotone metamodel

The term *ecotone* is used by landscape ecologists to specify transition zones between adjacent ecological systems or patches. Ecotones represent discontinuities within landscapes and play host to strong interactions between production and exchange processes, especially in coastal areas (Ray and Hayden 1992). A wide variety of physical and biological gradients exist in nearshore ecotones, and these can interact to produce systemic transformations propelled by negative and positive feedbacks. For example, Regier and Kay (1996) proposed an heuristic catastrophe model of aquatic ecosystems to account for shifts in the relative dominance of benthic and pelagic associations in response to nutrient loading.

A grasp of ecotone dynamics provides a powerful way to conceptualize systemic transformations (possibly including 'flips' between basins of attraction). The conservation of coastal ecotones has been the subject of several workshops sponsored by UNESCO. A summary document (Naiman, Décamps, and Fournier 1989) presented a suite of 20 hypotheses dealing with land/inland water ecotones. These hypotheses were grouped into three categories: ecotone functions, relations between ecotones and adjacent systems, and management. Nearshore ecotones typically harbor rich assemblages of flora and fauna, and play an important role in maintaining biodiversity and productivity by regulating energy and nutrient fluxes.

This brief overview of the elements of a sense-making portfolio is intended to suggest how it can facilitate the negotiation of meaning by supporting processes of participation and reification (Wenger 1998). Articulating the issue-aspiration statement, posing monitoring questions, and exploring the implications of the generative metaphor help to structure discussion and bring contrasting perspectives to light. Distinguishing the system-of-interest, building a data frame, and identifying potential indicators help to crystallize understanding and provide common referents. In effect, a sense-making portfolio is an ensemble of boundary objects—I like to think of them as 'condensation nuclei'—around which groups holding different interests and expectations can coordinate their work. The sport fishery of Long Point Bay will be used to illustrate some of these ideas in more detail.

8.3 An example: The sport fishery of Long Point Bay

I singled out the nearshore sport fishery for several reasons. The fishery is a topic of widespread concern in the region—angling is of considerable recreational and economic significance. Nearshore ecotones are also areas of great ecological importance where many gradients (e.g. depth, thermal regime, nutrient loading) interact to produce diverse and productive habitats. And in many ways the nearshore sport fishery constitutes a 'worst-case' scenario for monitoring: most fisheries research takes place offshore where confounding factors are either absent or more easily controlled. All-in-all, a nearshore fishery presents a truly messy, confusing situation ripe for sense-making.

The contents of the corresponding portfolio are listed in Box 8–1. A proposed issue–aspiration statement pertaining to the sport fishery, along with a set of monitoring questions, is given in Table 8–1. There are many legitimate aspirations of course; the spawning of indigenous species is singled out because a) stocks are most vulnerable during early life stages, and b) exotic species threaten to disrupt native ecosystems, and hence are frowned upon.

Box 8–1
Contents of the sport fishery portfolio

①	Issue-aspiration statement with a set of related monitoring questions	Table 8–1
②	Multiscale system-of-interest	Figures 8–3a,b,c
③	Data frame	Figure 8–7
④	Generative metaphor: an orchard	Figure 8–2
⑤	Sample listing of indicators	Table 8–5
⑥	Data exchange map	Figure 8–8
⑦	Gradients of the nearshore ecotone	Figure 8–9

Issue	Aspiration(s)	Some monitoring questions
Sport fishery of Long Point Bay	That principal native sport fish species remain self-sustaining over the next 15 years	• are fishing opportunities adequate? • are yellow perch and smallmouth bass being over-fished? • what is the condition and extent of spawning habitat? • do exotic species pose a threat? • what are zebra mussels doing? • are the bass nesting successfully? • do we need a spawning sanctuary for smallmouth bass?

Table 8–1
An aspiration with monitoring questions pertaining to the sport fishery

Spawning and juvenile recruitment are the core biotic processes around which the system definition will be built. The 'recruitment problem' is a long-standing one in aquatic ecology. Year–class strength is highly variable, and the recruitment of early life history stages is generally poorly understood. Lodge and others (1988) remarked that the heterogeneity of littoral habitats makes for many unknowns, such as interactions among macrophytes, periphyton, and grazers. Unfortunately, sport fisheries and nearshore areas receive relatively little official attention as management agencies are inclined to concentrate on commercial fisheries due to their historical economic importance. Open water studies tend to be logistically simpler than those undertaken in littoral zones. So a sport fishery conducted in nearshore waters—the situation at Long Point—promises a rather sparse data set indeed!

Wetlands are important for fish production in Lake Erie, providing spawning and nursery habitat for wetland-dependent species as well as cover for juvenile fish. Long Point Bay has supported a thriving sport fishery for decades. Based on the proportion of the catch that is actually harvested, smallmouth bass, largemouth bass, and yellow perch are indigenous species especially favored by anglers (Ontario Ministry of Natural Resources 1997). Table 8–2 provides a few particulars for each species. While the commercial fishery of Lake Erie is extensively monitored in both the U.S. and Canada, the recreational fishery has not been studied as closely. But there are a few data sets available.

Over the years there have been a few studies of nearshore fish communities in and around the bay, but ongoing monitoring is limited. As part of an effort to assess the fish community impacts of thermal discharges near the Nanticoke industrial complex, the movement and migration of selected species were traced through telemetry and tagging studies (MacGregor and Witzel 1987). Seasonal movements to and from the inner bay in response to changing water temperatures were noted. A few yellow perch tagged on spawning grounds in the inner bay were recovered in the central basin, indicating that this species can range quite widely.

The Lake Erie Fisheries Assessment Unit has conducted a standardized creel census in Long Point Bay since 1978. The census estimates fishing effort, but other aspects of fish population dynamics are poorly known. Leslie and Timmins (1997) reported the results of a 1985 fish sampling survey conducted along the south shore of the inner bay. Twenty-seven species of larvae and age 0+ juveniles were identified, and it was estimated that 86% of the age 0+ fishes hatched in the study area. Centrarchids represented 47% of the total catch. Evidently a fairly diverse percid-centrachid-cyprinid assemblage utilizes spawning and nursery habitats in Long Point Bay. Acquiring a systemic understanding of this fish community assemblage presents a considerable challenge, though.

Species	Notes
smallmouth bass *Micropterus dolomieui* Centrarchidae family (sunfish)	• sexual maturity 3–5 yrs (males), 4–6 yrs (females) • spawns late May to early June; egg deposition occurs when water temperature attains 16–18 °C • the male builds a nest ~1m diameter in quiet water; guards the nest, fans the eggs, guards young after hatching • strong winds are detrimental to nesting success • diet: crayfish, fish (adult); plankton→ immature aquatic insects (young) • very inactive in winter
largemouth bass *Micropterus salmoides* Centrarchidae family (sunfish)	• sexual maturity 3–4 yrs (males), 4–5 yrs (females) • prefers warm, still waters containing aquatic vegetation and low turbidity (is a sight feeder) • peak spawning early to mid June when water temperatures are 17–18°C (a little sooner than smallmouth bass) • male builds a nest in rocky or gravelly nearshore areas (also in the roots of aquatic vegetation) • little tolerance for low oxygen conditions • diet: fish, crayfish (adult); plankton→ insects (young) • significant incidence of cannibalism • fry remain around the nest for up to a month before dispersing
yellow perch *Perca flavescens* Percidae family (perch)	• a schooling species that is active throughout the year • spawns mid April to early May when water temperature attains 9–12°C • a broadcast spawner (no nest)—eggs are laid in gelatinous ribbons over plants and twigs in shallow water • very adaptable—uses a wide variety of habitats • preyed on by almost all other predatory fishes and some water birds (e.g. loons, gulls)

Table 8–2
The main indigenous sport fish species (*Sources*: Bolsenga and Herdendorf 1993; Coad, Waszczuk, and Labignan 1995; Scott and Crossman 1975)

The annual *Lake Erie Fisheries Report* provides a wealth of data and assessments. Angler surveys conducted in 1996 include (Ontario Ministry of Natural Resources 1997):

- an on-water roving creel survey of Long Point Bay (conducted from 29 June to 31 July)
- the lakewide Angler Diary Program (204 distributed, with 146 returned)
- an aerial creel/access point survey

Data from the index trawl surveys conducted in Long Point Bay during September and October of 1996 indicate that yellow perch enjoyed moderate spawning success in the inner bay, and good success in the outer bay. These findings are consistent with a long-term decline in young-of-the-year recruitment in the inner bay. Centrarchids show increased recruitment, with largemouth bass experiencing excellent spawning success in 1996. Shiners also showed improvements.

The nearshore fish community around Long Point is associated with the extensive marshes. Whillans (1985) noted a correlation between water level regime and changes in the relative abundances of most vegetation types (e.g. robust emergents were directly correlated with long-term annual change, and submergent bed vegetation was inversely correlated). He further observed that submerged vegetation is the cover type most significantly associated with high fish abundance. Nearshore fish species evidently utilize habitat quite flexibly, including spawning locations. While there appeared to be no strong cycles in the patterns of habitat occupation by species, Whillans suggested some evidence for community-level shifts (e.g. involving back water and open water taxa).

As geomorphic features go, the barrier spit complex that is Long Point is a dynamic one—it is nourished and sculpted by wind and water. Various physiographic zones can be roughly distinguished primarily in terms of sediment transport—that is, by varying rates of erosion, deposition, or resuspension. Processes such as these significantly influence the distribution and development of the coastal lagoon wetlands around Long Point, factors which in turn affect the character and quality of fish habitat. Water level fluctuations modify the intensity of coastal processes and also affect vegetation dynamics, especially in shallow lakes with gradually sloping shorelines (Gasith and Gafny 1990).

The issue-aspiration couple anchors the system description—it starts the business of narrowing focus and identifying phenomena of interest. The preceding discussion highlighted the significance of early life history—an appreciation of the spawning and juvenile recruitment of the native sport fish species is crucial to realizing the expressed aspiration; access to diverse spawning and interconnected nursery habitats also seems important (Leslie and Timmins 1997), along with an understanding of seasonal fish movements. Hence processes at multiple scales are pertinent, from habitat to lake basin level. This leads to the relevant multiscale system-of-interest, which considers three levels: an upper basin level (L+), the focal bay level (L), and a lower habitat level (L–).

Lake Erie has three major basins that were scoured by Pleistocene glacial ice: the western, central, and eastern. The central basin is the largest, separated from the eastern basin by a sand and gravel bar extending south from the base of Long Point. This wide bar likely marked the position of the ice front some 13000 years ago (Bolsenga and Herdendorf 1993). The eastern basin is relatively deep, with a mean depth of 24m. The deepest sounding in the lake (64m) is located in the eastern basin off the tip of Long Point. Bottom sediments are mostly silt-clay muds. The north shore of the central basin is an area of high shore erosion—glacial sediments eroded from bluffs to the west are extending the spit lakeward at a rate of 4–7 m annually (Davidson-Arnott and Fisher 1992).

On the basis of sediment budget and morphology, the sand spit itself can be divided into three zones: proximal, central, and distal (Davidson-Arnott and Fisher 1992). The proximal and central zones have a negative sediment budget, whereas the distal zone has a positive sediment budget and is prograding out into the eastern basin. The inner bay is also quite dynamic; its configuration and bathymetry have varied considerably over the centuries due to an influx of sediment delivered by washover events and by Big Creek, the major tributary. The mean annual suspended load for Big Creek is on the order of 2×10^4 tons/year (Downey, Radovich, and Lawrence 1996). The inner bay is almost entirely vegetated: it is fringed by emergent vegetation on three sides, and submerged vegetation carpets the bottom in more open waters (Wilcox and Knapton 1994). Figures 8–3a,b,c depict the relevant spatiotemporal objects at the basin, bay, and habitat levels; they are primarily distinguished in terms of geomorphology (e.g. sediment transport, substrate, and bathymetry)—hence they are *geomorphic types* in the sense of Allen, Bandurski, and King (1993).

The inner bay is rather uniformly shallow (with an average depth of less than 2m), but there is some variation in substrate composition and in the distribution of emergent and submerged macrophytes (Wilcox and Knapton 1994). Lane, Portt, and Minns (1996a,b,c) reviewed the literature on Great Lakes fishes to describe the habitat preferences of significant species at different life stages; they included such characteristics as water depth, substrate, and vegetation cover (Table 8–3).

Figure 8–3a
Basin level, L+

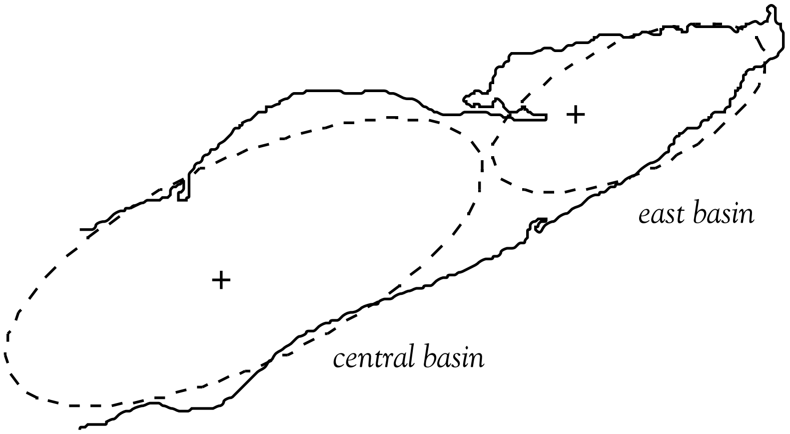
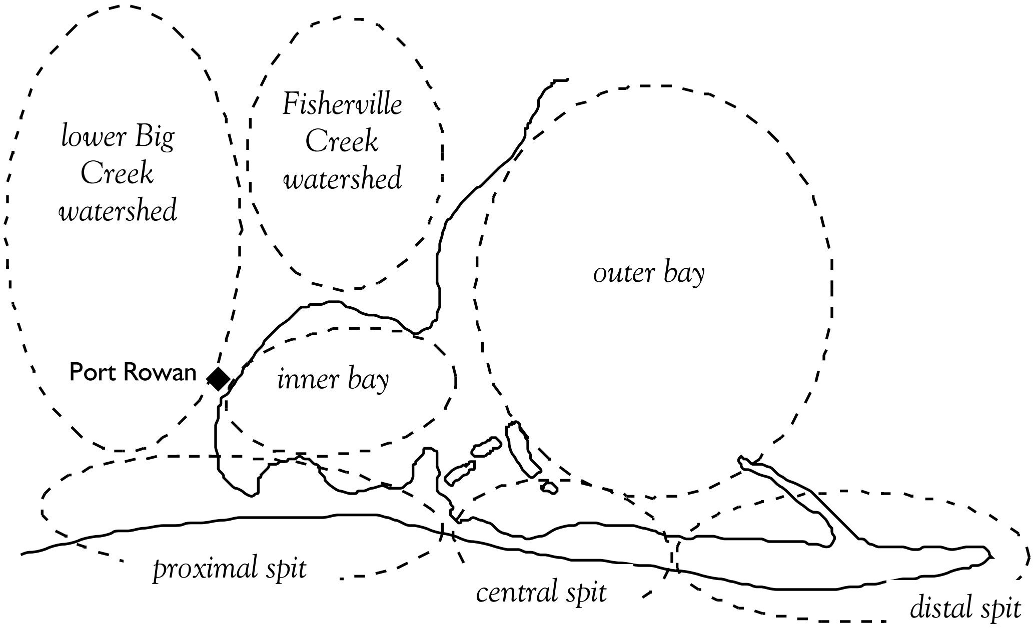


Figure 8–3b
Bay level, L



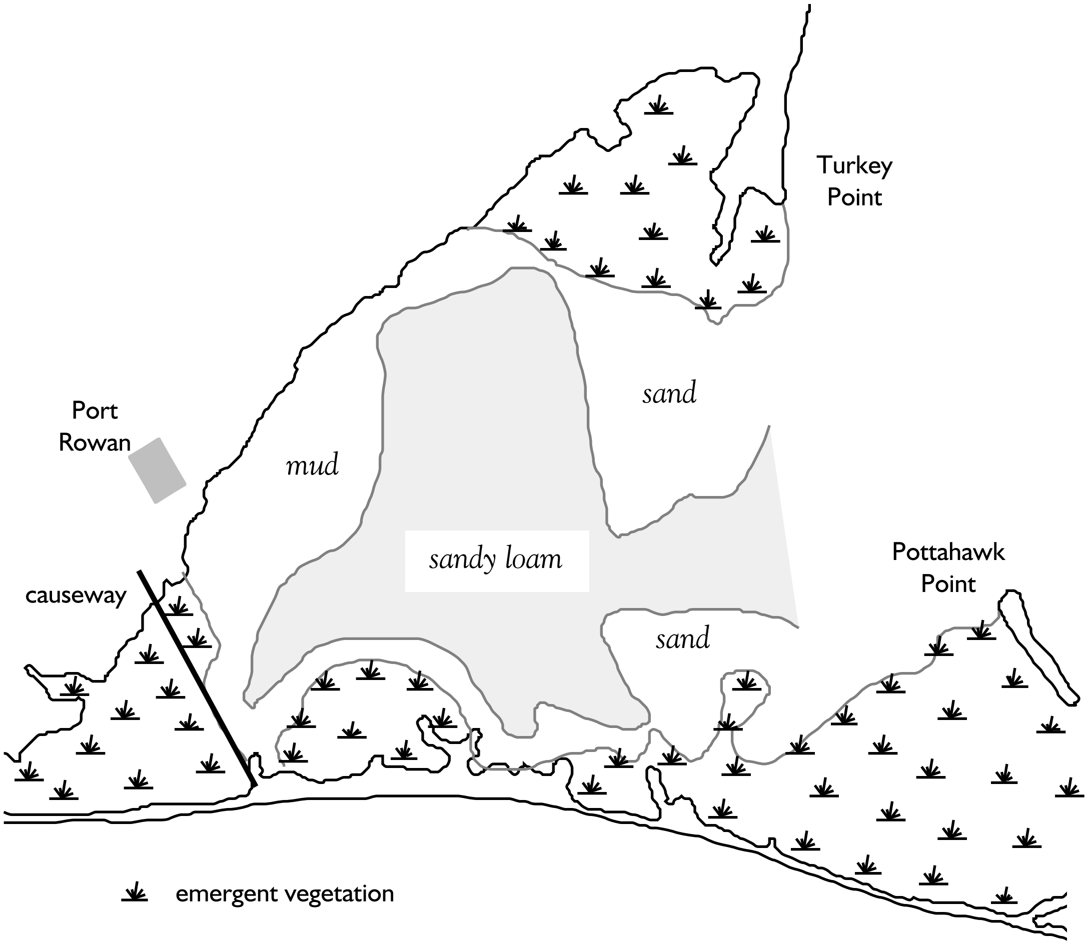


Figure 8–3c
Habitat level, L–
(*Source*: Wilcox
and Knapton 1994)

As I stated earlier, focusing on the spawning and juvenile recruitment of nearshore fishes represents a difficult scenario for monitoring: aquatic ecologists and limnologists have historically concentrated their efforts offshore in the pelagic zone, which offers fewer complications for sampling and controlled experimentation. Littoral zones often present a heterogeneous mosaic of habitats that pose methodological difficulties, a point emphasized by Lodge and others (1988) in their account of habitat interactions in lake communities. Long Point Bay is not exceptional in this regard. The nearshore fish community has never been subject to sustained study. Sporadic thesis work, the odd project, and anecdotal accounts comprise the local knowledge base. A twelve-year study conducted in the outer bay from 1971 to 1983 (MacGregor and Witzel 1987) was designed to assess impacts associated with industrialization around the Nanticoke complex.

The resulting report, while voluminous, had little to say about systemic processes not related to thermal plumes (the focus of the impact assessment), although there were some interesting observations regarding fish migrations.

Table 8–3
Habitat preferences by life stage (*Sources*: Lane, Portt, and Minns 1996a, 1996b, 1996c)

Stage	Water depth	Vegetation/cover[1]	Substrate[1]
Smallmouth bass			
Nursery	<2m (spring) >2m (fall)		**boulder, boulder-cobble, rubble** *bedrock*, *gravel*, *sand* silt
Adult	<2m (summer) 2-10m (year)	submergent, emergent logs	**boulder, cobble, rubble, gravel** *hard-pan clay* sand
Spawning	<2m	submergent, emergent boulders, docks, logs	**rubble, gravel** *bedrock* (with overlying gravel), *sand*
Largemouth bass			
Nursery	<2m (year) 2–5m (fall)	**submergent, emergent**	**silt** *sand*
Adult	<5m (year)	**submergent, emergent**	**sand, silt** gravel, clay
Spawning	<2m	**emergent** *submergent*	**sand, silt, clay** rubble, gravel
Yellow perch			
Nursery	<5m (spring) >5m (fall,winter)	*submergent*, *emergent*	**gravel, sand, silt**
Adult	0-10m+ (year)	*submergent*, *emergent*	**sand, silt** *gravel* bedrock, boulder, cobble, rubble, clay
Spawning	0-5m+	*submergent*, *emergent* rocks, brush, debris	**gravel, sand** *rubble*, *silt*, *clay*

[1] The strength of association is indicated by type style as follows: high (**bold**), medium (*italic*), low (roman)

While local knowledge is somewhat spotty, there has been considerable work done throughout the Great Lakes and in other freshwater ecosystems; these studies can be of great help in creating a sense-making portfolio to guide integration and inquiry. The next section dips into the broader scientific literature to describe some findings that inform the construction of the data frame. What follows is a potpourri of fisheries biology, aquatic ecology, and limnology. I've sampled a far-flung literature to pull together a few results and insights concerning the rich dynamics of littoral zones. My intent is not to be exhaustive (a task far beyond the capabilities of one person), but to establish a reasonable and plausible starting point for wider deliberation: Once upon a time…

8.4 Building a data frame

Aquatic macrophytes—large plants that are free-floating, completely submerged, or partly emergent—exert important influences in coastal wetlands. They create and modify habitat in nearshore areas, setting up 'microclimates' (i.e. vertical and horizontal gradients in water temperature, dissolved oxygen, light penetration) that affect the distribution of other organisms (Lodge et al. 1988). Using the designation loosely, macrophytes function as "autogenic engineers" that modulate resource flows by dint of their physical structures (Jones, Lawton, and Shachak 1994). Indeed, macrophytes are important components of littoral zones; when present, they mediate many sorts of interactions (Table 8–4).

Most submersed surfaces are overgrown by periphyton, attached algae and fungae that may remove soluble nutrients to the detriment of phytoplankton growth. Scheffer and Jeppesen (1998) also refer to the enhanced potential for 'top-down' control of algae by large zooplankton (especially cladoceran grazers, the water fleas) that seek refuge in vegetation during the day. Grazing pressure on the part of mussel populations can also be significant, especially in Lake Erie. Quagga and zebra mussels (i.e. *Dreissena bugensis* and *Dreissena polymorpha*, respectively) are found in considerable numbers on coarse substrate and mud in the eastern basin, including the outer bay (Graham and others 1996); these species suppress phytoplankton production, especially in nearshore areas where they can filter the entire water column. Petrie (1998) reported the distribution and abundance of zebra mussels in Long Point Bay for the period 1991–1995. A marked decline in mussel density since 1991 may be due to predation by increased numbers of waterfowl on the bay(especially Scaup spp. and Buffleheads).

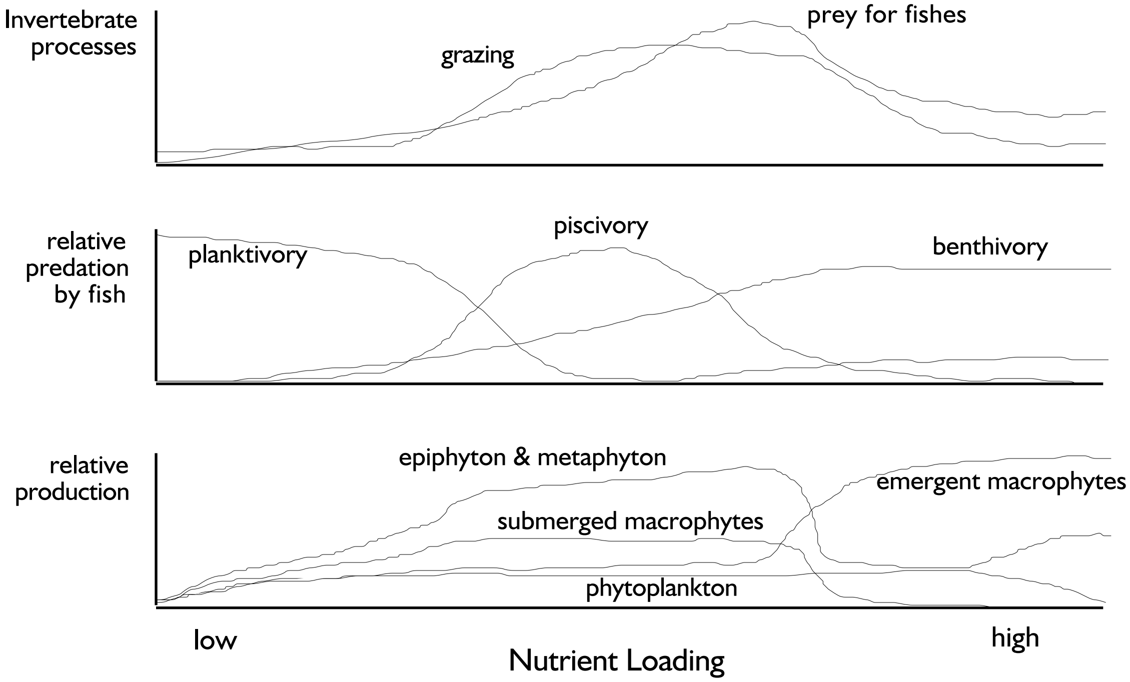
Table 8–4
Important influences of macrophytes in shallow lakes (*Source*: Barko and James 1998)

Nutrient supply	✔ root uptake, decomposition ✔ can enhance P mobilization from sediment (through daily and seasonal changes in pH, oxygen)
Thermal gradients	✔ establish horizontal and vertical gradients ✔ give rise to horizontal water movement (e.g. littoral-pelagic exchanges)
Sedimentation dynamics	✔ inhibit erosion and/or promote accretion by reducing turbulence and dampening wave action
Water quality	✔ suppress phytoplankton growth (compete for nutrients; shading; refuge for zooplankton) ✔ reduce turbidity—vegetation-turbidity interaction may be a positive feedback effect

Carpenter, van Donk, and Wetzel (1998) discuss trends in nutrient loading in shallow temperate lakes with respect to biological processes. Figure 8–4 illustrates the relative magnitude of some of these processes, and suggests that the relative contribution of phytoplankton is quite modest in wetlands—epiphyton and macrophytes tend to dominate. Søndergaard and Moss also state that "strong antagonistic forces exist between macrophytes and phytoplankton and that the presence of macrophytes generally is tantamount to low phytoplankton biomass in freshwater lakes" (1998, 120). Figure 8–4 suggests that different processes dominate as the nutrient load varies.

The role of macrophytes in modifying predator–prey interactions is not well understood. Indirect and mutual effects are probably more common then hitherto realized. Lodge and others (1988) suggested that important interhabitat links are mediated by food web interactions (Figure 8–5). They noted that linkages such as nutrient cycling, changes in nutrient ratios, predator–prey relations, and detritus transport have been little studied in littoral zones. Epiphyte productivity tends to be relatively high, and a portion of this is harvested by herbivores such a snails and insects and ultimately transported to the pelagic food web by fish. Crowder, McCollum, and Martin (1998) declared that intermediate densities of macrophytes enhance the growth rates of littoral fishes. Vegetated areas harbor more prey, but high densities adversely affect predator efficiency. The authors also proposed a generalized food web for submerged macrophyte systems (Figure 8–6).

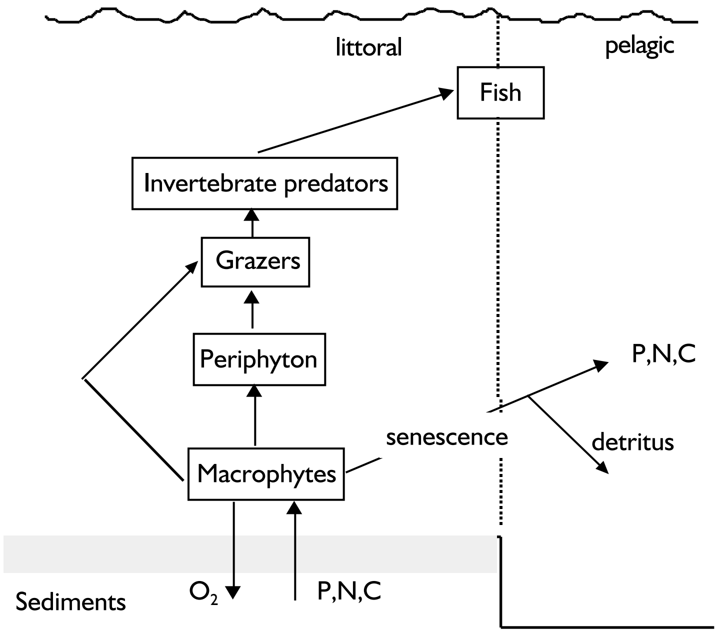
Figure 8–4
Some general trends in shallow lakes (*Source*: Carpenter, van Donk, and Wetzel 1998)



Many freshwater fish species use vegetation for cover, spawning, feeding, and as nursery sites. Vegetated areas offer both refuge and resources. Size plays a prominent role in habitat use (with respect to foraging and predator avoidance) and in interactions among fish species (or even within species—adult largemouth bass are not averse to eating their young). Most fish populations are size–structured in that habitat preference and prey vary with life stage. Shifts from zooplanktivory to benthivory to piscivory according to size class are not uncommon. Persson and Crowder

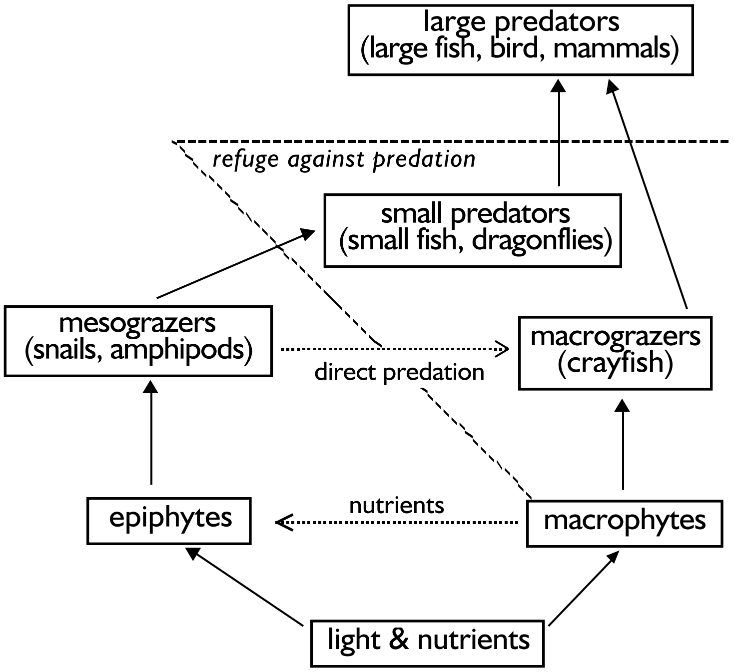
(1998) hypothesize that such substantial ontogenetic niche shifts may exact trade-off costs in piscivores who must compete with planktivores, particularly in highly productive systems—a competitive 'bottleneck' effect can arise to prevent the recruitment of juveniles to piscivorous adult stages. They further note that a shift in species dominating the fish community can occur along the productivity gradient. For instance, percids that dominate in moderately productive waters have been observed to give way to planktivorous/benthivorous cyprinids under highly productive conditions.

Figure 8–5
Biological and biogeochemical links (*Source*: Lodge et al. 1988, 191)



Whillans (1985) studied the nearshore fish community at Long Point for a number of years around 1980. He did not detect any species-level patterns in habitat occupation, but did cite evidence for community-level shifts with respect to back water and open water taxa. In a proposed heuristic model of succession, these two groups exhibit a differential delayed response to vegetation changes wrought by fluctuating water levels (that may be enhanced by dyking or sedimentation). For example, open water taxa are favored as the density of submerged and floating macrophytes increase due to a long-term (i.e. 3-5yrs) water level increase. But the response may vary depending upon the degree of marsh exposure.

Figure 8–6
A typical food web for submerged macrophyte systems (*Source*: Crowder, McCollum, and Martin 1998, 243)



Density–dependent effects reduce the likelihood of uniformly positive or negative influences. For example, Diehl and Kornijow (1998) suggest that fish that search visually (like largemouth bass) will profit by feeding on macroinvertebrates associated with macrophytes (i.e. those that are epiphytic), but be hindered in dense vegetation. It is speculated that changes in vegetation density will alter feedback mechanisms.

The general impression one gets—and the foregoing discussion reflects this—is that there are many unknowns when it comes to understanding nearshore ecotones. The rich dynamics of littoral zones continue to baffle us. Researchers regularly intone the need to examine *X* more fully, where *X* can be almost any sort of biological, chemical, or hydrological interaction. So what can we make of all this? The proposed data frame appears as Figure 8–7; it incorporates some of the results outlined above and attempts to synthesize insights from the literature. The data frame is best looked upon as an organizing device and as a sort of 'hypothesis generator' to guide more detailed investigations—it serves its purpose to the extent that it is both evocative and provocative. A sample indicator list (Table 8–5) and a partial data exchange map (Figure 8–8) complement the data frame.

As a further aid to understanding, the nearshore ecotone is conceived at the bay level in terms of three gradients: nutrient loading (productivity regime), seasonal temperature regime, and depth (Figure 8–9). This 'metamodel' can be used to conceptualize or model systemic transformations influenced by interacting gradients (I know—maybe I'm just throwing a bone to the hard-core modelers, here!). The large arrows in the figure are intended to suggest how modelers usually restrict themselves to transformations along a single gradient—investigations that span multiple gradients are vastly more difficult to undertake. Müller (1998) has argued that the formation and degradation of ecological gradients are fundamental aspects of ecosystem development, and he suggested that the study of gradients can contribute to theoretical integration.

The sense-making portfolio summarized here is a preliminary attempt at describing a set of boundary objects that can potentially draw together the different groups involved in monitoring work around Long Point. Many of the ideas it encapsulates have yet to receive sustained scrutiny from participants in the initiative, as the design process has barely moved beyond articulating issues and posing monitoring questions. The portfolio does hold promise for providing a basis for engaging in sense-making and developing what may eventually amount to a distributed environmental information network[1]. It is fully expected that a wider review will engender significant revisions—perhaps even an overhaul. As Star (1989) noted, the construction of a boundary object is, after all, a community process.

Presenting a terse and tidy conclusion is traditional at this point (yes, Dear Reader, the end is nigh), but I am loathe to offer one: this is very much an unfinished story. In its stead I present a status report.

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[1] The portfolio itself could be exchanged as an XML document. XML, the Extensible Markup Language, is a sibling to the HTML in which most web documents are written, but XML is much more flexible (it supports custom data models, document type definitions, tags, etc.); it is being more widely used in metadata applications. See <http://www.w3.org/XML/> for more information.

Figure 8–7
A data frame for the sport fishery of Long Point Bay

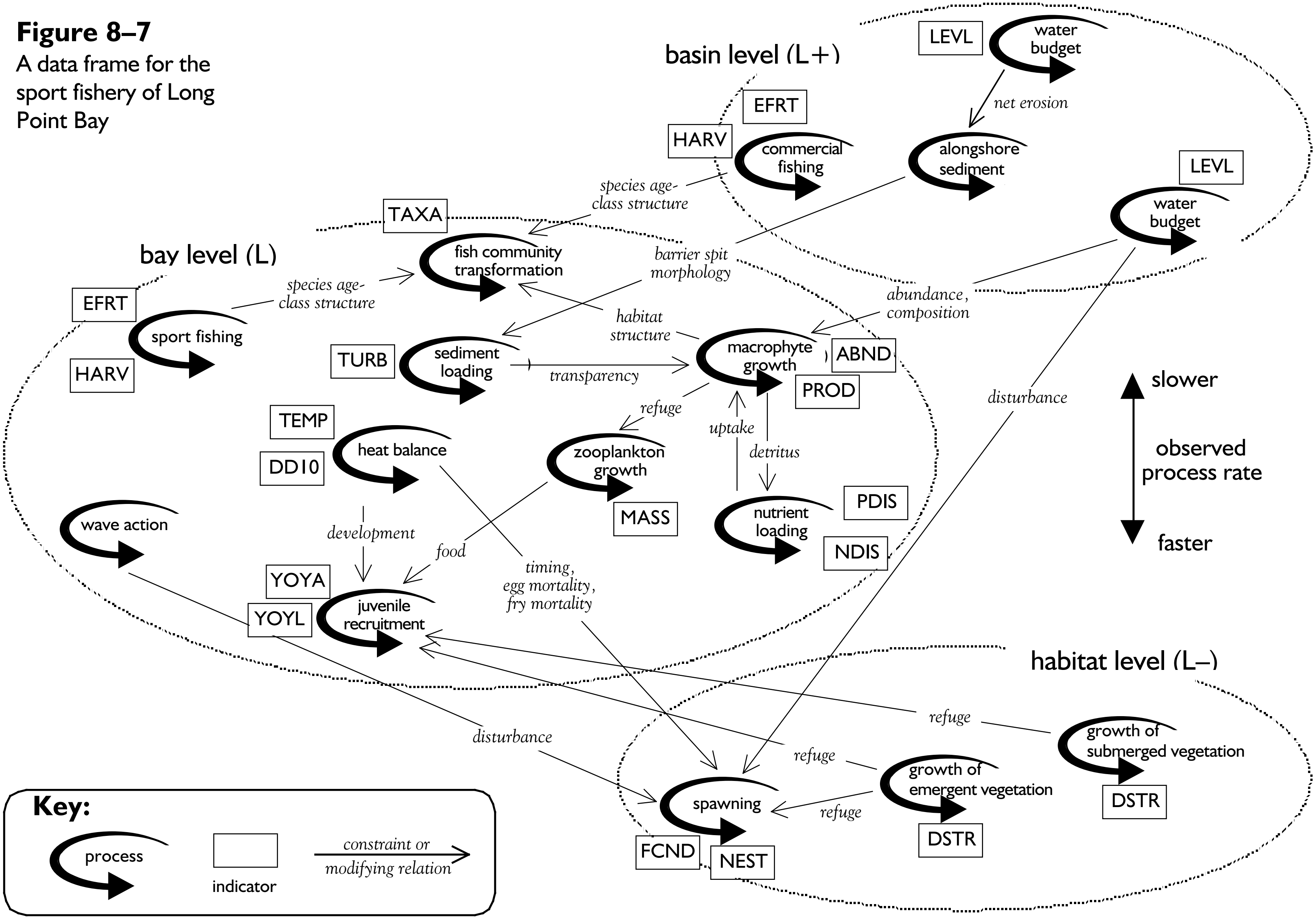


Table 8–5: Sample listing of potential indicators

Level	Process / Activity	Indicator	Frequency (temporal grain)	Tier	Code
Basin (L+)	Water budget	water height above datum	decade	I	LEVL
			month	I	
	Commercial fishing	total effort	season	I	EFRT
		total landings	season	I	HARV
	Alongshore sediment transport				
Bay (L)	Fish community transformation	Relative taxonomic composition	decade	II	TAXA
	Sport fishing	total effort (rod-hours, by species)	season	I	EFRT
		total harvest (number, by species)	season	I	HARV
	Sediment loading	Turbidity	season	I	TURB
	Macrophyte growth	Relative abundance (area)	season	II	ABND
		Productivity	season	III	PROD
	Heat balance	Mean surface water temperature	month	I	TEMP
		Degree-days exceeding 10C	season	I	DD10
	Zooplankton growth	Total biomass (by size category)	season	II	MASS
	Nutrient loading	Concentration of dissolved phosphorus	month	I	PDIS
		Concentration of dissolved nitrogen	month	I	NDIS

Table 8–5 continued: Sample listing of potential indicators

Level	Process / Activity	Indicator	Frequency (temporal grain)	Tier	Code
Bay (L)	Nutrient loading	Concentration of dissolved phosphorus	month	I	PDIS
		Concentration of dissolved nitrogen	month	I	NDIS
	Wave action (during spawning)		week	III	
	Juvenile recruitment	Relative abundance of young-of-the-year	season	II	YOYA
		Mean length of young-of-the-year	season	II	YOYL
Habitat (L–)	Spawning	Nest density	season	II	NEST
		Fecundity	season	II	FCND
	Growth of emergent vegetation	Distribution (area)	season	II	DSTR
	Growth of submerged vegetation	Distribution (area)	season	II	DSTR

Figure 8–8

A data exchange map

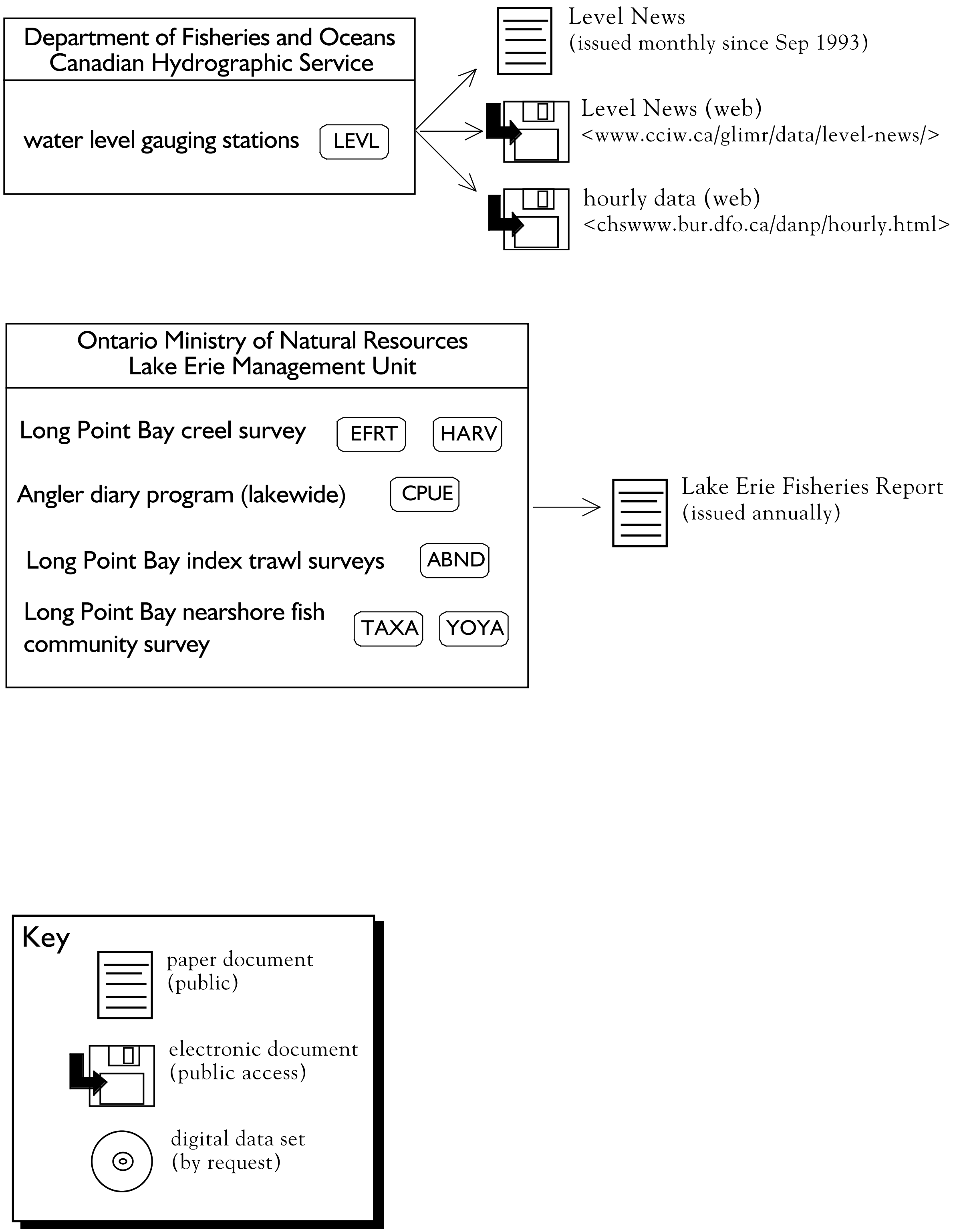
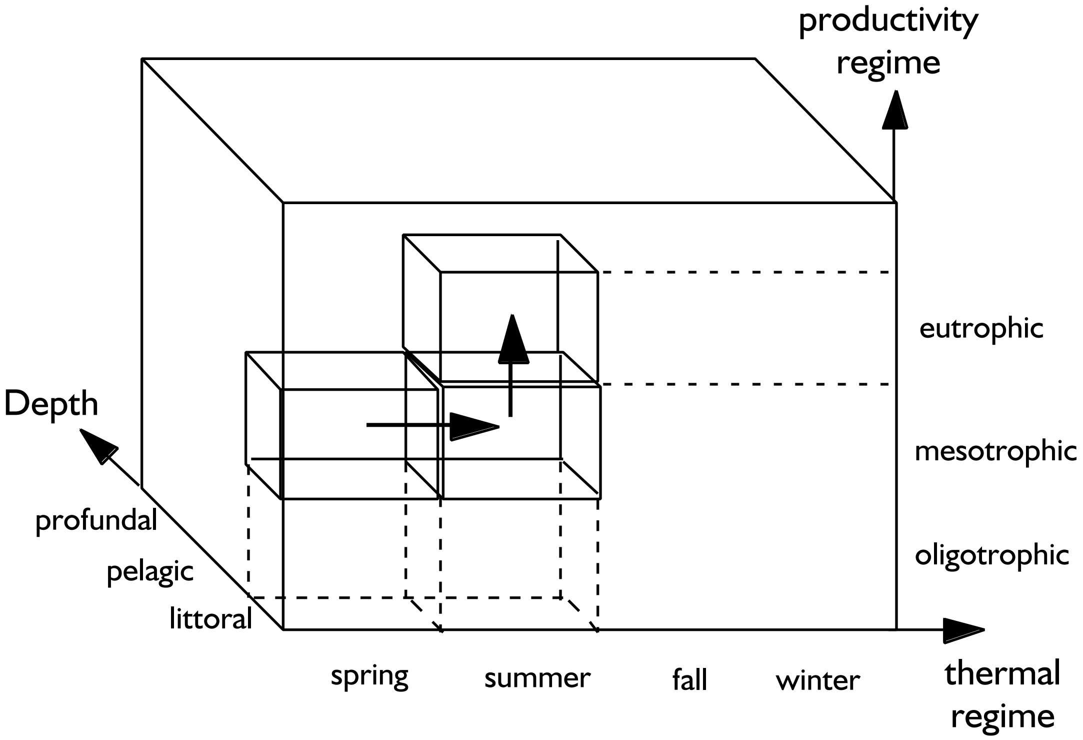


Figure 8–9
Gradients of the nearshore ecotone



8.5 A status report

While tidy endings are commonplace in folk tales, research conducted beyond the rarefied confines of a laboratory frequently does not admit neat summaries; furthermore, the contingencies of design can frustrate attempts to package neat solutions. And to top it off, community initiatives tend to proceed by fits and starts (sometimes the former seem to predominate!), so progress is often halting. My experiences during this study highlighted the contingent character of 'naturalistic' inquiry. I presented nothing so condensed as a 'method' for integrated monitoring: the outlines of an approach, yes—even some guiding principles are put forth here—but no stark recipe. Indeed, I have kicked open more doors than I've closed while strolling through the conceptual edifice of environmental monitoring. I've inspected the foundations, peered into a few closets, poked into nooks and crannies, and generally stirred up a lot of dust. In lieu of a polished capstone I offer a status report.

If instrumental rationality cleaves to procedures that are "clean, calculating, and homogenizing" (Dryzek 1993, 213), then it may be ill suited to situations that are messy, scrappy, and heterogeneous. Integrated monitoring initiatives are sustained by a complex melange of scientific, social, and political issues that call for two types of work: technical work across scales and adaptive work across perspectives. Trying to do both under the rubric of participatory or cooperative design can be a scrappy affair that resists easy prescription. The conventional outlook that sees monitoring initiatives as being exclusively scientific affairs aimed at providing support for managerial decision-making is poorly disposed to deal with ambiguous and confusing situations. It's hard to find answers when you're not sure what the questions are.

Biosphere reserves reflect fairly unusual circumstances: they display a diversity of local concerns and voluntary arrangements that do not fit easily within management plans bent toward making decisions that are scientifically and legally defensible. And the marginalization of lay perspectives as experts pursue disciplinary rigor makes for a situation not entirely in keeping with the spirit of the biosphere reserve concept. I have argued that an alternative design approach that reaches beyond scientists and resource managers is better suited to the heterogeneity of actors and issues found within biosphere reserves.

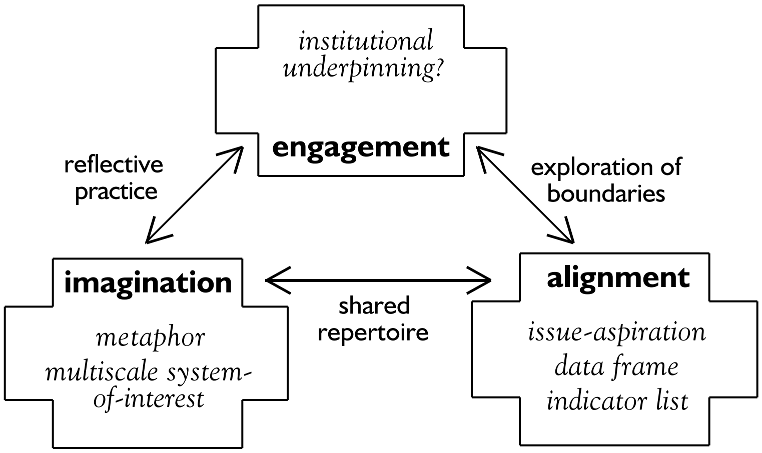
What sort of approach is called for? First off, I argue against what might be labeled 'mulligan-stew' monitoring: an approach that consists of tossing favored indicators into a pot, stirring them up, and then ladling out the concoction with a geographic information system in the hope that a nourishing meal will result. Unfortunately, unless close attention is paid to how data are interpreted and combined, the erstwhile analyst is likely to end up with thin gruel indeed. Secondly, soft systems thinking with its emphasis on appreciation and learning is more agreeable to the tenets of sense-making. And thirdly, explicit attention must be paid to managing the tension between heterogeneity and cohesion within a community of practice in order to ensure that learning continues and understanding does not lapse into a recitation of stale nostrums. Indeed, there are a number of vital tensions that must be managed in order to invigorate a well-tempered process of inquiry that maintains a lively balance between processes of participation and reification:

- learning vs. performance
- participation vs. reification
- change vs. continuity
- heterogeneity vs. cooperation
- instrumental heuristics (e.g. efficiency) vs. value heuristics (e.g. participation)

Many of the interview participants admitted that some form of integration would be desirable, but difficult to undertake without sufficient resources or a means of coordination. Clearly, a 'cadillac' framework is beyond reach. A sense-making portfolio represents a possible (dare I say practical?) means of encouraging local involvement and broader cooperation among monitoring groups; it provides a set of boundary objects that mediate between groups possessing different interests, knowledge, and viewpoints. The basic aim is to facilitate learning. How likely is this? Figure 8–10 compares the sense-making portfolio—at least in prospect—against Wenger's (see Figure 6–5) three infrastructures of learning.

Facilities for exercising imagination and securing alignment are present, but facilities for engagement seem to be the weakest link. The prospects for engagement are unclear, mainly because the sense-making concept, like integrated monitoring itself, currently lacks an institutional basis in the region. It's difficult to foresee what may arise to fill this gap, although it's possible to speculate. Regional municipalities in Ontario are now required to undertake general health surveys, broadly construed to include environmental factors; such studies may give rise to cooperative data collection and reporting. Or perhaps the efforts of the recently formed Canadian Biosphere Reserve Association (CBRA) may help to spur the creation of a coordinating apparatus. However if excessive coordination "tends to turn people off" as one interview participant suggested, then overly elaborate procedures should be avoided.

Figure 8–10
Comparison with Wenger's infrastructures of learning



Does what I have laid out amount to a full-blown *method* for undertaking sense-making? Not really. Some of the important characteristics of the approach are presented in Box 8–2. These basic premises depart from the usual technocratic imperatives to apply structured methods in pursuit of 'solutions' to pre-defined problems; they try to deflate the overweening expectations that are built into most managerial initiatives. Ambiguity, surprise, and complexity are viewed as opportunities for learning rather than as hindrances to efficient performance.

Design is an activity that resists prescription; it unfolds rather than unwinds. Bucciarelli (1994) is hard pressed to articulate a 'science' of design, even as it is practiced by engineers:

> Contemporary design is, in most instances, a complex affair in which participants with different responsibilities and interests—that is, working within different object worlds—must bring their stories into coherence. This is no simple synthesis achieved according to some straight-

> forward instrumental technique, as much as that might be desired by professors of management or engineering design, or even by the participants themselves. Object worlds are not congruent. Interests conflict, trade-offs must be made among different domains, and negotiation is necessary. Design is a social process as much as it is getting things right within object worlds. (Bucciarelli 1994, 83)

Box 8–2
Basic premises of monitoring in support of sense-making

- does not ignore the social context of information use—integrated monitoring has both technical and social dimensions
- shuns an ethos of "silicon positivism" that only considers datalogical and hardware aspects of information use
- aims to contribute to a well-tempered process of deliberation that attends to both participation and reification
- recognizes the need to coordinate perspectives and establish coherence among participants—this is the 'soft underbelly' of integrated monitoring
- pays close attention to 'boundary objects' that congeal understanding and provide centers of coordination (i.e. rallying points or 'condensation nuclei')
- uses a sense-making portfolio to structure discussion and debate
- is partial to a constructivist outlook that takes process as prime
- recognizes that ecosystems are not easily mapped, and is mindful of the shortcomings of exact-object models

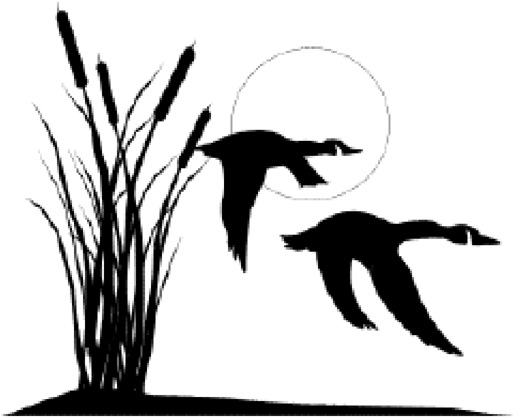
Remaining bereft of standard operating procedures should occasion no great alarm, however. It is possible to distill a number of guiding principles that inform the design of an ecosystem approach to monitoring in support of sense-making (Box 8–3); taken together they stand in contrast to traditional frameworks dedicated exclusively to the support of decision-making. There are methodological implications in recognizing that there are technical and social dimensions to how people use—or fail to use—environmental information. But instead of grafting social considerations onto a technically-conceived method in order to incorporate a 'user' perspective, I prefer to embed technical elements within a broader social (i.e. soft-systems) framework; such an approach makes room for sense-making and does not run roughshod over activities that support the development of an infrastructure for learning.

The ecosystem approach advocated here is unabashedly local, given that the dynamics (biophysical and social) in a biosphere reserve are likely to be quite idiosyncratic. So what can be generalized to other settings? The spirit of an approach that emphasizes local participation and favors learning over precise prediction, one that is not given to overly heroic assumptions or expectations. Admittedly, such an approach is unlikely to find a genial home within the average bureaucracy—the flexibility and openness it requires is anathema to a managerial mindset (the relatively free-wheeling style makes most managers nervous).

Box 8–3
Guiding design principles

- see design as a social process of communication, learning, and negotiation—not mere instrumental problem-solving
- cast the designer as animateur, not master architect
- pursue a dialogic mode of inquiry rather than a decisionist one
- emphasize working toward community aspirations, not pre-defined and measurable goal-states
- do not become strongly attached to fixed timetables or other scripting aids—let design activity unfold "on the fly"
- recognize that boundary objects must be continually reshaped and realigned—design is ongoing and evolutionary
- take advantage of metaphors to reframe a situation or to explore alternative perspectives
- heed those dimensions of practice that promote—or threaten to dissolve—coherence among participants

If learning is a process of social reconfiguration (Wenger 1998), then perhaps the approach is best directed at the supraorganizational level where diverse communities of practice intersect. Here, we have to settle for not so much "getting it right" as not getting it irretrievably wrong.



Appendixes

The material presented in this appendix describes a long-standing problem in spatial analysis: the 'modifiable areal unit problem' (MAUP). Some implications for ecological applications of geographic information systems are discussed, and the pitfalls of applying exact object models to vague ecological objects are also pointed out.

A.1 Modifiable areal units

Inferring relations between spatial units poses some difficulties if the units are 'modifiable', or arbitrarily bounded in space. Using data grouped according to a contiguity constraint (i.e. where grouped units are neighbors) in order to discern associations between individual entities is a common practice, especially with socioeconomic data. For example, some of the problems that arise when using census data to infer the behaviors of households have been known for decades. More generally, the application of regression techniques to spatial aggregates suggest that the magnitudes of the correlations obtained depend upon the areal unit chosen if that unit is modifiable. Yule and Kendall (1965) illustrated this by considering the yields of wheat and potatoes in 48 counties in England for 1936. The correlations were sensitive to the properties of the 'unit mesh' imposed on the system—the results were sensitive to how the map was partitioned into zones. So the definition of geographic objects cannot be taken too lightly.

Openshaw and Taylor (1979) looked at Iowa census data and analyzed voting behavior as a function of the proportion of the population over 60 years of age; they observed that at all scales of analysis a wide range of correlations could be obtained as either the level of aggregation or the partitioning scheme was varied. The arbitrary nature of county and district boundaries proved to be problematic: "If all researchers in a field of geographical enquiry agree on their objects of interest, and these objects can be defined in a non-arbitrary manner, then this constitutes a unique set of units and the problem disappears" (1979, 143). Unfortunately, a 'unique' set of units can be hard to come by in *any* field of research.

Openshaw (1983) has provided a systematic account of what is commonly known as the *modifiable areal unit problem* (MAUP).

The heart of the problem concerns the inappropriate extension of results based on aggregate zonal data to individual zones that are not completely homogeneous—the so-called ‘ecological fallacy’. Oppenshaw distinguished two sub–problems:

- the *scale problem*, where the results vary as areal units are progressively clumped into fewer and larger units
- the *aggregation problem*, where the results vary due to the use of different partitions (with the number of units remaining constant)

The upshot is that apparent regularities are zone-dependent. According to Openshaw: “The MAUP exists because of uncertainty as to what are the spatial entities which are being studied” (1983, 33). While completely homogeneous data do not display any zone-dependency, real data are almost never so structureless.

On the face of it, an increase in the correlation coefficient as the level of data aggregation increases is not hard to understand. The aggregation process essentially performs a smoothing operation. The correlation coefficient r_{XY} between two variables is given by (Fotheringham and Wong 1991)

$$r_{XY} = \text{cov}\,[X,Y] \,/\, S_X S_Y\,,$$

where cov [X,Y] is the covariance of x and y, and S_X denotes the standard deviation of x (likewise for S_Y). It’s clear that r_{XY} increases as S_X and S_Y decrease.

Fotheringham and Wong investigated the MAUP in the context of multivariate analysis, and alluded to the paucity of theoretical work in this area. They concluded that the effects of scale and zoning definition remain difficult, if not impossible, to predict. Using block group data from the Buffalo Metropolitan Area (1980 census), parameter estimates for two models were shown to vary with aggregation level; different zoning systems at a given aggregation level varied in a similar manner. Sounding a warning note, the authors concluded: “Calibration results from one set of areal units are highly suspect and should not be relied upon to draw any substantive conclusions about the underlying relationships being examined” (1991, 1042).

Another area in which the MAUP has received some attention is thematic cartography. The basic notion is this: there is no 'natural' way to represent a given facet of a population. Dorling (1995) explored visualization problems in the field of human geography, and the construction of cartograms in particular. A cartogram is a map deliberately exaggerated to better represent some chosen aspect of the object or phenomenon under investigation. The ordinary topographic base map can be considered an equal land area cartogram, but one may also choose to work with an equal population area cartogram if, say, an easily interpreted display of population distribution is of interest.

How the characteristics are displayed on a cartogram depends on how many areal units are used, and on the final size of each unit. These circumstances reflect the issues of scale and zoning that are intrinsic to the MAUP. The recognition of modifiable units might be seen to confer license to address a range of communication or analytical needs for which the traditional base map may not be very useful.

Choropleth mapping further aggregates data by introducing a classification scheme that groups a range of data into a single category. Monmonier (1991) describes many of the issues raised by classification. For example, different schemes for breaking classes (e.g. equal-interval classes and quantile classes) produce different maps. Which offers a better representation? "Hastily selected or deliberately manipulated categories can diminish the visual similarity of two essentially identical trends or force an apparent similarity between two very different patterns" (Monmonier 1991, 135). The rule of thumb that emerges here is that 'one-map solutions' should be regarded with considerable skepticism—a single map is never sufficient to convey the effects of aggregation and classification.

The MAUP was first recognized in working with socioeconomic data sets, and it has merited the closest attention from analysts using such data. But one should resist the inclination to suppose that it is only with census data that care must be exercised. Social or administrative boundaries are human constructs, so any interpretation predicated on these eminently modifiable units can be lead astray. Goodchild (1996) cautions that there are no simple techniques to determine if a spurious inference is in the offing when aggregating heterogeneous spatial data; he goes on to suggest two coping strategies:

- analyze and display data only at the lowest level of aggregation; or
- explore and report zone effects by reaggregating and reanalyzing the data.

Very few investigators have gone to such lengths. Sensitivity analysis—an exploration of the relationship between assumptions and conclusions—does not appear to figure prominently in most GIS projects. Ignoring the implications of modifiable units seems to be the default behavior. In particular, the literature about ecological applications of GIS can be rather cursory when it comes to boundary definitions and the ramifications for certain types of analysis. Given the 'soft' nature of social data, perhaps there is a feeling that 'hard' measurements of biophysical reality are immune to the effects of human constructions. However, even ecological boundaries can be notoriously difficult to distinguish, and complications arise when the phenomena of interest include processes that are not easily described in terms of fixed spatial units.

A.2 Some implications for ecological applications of geographic information systems

Ecological phenomena span a vast range of spatial scales. Hierarchy theory has been widely favored as a framework for considering scale translations. King (1991) discusses several analytical methods for accomplishing this in the context of simulation modeling; these methods are most appropriate when there are no strong influences between sites (i.e. point data are independent), and scale-dependent phenomena do not intrude into the area of interest. King starts by characterizing a landscape as a *nested hierarchy* , where levels of organization are ordered in terms of space (areal extent) and time (frequency of behavior). The problem of scaling up information is posed this way: "The challenges of scaling up landscape information lie in (1) correctly defining the spatial (and temporal) heterogeneity of the fine-scale information, and (2) correctly integrating or aggregating this heterogeneity" (King 1991, 481).

Four methods are described by King and demonstrated using computational examples:

- *lumping* is one of the simplest methods, where averages of model arguments are used to represent larger scales (but this only works if the system equations are linear and system properties are scale-invariant)
- *direct extrapolation* may be performed to increase the areal extent of a model—model structure is unaltered, and there is no averaging of data
- *extrapolation by expected value* involves taking the arguments of a local model to be spatially distributed random variables (the estimation of probability distributions is chief source of error here)
- *explicit integration* assumes that heterogeneity can be described by some explicit function of space (but rarely applicable to natural systems)

De Cola (1994) presents a formal approach to mapping spatial data that are conceived as an abstract 'field': a space-filling function whose value varies with position on the Euclidean plane. Measurement consists of sampling a plane, where a given data set represents a set of observations made at a particular resolution level. Thus a data set $f(A)$ should properly be labeled with a scale index λ, and multiscale analysis then amounts to investigating the behavior of $f(A_\lambda)$. De Cola goes on to suggest that the operations of measurement and aggregation may not commute. For example, aggregating measurements from a sensor with a resolution of 10m may yield a pattern distinct from that obtained by separate measurements using a sensor with a 20m resolution. However, De Cola merely raised this issue and did not pursue it further. Figure A–1 depicts the situation.

Figure A–1 Commutivity diagram for aggregation and measurement operations (*Source*: De Cola 1994, Fig. 2)

$$\begin{tikzcd}
A_{\lambda+1} \arrow[r] & f(A_{\lambda+1}) \overset{?}{=} (f(A_\lambda))_{\lambda+1} \\
A_\lambda \arrow[u, "\text{aggregation}"] \arrow[r, "\text{measurement}"'] & f(A_\lambda) \arrow[u]
\end{tikzcd}$$

It would be an interesting exercise to show under what conditions commutivity holds (another thesis topic, alas). There is the trivial case of a perfectly homogeneous observation set, but how far can one stray from ideality before Figure A–1 does not commute?

Other researchers have not been reluctant to assert the non-commutivity of measurement and aggregation operations. For instance, Fox (1992) is explicit about the scale-specific character of environmental information, adding that it is usually necessary to use multiple scales to adequately describe any environmental phenomenon.

How has the integration of multiscaled data sets worked in practice? Results from the FIFE (First ISLSCP Field Experiment) project are illuminating. The project was conceived as a multiscale experiment to investigate surface-atmosphere fluxes on a 15x15km grassland site in Kansas (Sellers and others 1992). Satellite, meteorological, biophysical, and hydrological data were simultaneously acquired in a series of field campaigns conducted between 1987 and 1989 on scales ranging from 1m to 1km resolutions.

The integrative science group sought to link biophysical parameters and landscape characteristics. Energy balance models and remote sensing algorithms that had been developed and validated at small scales (1m-30m) were then used to estimate surface fluxes (heat, moisture, CO_2) at intermediate scales from 100m to 15km (Hall and others 1992). Scale invariance hinged on the absence of nonlinearities in the models and/or their parameters. While vegetation index–transpiration relationships were ‘nearlinear’, scale–dependent errors precluded the use of thermal infrared data to calculate sensible heat fluxes. In a summary article Sellers and Hall (1992) questioned whether the perceived scale-invariant relationships apply only to temperate grasslands. They concluded that the prospects for applying the methods to other landscapes—especially those with more extreme topographies—are unclear, and called for more comprehensive research into these matters.

Wessman (1992) reviewed other attempts to extrapolate from local to regional scales using remote sensing and simulation models. Spatial heterogeneity (i.e. the existence of spatial autocorrelation, or ‘patchy’ landscapes) apparently impairs the ability to translate upscale. As with the FIFE data, nonlinearities are the major complication. The trick is to be able to identify process nonlinearities that crop up as the scale is changed. Wessman points to geographic information systems as being useful for combining disparate types of information. In a similar vein, Cowan and others (1996) declare that map coordinates represent a natural basis for relating environmental data sets to each other, and envision the development of multimedia, computer-based systems as powerful decision-support tools.

Wiens (1989) outlined several approaches that have been applied to defining so-called domains of scale within which patterns are either constant or only vary monotonically with scale changes. For point samples methods of spatial autocorrelation, spectral analysis, or dimensional analysis are sensitive to the grain and extent of the data set. Alternatively, fractal methods may be applied if one supposes that a change in the fractal dimension of a pattern indicates that different processes or constraints have come to the fore. For most methods the underlying notion is that transitions between scale domains are marked by instabilities or chaotic dynamics.

One can view the MAUP as an argument supporting the design of temporal GIS in ecological applications. If GIS is to become institutionalized in environmental management, then tracking change over time becomes crucial. It's not clear how this might work, although it is a topic of current interest to database researchers. A fairly recent monograph (Langran 1992) offered an extensive review of the pertinent literature and reported on some initial explorations of various partitioning strategies. The use of irregular partitions or regular, offset partitions seemed to be the most promising approaches; these early results seem to indicate that hierarchical organization conceived as a partition (i.e. perfectly nested) imposes some severe limitations in interpreting multidimensional data.

Schneider (1997) has pointed out that most applications of spatial database systems adopt an *exact object model* that assumes boundaries are precisely defined and can be universally recognized. Furthermore, the properties of spatial 'objects' are assumed to be uniform over their entire extent. Unfortunately, *vague spatial objects* are not currently supported in commercial geographic information systems.

> The assumption of crisp boundaries harmonizes very well with the internal representation and processing of spatial objects in a computer which requires precise and unique internal structures. Hence, in the past, there has been a

> tendency to force reality into determinate objects. (Schneider 1997, 241)

Unfortunately, research on spatiotemporal data types is only in the very early stages. According to Burrough and Frank (1995), commercial implementations of geographic information systems are best suited for dealing with anthropogenic entities such as land parcels and administrative districts: “The information systems have been designed to meet a limited paradigm in which real world phenomena can be approximated by exact geographical data types which are termed ‘objects’ or by smooth, continuous ‘fields’ ” (1995, 105). They admit the difficulties of combining data acquired using dissimilar ‘paradigms’, and consider the blanket adoption of object-field models to be “procrustean”.

Consider this brief appendix as an argument against thoughtlessly using geographic information systems to integrate environmental data. It urges GIS users to exercise caution when combining disparate, multiscale environmental data sets. Modeling vaguely defined spatial objects is far from trivial; preliminary attempts by researchers using fuzzy set theory or probability theory make this abundantly clear[1]. The ‘canned’ analyses performed by the current crop of commercial geographic information systems—with their proprietary algorithms—hide much from the user. The scale-dependent nature of environmental data can easily lead unwary analysts astray while a GIS beguiles them with spiffing digital maps.

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[1] A collection of essays on the topic can be found in the volume edited by H. Couclelis, *Geographic Objects with Indeterminate Boundaries* (1996). A series of papers that examine various statistical aspects of the MAUP appeared in the journal *Geographical Systems*, vol. 3 (1996).

Information sheet

Prospects for ecosystem monitoring at Long Point

What is the aim of the study?

The aim of the interview portion of the study is to learn about what sorts of monitoring activities are taking place around Long Point, and how they are influenced by the biosphere reserve designation. It is hoped that a better understanding of the technical and institutional demands of monitoring work can contribute towards the development of a framework for ecosystem monitoring.

How was I chosen?

I will be interviewing about ten people possessing current or recent experience with environmental monitoring in the Haldiman-Norfolk region. Some of the people were selected from a contact list included in a recent compilation of monitoring programs in the region (prepared by Christine Poff in May 1996 for the Long Point World Biosphere Reserve Foundation); other names were suggested by persons on this list.

What will be involved in participating?

I will schedule one or more interviews with you to take place at a time and location of mutual convenience. The interviews will last no more than 45-60 minutes (it is unlikely that more than one interview will be required). With your permission, I will audiotape the interview(s) and have transcripts prepared from the tapes. The questions will focus on your personal experiences with monitoring work around Long Point: tasks, responsibilities, interactions with other organizations, and so on.

Who will know what I say?

Only the following individuals will have access to your tapes and transcripts: Richard Martell (student investigator and interviewer), a Masters student at the University of Waterloo; Prof. James Kay (faculty supervisor) of the Department of Environment and Resource Studies; and possibly a professional transcriptionist.

What risks and benefits are associated with participation?

The possible breach of confidentiality is a potential risk. To protect against this, all tapes and transcripts are maintained securely in the possession of the student investigator; access is limited to this individual and his faculty supervisor. Your name will not appear in the transcript. The tapes will be destroyed two years after the study concludes.

Sometimes people find an interview beneficial in giving them an opportunity to talk about their experiences and expectations. Also, your contribution may help to show how a framework for ecosystem monitoring can accommodate local concerns and circumstances.

What are my rights as a participant?

You may withdraw from the study at any time. Your participation is voluntary. You may decline to answer any question(s), or halt the interview at any time.

Where can I get more information about this study?

This study has been approved by the Office of Human Research and Animal Care (OHRAC) at the University of Waterloo. If you have any concerns or questions about your involvement, please contact the office (519–888–4567, ext. 6005). Richard Martell, the student investigator, can be reached at (519) 886-4683 (email: rjmartel@fes.uwaterloo.ca). Prof. James Kay, the faculty supervisor, may be contacted at (519) 888-4567, ext. 3065.

Interview guide

Thank you for agreeing to participate in this interview. First I'd like to assure you that this is completely confidential—no records of the interview will have your name on them. A transcript will be prepared, and it will be made available to you if you'd like to check it over.

There are a few areas I'd like to explore, and I'd like to encourage you to provide as much detail as you can. I'm especially interested in your personal experiences with monitoring programs in the region, so examples would be particularly helpful in giving me a richer appreciation of your work.

1. How long have you been involved with monitoring programs around Long Point?

   [PROBE: purposes, tasks, responsibilities]

2. Do you interact with other groups or organizations in the course of your own work?

   [PROBE: nature and frequency of interaction]

3. Does the biosphere reserve designation influence your work?

   [PROBE: concrete examples]

4. You may be aware that over the years there has been a fair amount of monitoring undertaken by various groups and agencies in the region. Have you formed an impression of these activities?

   [PROBE: note respondent's vocabulary, underlying assumptions; clarify if necessary]

5. Can you think of any aspect of your experience with monitoring that we haven't covered?

Thanks for your time and thoughts. I'll leave you my card in case you want to get in touch with me. I'd like permission to contact you again if I need to clarify a point or two.

Consent Form

Department of Environment and Resource Studies
University of Waterloo

Prospects for ecosystem monitoring at Long Point

I agree to participate in an interview being conducted by Richard Martell of the Department of Environment and Resource Studies under the supervision of Professor James Kay. I have made this decision based on the information presented in the Information Sheet, together with additional details I sought through other sources. As a participant in this study, I realize that I will be asked to take part in an interview lasting 45-60 minutes, and that an audiotape recording will be made unless I withhold permission. In addition, I may decline to answer any of the questions, or halt the recording at any point. While I recognize that excerpts from the interview may be made part of the final thesis or report, under no circumstances will my name or identifying characteristics be included unless I have (a) read the excerpt and surrounding text, and (b) consented (by written notice) to be identified as the source. Otherwise all information which I provide must be held in confidence.

I understand that I may withdraw this consent to participate at any time by asking that the interview be stopped. I also understand that this project has been reviewed by—and received ethics approval through—the Office of Human Research and Animal Care at the University of Waterloo (tel: 519–888–4567, ext. 6005), and that I may contact this office if I have any concerns or questions about my participation in this study.

Participant's Name: ______________________________

Participant's Signature: ______________________________

Name of Witness: ______________________________

Signature of Witness: ______________________________

Date: ______________________

Ahl, V., and T.F.H. Allen. 1996. *Hierarchy Theory: A Vision, Vocabulary, and Epistemology*. New York: Columbia University Press.

Albæk, E. 1995. Between knowledge and power: Utilization of social science in public policy making. *Policy Sciences*, 28: 79–100.

Allen, T.F.H., B.L. Bandurski, and A.W. King. 1993. *The Ecosystem Approach: Theory and Ecosystem Integrity*. Report to the Great Lakes Science Advisory Board. *n.p.*: International Joint Commission.

Allen, T.F.H., and T.W. Hoekstra. 1992. *Toward a Unified Ecology*. New York: Columbia University Press.

Allen, T.F.H., and T.B. Starr. 1982. *Hierarchy: Perspectives for Ecological Complexity*. Chicago: University of Chicago Press.

Ankersen, T.T., and R. Hamann. 1996. Ecosystem management and the Everglades: A legal and institutional analysis. *Journal of Land Use & Environmental Law*, 11: 473–536. CIS/Envirofiche, 97–01086, microfiche.

Argyris, C., and D.A. Schön. 1978. *Organizational Learning: A Theory of Action Perspective*. Reading, MA: Addison-Wesley.

Ashby, W.R. 1976. *An Introduction to Cybernetics*. London: Methuen & Co Ltd, University Paperbacks. Original edition, London: Chapman & Hall Ltd, 1956.

Atmanspacher, H., and G.J. Dalenoort, ed. 1994. *Inside Versus Outside: Endo- and Exo-Concepts of Observation and Knowledge in Physics, Philosophy and Cognitive Science*. Springer Series in Synergetics, Vol. 63. Berlin: Springer-Verlag.

Bailey, R.G. 1996. *Ecosystem Geography*. New York: Springer–Verlag.

Bakkes, J.A., and J.W. van Woerden, ed. 1997. *The Future of the Global Environment: A Model-based Analysis Supporting UNEP's First Global Environment Outlook*. UNEP/DEIA/TR.97–1. Nairobi: United Nations Environment Programme; Bilthoven: Netherlands Institute of Public Health and the Environment (RIVM). Available [Online]: <http://www.geo.rivm.nl/unep.pdf> [27 August 1998].

Bannon, L., and S. Bødker. 1997. Constructing common information spaces. In *ECSCW '97: Proceedings of the Fifth European Conference on Computer Supported Cooperative Work*, ed. J.A. Hughes, W. Prinz, T. Rodden, and K. Schmidt, 81–96. Dordrecht: Kluwer Academic Publishers.

Barko, J.W., and W.F. James. 1998. Effects of submerged aquatic macrophytes on nutrient dynamics, sedimentation, and resuspension. In *The Structuring Role of Submerged Macrophytes in Lakes*, ed. E. Jeppesen, M. Søndergaard, M. Søndergaard, and K. Christoffersen, 197–214. New York: Springer-Verlag.

Barnes, B., D. Bloor, and J. Henry. 1996. *Scientific Knowledge: A Sociological Analysis*. Chicago: University of Chicago Press.

Bar–Yam, Y. 1997. *Dynamics of Complex Systems*. Reading, MA: Addison–Wesley.

Batisse, M. 1993. The silver jubilee of MAB and its revival. *Environmental Conservation*, 20(2): 107–112.

Bechtel, W., and R.C. Richardson. 1993. *Discovering Complexity: Decomposition and Localization as Strategies in Scientific Research.* Princeton: Princeton University Press.

Bell, D. 1973. *The Coming of Post-Industrial Society*. New York: Basic Books.

Berry, J., G.D. Brewer, J.C. Gordon, and D.R. Patton. 1998. Closing the gap between ecosystem management and ecosystem research. *Policy Sciences*, 31: 55–80.

Bertalanffy, L. von. 1950. An outline of General System Theory. *British Journal for the Philosophy of Science*, 1(2): 134–165.

———. 1969. *General System Theory: Foundations, Development, Applications*. New York: George Braziller. Original edition, New York: George Braziller, 1968.

Boguslaw, R. 1965. *The New Utopians: A Study of System Design and Social Change*. Englewood Cliffs, NJ: Prentice-Hall.

Boland, R.J. 1987. The in-formation of information systems. In *Critical Issues in Information Systems Research*, ed. R.J. Boland Jr. and R.A. Hirschheim, 363–379. Chichester: John Wiley & Sons.

Bolsenga, S.J. and C.E. Herdendorf, ed. 1993. *Lake Erie and Lake St. Clair Handbook*. Detroit: Wayne State University Press.

Bormann, B.T., M.H. Brookes, E.D. Ford, A.R. Kiester, C.D. Oliver, and J.F. Weigand. 1994. *A Framework for Sustainable-Ecosystem Management*. Eastside Forest Ecosystem Health Assessment, Volume V. General Technical Report PNW-GTR-331. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture.

Boulding, K.E. 1956. General Systems Theory—The skeleton of science. *Management Science*, 2(3): 197–208.

Boyle, M.S. 1998. An adaptive ecosystem approach to monitoring: Developing policy performance indicators for OMNR. M.E.S. thesis, Department of Environment and Resource Studies, University of Waterloo.

Brown, J.H. 1997. *An Ecological Perspective on the Challenge of Complexity*. EcoEssay Series No. 1. Available [Online]: <http://www.nceas.ucsb.edu/fmt/doc?/nceas-web/resources/ecoessay/brown/> [18 March 1998].

Bruner, J. 1990. *Acts of Meaning*. Cambridge, MA: Harvard University Press.

Brunner, R.D., and T.W. Clark. 1997. A practice-based approach to ecosystem management. *Conservation Biology*, 11(1): 48–58.

Brydges, T., and A. Lumb. 1998. Canada's Ecological Monitoring and Assessment Network: Where We Are At and Where We Are Going. *Environmental Monitoring and Assessment*, 51: 595–603.

Bucciarelli, L.L. 1994. *Designing Engineers*. Cambridge, MA: MIT Press.

Buchanan, R. 1995. Rhetoric, humanism, and design. In *Discovering Design: Explorations in Design Studies*, ed. R. Buchanan and V. Margolin, 23–66. Chicago: University of Chicago Press.

Burrough, P.A., and A.U. Frank. 1995. Concepts and paradigms in spatial information: Are current geographical information systems truly generic? *International Journal of Geographical Information Systems*, 9(2): 101–116.

Caldwell, L.K. 1994. Disharmony in the Great Lakes Basin: Institutional jurisdictions frustrate the ecosystem approach. *Alternatives*, 20(3): 26–31.

Campbell, H., and I. Masser. 1992. GIS in local government: Some findings from Great Britain. *International Journal of Geographical Information Systems*, 6(6): 529–546.

Canadian Council of Ministers of the Environment (CCME). 1996. *A Framework for Developing Ecosystem Health Goals, Objectives, and Indicators: Tools for Ecosystem-Based Management*. Canadian Research Index, 98-01721, microfiche.

Canadian Heritage. Parks Canada. 1998. *State of the Parks, 1997 Report*. Available [Online]: <http://parkscanada.pch.gc.ca/library/DownloadDocuments/DocumentsArchive/SOP_e.pdf> [6 May 1999].

Canny, M.J. 1981. A universe comes into being when a space is severed: Some properties of boundaries in open systems. *Proceedings of the Ecological Society of Australia*, 11: 1–11.

Carew–Reid, J., R. Prescott–Allen, S. Bass, and B. Dalal–Clayton. 1994. *Strategies for National Sustainable Development: A Handbook for their Planning and Implementation*. London: Earthscan Publications, in association with IUCN and IIED.

Carnap, R. 1965. Logical foundations of the unity of science. In *Encyclopedia and Unified Science*, ed. O. Neurath, R. Carnap, and C. Morris, 42–62. International Encyclopedia of Unified Science, vol. 1, no. 1. Chicago: University of Chicago Press. Original edition, Chicago: University of Chicago Press, 1938.

Carpenter, S.R. , E. van Donk, and R.G. Wetzel. 1998. Nutrient-loading gradient in shallow lakes: Report of the group discussion. *In The Structuring Role of Submerged Macrophytes in Lakes*, ed. E. Jeppesen, M. Søndergaard, M. Søndergaard, and K. Christoffersen, 393-396. New York: Springer-Verlag.

Cartwright, N. 1994. Fundamentalism vs. the patchwork of laws. *Proceedings of the Aristotelian Society*, 94: 279–292.

Casti, J.L. 1986. On system complexity: Identification, measurement, and management. In *Complexity, Language, and Life: Mathematical Approaches*, ed. J.L. Casti and A. Karlqvist, 146–173. Berlin: Springer-Verlag.

———. 1994. *Complexification: Explaining a Paradoxical World Through the Science of Surprise*. New York: HarperCollins.

Checkland, P. 1981. *Systems Thinking, Systems Practice*. Chichester: John Wiley & Sons.

———. 1995. Model validation in soft systems practice. *Systems Research*, 12(1): 47-54.

Checkland, P., and S. Holwell. 1998. *Information, Systems and Information Systems: Making Sense of the Field*. Chichester: John Wiley & Sons.

Checkland, P., and J. Scholes. 1990. *Soft Systems Methodology in Action*. Chichester: John Wiley & Sons.

Clarke, S. 1998. *Metaphysics and the Disunity of Scientific Knowledge*. Aldershot: Ashgate.

Coad, B.W., H. Waszczuk, and I. Labignan. 1995. *Encyclopedia of Canadian Fishes*. Ottawa: Canadian Musuem of Nature and Canadian Sportfishing Productions Inc.

Collingridge, D., and C. Reeve. 1986. *Science Speaks to Power: The Role of Experts in Policy Making*. New York: St. Martin's Press.

Committee on Environment and Natural Resources. 1997a. *Integrating the Nation's Environmental Monitoring and Research Networks and Programs: A Proposed Framework*. Available [Online]: <http://www.epa.gov/cludygxb/Pubs/framewrk.pdf> [15 August 1998].

———. 1997b. Chapter 3–Integrating activites and perspectives. In *Our Changing Planet: The FY 1998 U.S. Global Change Research Program*. Available [Online]: <http://www.gcrio.org/ocp98/ch3.html> [18 April 1998].

Cortner, H.J., M.A. Shannon, M.G. Wallace, S. Burke, and M.A. Moote. 1996. Institutional Barriers and Incentives for Ecosystem Management: A Problem Analysis. General Technical Report PNW-GTR-354. Portland, OR: U.S. Department of Agriculture, Forest Service.

Cowan, G.A., D. Pines, and D. Meltzer, eds. 1994. *Complexity: Metaphors, Models, and Reality*. Proceedings volume XIX, Santa Fe Institute studies in the sciences of complexity. Reading, MA: Addison–Wesley Publishing Company.

Cowan, D.D, P.M. Koch, C.I. Mayfield, and D.A. Swayne. 1996. An information framework for environmental research and management. In *Environmental Software Systems*, ed. R. Denzer, G. Schimak, and D. Russell, 69–79. London: Chapman & Hall on behalf of the International Federation for Information Processing.

Coyne, R. 1995. *Designing Information Technology in the Postmodern Age: From Method to Metaphor*. Cambridge, MA: MIT Press.

Craig, B., J. Robinson, and A. Langford. 1993. Long Point Ecosystem Stresses. Summary of a workshop held at the Backus Mills Heritage Conservation Area, Port Rowan, Ontario, 28 May 1993. Long Point World Biosphere Reserve Foundation. Photocopied.

Crowder, L.B., E.W. McCollum, and T.H. Martin. 1998. Changing perpectives on food web interactions in lake littoral zones. In *The Structuring Role of Submerged Macrophytes in Lakes*, ed. E. Jeppesen, M. Søndergaard, M. Søndergaard, and K. Christoffersen, 240-249. New York: Springer-Verlag.

Crowe, M., R. Beeby, and J. Gammack. 1996. *Constructing Systems and Information: A Process View*. Maidenhead, UK: McGraw-Hill.

Dahlbom, B., and L. Mathiassen. 1993. *Computers in Context: The Practice and Philosophy of Systems Design*. Cambridge, MA and Oxford: NCC Blackwell.

Davidson-Arnott, R.G.D., and J.D. Fisher. 1992. Spatial and temporal controls on overwash occurrence on a Great Lakes barrier spit. *Canadian Journal of Earth Science*, 29: 102–117.

Davies, L.J., and A.T. Wood–Harper. 1989. Information systems development: Theoretical frameworks. *Journal of Applied Systems Analysis*, 16: 61–73.

De Cola, L. 1994. Simulating and mapping spatial complexity using multi-scale techniques. *International Journal of Geographical Information Systems*, 8(5): 411-427.

Dery, D. 1990. *Data and Policy Change: The Fragility of Data in the Policy Context*. Boston: Kluwer Academic Publishers.

Diehl, S., and R. Kornijów. 1998. Influence of submerged macrophytes on trophic interactions among fish and macroinvertebrates. In *The Structuring Role of Submerged Macrophytes in Lakes*, ed. E. Jeppesen, M. Søndergaard, M. Søndergaard, and K. Christoffersen, 24-46. New York: Springer-Verlag.

Donahue, M.J. 1988. Institutional arrangements for Great Lakes management. In *Perspectives on Ecosystem Management for the Great Lakes: A Reader*, ed. L.K. Caldwell, 115–139. Albany: State University of New York Press.

Doodge, J.C.I., G.T. Goodman, J.W.M la Rivière, J. Marton-Lefèvre, T. O'Riordan, and F. Praderie, ed. 1992. *An Agenda of Science for Environment and Development into the 21st Century*. Cambridge: Cambridge University Press.

Dorling, D. 1995. The visualization of local urban change across Britain. *Environment and Planning B*, 22: 269-290.

Downey, A.M., S. Radovich, and P. Lawrence. 1996. Water quality of Long Point Bay: Issues and areas of concern for planning and management. In *Long Point Environmental Folio*, ed. J.G. Nelson and K.L. Wilcox, chap. 13. Waterloo, ON: Heritage Resources Centre, University of Waterloo.

Dryzek, J.S. 1993. Policy analysis and planning: From science to argument. In *The Argumentative Turn in Policy Analysis and Planning*, ed. F. Fischer and J. Forester, 213–232. Durham: Duke University Press.

Duane, T.P. 1997. Community participation in ecosystem management. *Ecology Law Quarterly*, 24(4): 771–797.

Dupré, J. 1993. *The Disorder of Things: Metaphysical Foundations of the Disunity of Science* . Cambridge, MA: Harvard University Press.

Earth Council. 1997. *Earth Council Chairman's Report to the UN Commission on Sustainable Development*. Available [Online]: <http://www.ecouncil.ac.cr/rio5/forum/english/annex1.htm> [15 April 1998].

Ecological Monitoring Coordinating Office. 1997. *The Ecological Monitoring and Assessment Network (EMAN): What it is, how it works, and why we need it*. Available [Online]: <http://www.cciw.ca/eman-temp/program/vision/ > [19 April 1998].

Ecological Society of America. Committee for a Research Agenda for the 1990s. 1991. The Sustainable Biosphere Initiative: An ecological research agenda. *Ecology*, 72: 371–412.

———. Committee on the Scientific Basis for Ecosystem Management. 1996. The report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. *Ecological Applications*, 6(3): 665–691.

Ecological Stratification Working Group. 1996. *A National Ecological Framework for Canada*. Ottawa, ON: Agriculture and Agri-Food Canada; Hull, PQ: Environment Canada.

Environment Canada. 1995. *Guiding Principles for Ecosystem Initiatives*. Ottawa: Ecosystem Conservation Directorate, Environment Canada. Canadian Research Index, 95–06672, microfiche.

———. Task Group on Ecosystem Approach and Ecosystem Science. 1996. *The Ecosystem Approach: Getting Beyond the Rhetoric*. En21-152/1996. Environment Canada.

———. 1998a. *SOLEC '98: Working toward a consensus on Great Lakes indicators*. Available [Online]: <http://www.cciw.ca/solec/solec98-desc.html> [18 April 1998].

———. Indicators, Monitoring and Assessment Branch. 1998b. The New Vision for State of Environment Reporting. Summary paper prepared for the EMAN 4th National Science Meeting, Point-au-Pique/La Malbaie, PQ, 21-24 January. 59 pp.

Environmental Protection Agency. 1997. *Environmental Monitoring and Assessment Program (EMAP): Research Strategy*. Available [Online]: <http://www.epa.gov/emap/html/emapstra.pdf> [20 August 1998].

Estes, J.E., M. Ehlers, J.P. Malingreau, I.R. Noble, J. Raper, A. Sellman, J.L. Starr, and J. Weber. 1992. *Advanced Data Acquisition and Analysis Technologies for Sustainable Development*. MAB Digest 12. Paris: UNESCO.

Evans, J. 1994. Sharing spatial environmental information across agencies, regions, and scales: Issues and solutions. In *Environmental Information Management and Analysis: Ecosystem to Global Scales* , ed. W.K. Michener, J.W. Brunt, and S.G. Stafford, 203–219. London: Taylor & Francis.

Feldman, M.S., and J.G. March. 1981. Information in organizations as signal and symbol. *Administrative Science Quarterly*, 26: 171–186.

Feyerabend, P.K. 1978. *Science in a Free Society*. London: NLB.

———. 1993. *Against Method*. 3d ed. London: Verso.

———. 1995. *Killing Time: The Autobiography of Paul Feyerabend*. Chicago and London: University of Chicago Press.

Finlayson, A.C. 1994. *Fishing for Truth: A Sociological Analysis of Northern Cod Stock Assessments from 1977 to 1990*. Social and Economic Studies No. 52. St. John's: Institute of Social and Economic Research, Memorial University of Newfoundland.

Fischer, F. 1990. *Technocracy and the Politics of Expertise*. Newbury Park, CA: Sage Publications.

Fitzsimmons, A.K. 1994. Federal ecosystem management: A "train wreck" in the making. Cato Institute Policy Analysis No. 217. Available [Online]: <http://www.cato.org/pubs/pas/pa-217.html> [5 September 1998].

———. 1996. Sound policy or smoke and mirrors: Does ecosystem management make sense? *Water Resources Bulletin*, 32(2): 217–227.

Flood, R.L., and N.R.A. Romm. 1996. *Diversity Management: Triple Loop Learning*. Chichester: John Wiley & Sons.

Forman, R.T.T. 1995. *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge: Cambridge University Press.

Fotheringham, A.S., and D.W.S. Wong. 1991. The modifiable areal unit problem in multivariate statistical analysis. *Environment and Planning A* , 23: 1025-1044.

Fox, J. 1992. The problem of scale in community resource management. *Environmental Management*, 16(3): 289-297.

Francis, G.R. 1986. Great Lakes governance and the ecosystem approach: Where next? *Alternatives*, 13(3): 61–70.

———. 1991. Development of UNESCO/MAB's global network of biosphere reserves: Canada's contribution to this goal. In *Strengthening Biosphere Reserves in Canada*, ed. A. Bailly, G. Francis, and G. Nelson, 3–10. Working Paper No. 1. Waterloo, ON: Heritage Resources Centre, University of Waterloo.

Francis, G.R., A.P. Grima, H.A. Regier, and T.H. Whillans. 1985. *A Prospectus for the Management of the Long Point Ecosystem*. Technical Report No. 43. Ann Arbor, MI: Great Lakes Fishery Commission.

Fritz, J.S. 1997. *Earthwatch 25 Years On: Between Science and International Environmental Governance*. IIASA Interim Report IR-97-059. Available [Online]: <http://www.iiasa.ac.at/Publications/Documents/IR-97-059.pdf> [24 August 1998].

Fujimura, J.H. 1992. Crafting science: Standardized packages, boundary objects, and "translation". In *Science as Practice and Culture*, ed. A. Pickering, 168–211. Chicago: University of Chicago Press.

Funtowicz, S.O., and J.R. Ravetz. 1994. Uncertainty, complexity and post-normal science. *Environmental Toxicology and Chemistry*, 13(12): 1881–1885.

Gasith, A., and S. Gafny. 1990. Effects of water level fluctuation on the structure and function of the littoral zone. In *Large Lakes: Ecological Structure and Function*, ed. M.M. Tilzer and C. Serruya, 156-171. Berlin: Springer-Verlag.

Gibbons, M., C. Limoges, H. Nowotny, S. Schwartzman, P. Scott, and M. Trow. 1996. *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. London: Sage Publications. Original edition, London: Sage Publications, 1994.

Gieryn, T.F. 1995. Boundaries of science. In *Handbook of Science and Technology Studies*, ed. S. Jasanoff, G.E. Markle, J.C. Petersen, and T. Pinch, 393–443. Thousand Oaks, CA: Sage Publications.

Goodchild, M.F. 1996. Geographic information systems and spatial analysis in the social sciences. In *Anthropology, Space, and Geographic Information Systems*, ed. M. Aldenderfer and H.D.G. Maschner, 241–250. New York: Oxford University Press.

Government of Ontario. 1992. *Niagara Escarpment Planning and Development Act*. Revised Statutes of Ontario, 1990, Chapter N.2. Available [Online]: <http://204.191.119.105/en/index.html> Select: "To Search Ontario's Statutes" Search: for chapter number "N.2" [30 August 1998].

Graham, D.M., J.A. Dahl, E.. Millard, O.E. Johannsson, and L.L. White. 1996. *Assessment of the abundance, biomass and production of the lower trophic levels in the eastern basin of Lake Erie, 1994*. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2110. Burlington, ON: Department of Fisheries and Oceans. Canadian Research Index, 96-05307, microfiche.

Grant, K. 1997. *Reaching New Heights: A Handbook for Developing Community Based Ecosystem Health Goals, Objectives and Indicators*. En 40-234/1-1997E. Vancouver, BC: Environment Canada, Fraser River Action Plan.

Grumbine, R.E. 1994. What is ecosystem management? *Conservation Biology*, 8(1): 27–38.

———. 1997. Reflections on "What is Ecosystem Management?" *Conservation Biology*, 11(1): 41–47.

Guba, E.G., and Y.S. Lincoln. 1989. *Fourth Generation Evaluation*. Newbury Park: Sage Publications.

GTOS Secretariat. 1997. *Global Terrestrial Oberving System: Annual Report 1997*. GTOS–14. Available [Online]: <ftp://ext-ftp.fao.org/GTOS/97report.pdf > [21 August 1998].

Hacking, I. 1995. *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science*. Cambridge: Cambridge University Press. Original edition, Cambridge: Cambridge University Press, 1983.

Hahn, H., O. Neurath, and R. Carnap. 1973. The Scientific Conception of the World: The Vienna Circle [Wissenschaftliche Weltauffassung: Der Wiener Kreis]. In *Empiricism and Sociology*, ed. M. Neurath and R.S. Cohen, 299–318. Vienna Circle Collection, volume 1. Dordrecht: D. Reidel Publishing Company.

Hajer, M.A. 1995. *The Politics of Environmental Discourse: Ecological Modernization and the Policy Process*. Oxford: Clarendon Press.

Hall, F.G., K.F. Huemmrich, S.J. Goetz, P.J. Sellers, and J.E. Nickeson. 1992. Satellite remote sensing of surface energy balance: success, failures, and unresolved issues in FIFE. *Journal of Geophysical Research*, 97(D17): 19,061-19,089.

Hammond, K.R., J. Mumpower, R.L. Dennis, S. Fitch, and W. Crumpacker. 1983. Fundamental obstacles to the use of scientific information in public policy making. *Technological Forecasting and Social Change*, 24: 287–297.

Haraway, D. J. 1976. *Crystals, Fabrics, and Fields: Metaphors of Organicism in Twentieth-Century Developmental Biology*. New Haven: Yale University Press.

Hardi, P., and T. Zdan. 1997. *Assessing Sustainable Development: Principles in Practice*. Winnipeg: International Institute for Sustainable Development. Available [Online]: <http://iisd.ca/pdf/bellagio.pdf> [18 April 1998].

Hartig, J.H., M.A. Zarull, T.M. Heidtke, and H. Shah. 1998. Implementing ecosystem-based management: Lessons from the Great Lakes. *Journal of Environmental Planning and Management*, 41(1): 45–75.

Harwell, M.A. 1997. Ecosystem management of South Florida: Developing a shared vision of ecological and societal sustainability. *BioScience*, 47(8): 499–512.

Hayles, N.K. 1995. Searching for common ground. In *Reinventing Nature? Responses to Postmodern Deconstruction*, ed. M.E. Soulé and G. Lease, 47–63. Washington, D.C.: Island Press.

Heal, O.W., J.C. Menaut, and W.L. Steffen, ed. 1993. *Towards a Global Terrestrial Observing System (GTOS): Detecting and Monitoring Change in Terrestrial Ecosystems*. MAB Digest 14. Paris: UNESCO; Stockholm: IGBP.

Heifetz, R. A. 1994. *Leadership Without Easy Answers*. Cambridge: Harvard University Press, Belknap Press.

Heims, S.J. 1991. *The Cybernetics Group*. Cambridge, MA: MIT Press.

Hellawell, J.M. 1991. Development of a rationale for monitoring. In *Monitoring for Conservation and Ecology*, ed. B. Goldsmith, 1–14. London: Chapman and Hall.

Hicks, B.B., and T.G. Brydges. 1994. A strategy for integrated monitoring. *Environmental Management*, 18(1): 1–12.

Hodge, T., S. Holtz, C. Smith, and K. Hawke Baxter, ed. 1995. *Pathways to Sustainability: Assessing Our Progress*. Ottawa: National Round Table on the Environment and the Economy.

Hoos, I.R. 1983. *Systems Analysis in Public Policy: A Critique*. Revised edition. Berkeley, CA: University of California Press.

Hutchings, J.A., C. Walters, and R.L. Haedrich. 1997. Is scientific inquiry incompatible with government information control? *Canadian Journal of Fisheries and Aquatic Sciences*, 54: 1198–1210.

Interagency Ecosystem Management Task Force. 1995. *The Ecosystem Approach: Healthy Ecosystems and Sustainable Economies, Volume I—Overview*. Available [Online]: <http://www.denix.osd.mil/denix/Public/ES-Programs/Conservation/Ecosystem/ecosystem1.html> [4 September 1998].

International Joint Commission. Indicators for Evaluation Task Force. 1996. *Indicators to Evaluate Progress Under the Great Lakes Water Quality Agreeement*. Available [Online]: <http://www.ijc.org/boards/ietf/ietf.html> [29 August 1998].

———. 1997. *What is the Great Lakes Water Quality Agreement?* Available [Online}: <http://www.ijc.org/agree/quality.html> [19 April 1998].

International Joint Commission. 1998. Indicator Implementation Task Force—Progress Report, July 1998. Available [Online]: <http://www.ijc.org/boards/iitf/prog0798.html> [29 August 1998].

Irwin, A. 1995. *Citizen Science: A Study of People, Expertise and Sustainable Development*. London and New York: Routledge.

Jamieson, D. 1998. Sustainability and beyond. *Ecological Economics*, 24: 183–192.

Jones, C.G., J.H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. *Oikos*, 69: 373-386.

Kampis, G. 1991. *Self-modifying Systems in Biology and Cognitive Science: A New Framework for Dynamics, Information and Compexity*. Oxford: Pergamon Press.

———. 1994. Biological evolution as a process viewed internally. In *Inside Versus Outside: Endo– and Exo–Concepts of Observation and Knowledge in Physics, Philosophy and Cognitive Science*, ed. H. Atmanspacher and G.J. Dalenoort, 85–110. Berlin: Springer–Verlag.

Kay, J.J., and E. Schneider. 1994. Embracing complexity: The challenge of the ecosystem approach. *Alternatives* 20(3): 32–39.

Kendall, J.E., and K.E. Kendall. 1993. Metaphors and methodologies: Living beyond the systems machine. *MIS Quarterly*, 17(2): 149–171.

Kennel, C.F., P. Morel, and G.J. Williams. 1997. Keeping watch on the Earth: An integrated global observing strategy. *Consequences*, 3(2). Available [Online]: <http://www.gcrio.org/CONSEQUENCES/vol3no2/keepwatch.html> [19 April 1998].

Keystone Center. Science and Public Policy Program. 1996. The Keystone National Policy Dialogue on Ecosystem Management: Final Report. Available [Online]: <http://www.keystone.org/spp/reports/emtoc.html> [4 September 1998].

King, A.W. 1991. Translating models across scales in the landscape. In *Quantitative Methods in Landscape Ecology: The Analysis and Interpretation of Landscape Heterogeneity*, ed. M.G. Turner and R.H. Gardner, 479–517. New York: Springer-Verlag.

———. 1993. Considerations of scale and hierachy. In *Ecological Integrity and the Management of Ecosystems*, ed. S. Woodley, J. Kay, and G. Francis, 19–45. Delray Beach, FL: St. Lucie Press.

Klir, G.J. 1985. *Architecture of Systems Problem Solving*. New York: Plenum Press.

Kuhn, T.S. 1970. *The Structure of Scientific Revolutions*. 2nd ed. International Encyclopedia of Unified Science, vol. 2, no. 2. Chicago: The University of Chicago Press.

Lake Superior Work Group. Ecosystem Objectives Subgroup. 1995. Ecosystem Principles and Objectives for Lake Superior. Discussion paper, Lake Superior Binational Forum. Photocopied.

Lane, A.M.J. 1997. The U.K. Environmental Change Network database: An integrated information resource for long-term monitoring and research. *Journal of Environmental Management*, 51: 87–105.

Lane, J.A., C.B. Portt, and C.K. Minns. 1996a. *Adult habitat characteristics of Great Lakes fishes*. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2358. Burlington, ON: Department of Fisheries and Oceans. Canadian Research Index, 96-06077, microfiche.

———. 1996b. *Nursery habitat characteristics of Great Lakes fishes*. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2338. Burlington, ON: Department of Fisheries and Oceans. Canadian Research Index, 96-02272, microfiche.

———. 1996c. *Spawning habitat characteristics of Great Lakes fishes*. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2368. Burlington, ON: Department of Fisheries and Oceans. Canadian Research Index, 97-00277, microfiche.

Langran, G. 1992. *Time in Geographic Information Systems*. London: Taylor & Francis.

Latour, B. 1987. *Science in Action: How to Follow Scientists and Engineers Through Society*. Milton Keynes: Open University Press.

Lee, K.N. 1993. *Compass and Gyroscope: Integrating Science and Politics for the Environment*. Washington, DC: Island Press.

Leslie, J.K., and C.A. Timmins. 1997. *Early life history of fishes in Long Point inner bay, Lake Erie*. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2150. Burlington, ON: Department of Fisheries and Oceans.

Levins, R., and R. Lewontin. 1985. *The Dialectical Biologist.* Cambridge, MA: Harvard University Press

Lewis, P.J. 1994. *Information-Systems Development: Systems Thinking in the Field of Information-Systems*. London: Pitman Publishing.

Lindblom, C.E. 1959. The science of "muddling through". *Public Administration Review*, 19: 79–88.

Linder, S.H., and B. G. Peters. 1995. The two traditions of institutional designing: Dialogue versus decision? In *Institutional Design*, ed. D.L. Weimer, 133–160. Boston: Kluwer Academic Publishers.

Lloyd, S. 1990. The calculus of intricacy. *The Sciences*, 30(5): 38–44.

Lodge, D.M., J.W. Barko, D. Strayer, J.M. Melack, G.G. Mittelbach, R.W. Howarth, B. Menge, and J.E. Titus. 1988. Spatial heterogeneity and habitat interactions in lake communities. In *Complex Interactions in Lake Communities*, ed. S.R. Carpenter, 181-208. New York: Springer-Verlag.

Long Point World Biosphere Reserve Foundation. 1994. Long Point Country Community Action Plan. Port Rowan, ON: Long Point World Biosphere Reseve Foundation and Environment Canada.

Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, resource exploitation, and conservation: Lessons from history. *Science*, 260: 17,36.

MacGregor, R.B., and L.D. Witzel. 1987. *A Twelve year study of the fish community in the Nanticoke region of Long Point Bay, Lake Erie: 1971-1983 summary report*. Port Dover, ON: Ontario Ministry of Natural Resources, Lake Erie Fisheries Assessment Unit. Canadian Research Index, 88-05219, microfiche.

MacKenzie, S.H. 1996. *Integrated Resource Planning and Management: The Ecosystem Approach in the Great Lakes Basin*. Washington, DC: Island Press.

MacViro Consultants. 1994. *Monitoring Cumulative Environmental Effects in the Niagara Escarpment Plan Area: Phase I Report*. Report prepared for the Ontario Ministry of Environment and Energy. Canadian Research Index, 94–03799, microfiche.

———. 1995. *Cumulative Effects Monitoring Program for the Niagara Escarpment Plan Area: Phase II Final Report*. Report prepared for the Ontario Ministry of Environment and Energy. Canadian Research Index, 97–04409, microfiche.

Madsen, K.H. 1989. Breakthrough by breakdown: Metaphors and structured domains. In *Systems Development for Human Progress*, ed. H.K. Klein and K. Kumar, 41-53. Amsterdam: Elsevier Science Publishers.

Majone, G. 1989. *Evidence, Argument and Persuasion in the Policy Process*. New Haven, CT: Yale University Press.

March, J.G., and J.P. Olsen. 1979. *Ambiguity and Choice in Organizations*. 2nd ed. Bergen, Norway: Universitetsforlaget.

McCormick, F.J. 1999. Principles of ecosystem management and sustainable development. In *Ecosystem Management for Sustainability: Principles and Practices Illustrated by a Regional Biosphere Reserve Cooperative*, ed. J.D. Peine, 3–21. Boca Racon, FL: CRC Press.

Michael, D.N. 1995. Barriers and bridges to learning in a turbulent human ecology. In *Barriers and Bridges to the Renewal of Ecosystems and Institutions*, ed. L.H. Gunderson, C.S. Holling, and S.S. Light, 461–485. New York: Columbia University Press.

Michener, W.K., J.W. Brunt, J.J. Helly, T.B. Kirchner, and S.G. Stafford. 1997. Nongeospatial metadata for the ecological sciences. *Ecological Applications*, 7(1): 330–342.

Mikulecky, D.C. 1996. Complexity, communication between cells, and identifying the functional components of living systems: Some observations. *Acta Biotheoretica*, 44: 179–208.

Milbrath, L.W. 1989. *Envisioning a Sustainable Society: Learning Our Way Out*. Albany: State University of New York Press.

Miles, R.K. 1988. Combining 'soft' and 'hard' systems practice: Grafting or embedding? *Journal of Applied Systems Analysis*, 15: 55–60.

Miller, D. 1993. The architecture of simplicity. *Academy of Management Review*, 18(1): 116–138.

Miller, J.G. 1978. *Living Systems.* New York: McGraw–Hill Book Company.

Mintzberg, H. 1994. *The Rise and Fall of Strategic Planning: Reconceiving Roles for Planning, Plans, Planners*. New York: Macmillan, Free Press.

Monmonier, M. 1991. *How to Lie With Maps*. Chicago: University of Chicago Press.

Morrissey, W.A. 1993. Data management and global change research: Technology and infrastructure. *Government Information Quarterly*, 10(2): 159–201.

Müller, F. 1998. Gradients in ecological systems. *Ecological Modelling*, 108: 3–21.

Myers, N., ed. 1993. *Gaia: An Atlas of Planet Management*. rev. ed. New York: Doubleday, Anchor Books. Original edition, New York: Anchor Books, 1984.

Nagel, T. 1986. *The View From Nowhere*. New York: Oxford University Press.

Naiman, R. J., H. Décamps, and F. Fournier, ed. 1989. *The Role of Land/Inland Water Ecotones in Landscape Management and Restoration: A Proposal for Collaborative Research*. MAB Digest 4. Paris: UNESCO.

National Aeronautics and Space Administration. 1998. *Understanding Our Changing Planet: NASA's Earth Science Enterprise 1998 Fact Book*. Available [Online]: <ftp://eospso.gsfc.nasa.gov/docs/Factbook.pdf> [2 May 1999].

National Research Council. 1990. *Monitoring Southern California's Coastal Waters*. Washington, D.C.: National Academy Press.

———. 1992. *Combining Information: Statistical Issues and Opportunities for Research*. Washington, D.C. National Academy Press.

———. 1995a. *Finding the Forest in the Trees: The Challenge of Combining Diverse Environmental Data*. Report by the Committee for a Pilot Study on Database Interfaces. Washington, D.C.: National Academy Press.

———. 1995b. *Review of EPA's Environmental Monitoring and Assessment Program: Overall Evaluation*.Washington, DC: National Academy Press.

Nelson, J.G., P.L. Lawrence, K. Beazley, R. Stenson, A. Skibicki, C.L. Yeung, and K. Pauls. 1996. An environmental folio for the Long Point World Biosphere Reserve and area. In *Long Point Environmental Folio*, ed. J.G. Nelson and K.L. Wilcox, chap. 1. Waterloo, ON: Heritage Resources Centre, University of Waterloo.

Neurath, O. 1965. Unified science as encyclopedic integration. In *Encyclopedia and Unified Science*, ed. O. Neurath, R. Carnap, and C. Morris, 1–27. International Encyclopedia of Unified Science, vol. 1, no. 1. Chicago: University of Chicago Press. Original edition, Chicago: University of Chicago Press, 1938.

Norton, B.G. 1998. Improving ecological communication: The role of ecologists in environmental policy formation. *Ecological Applications*, 8(2): 350–364.

Office of the Vice President. 1993. Reinventing Environmental Management. Accompanying Report of the National Performance Review. Available [Online]: <http://whitehouse.dm.net/library/1994/NPRENVIR.TXT > [5 September 1998].

O'Neill, R.V., D.L. DeAngelis, J.B. Waide, and T.F.H. Allen. 1986. *A Hierarchical Concept of Ecosystems*. Princeton, NJ: Princeton University Press.

O'Neill, R.V., R.H. Gardner, B.T. Milne, M.G. Turner, and B. Jackson. 1991. Heterogeneity and spatial hierarchies. In *Ecological Heterogeneity*, ed. J. Kolasa and S.T.A. Pickett, 85–96. New York: Springer Verlag.

Ontario Ministry of Environment and Energy. 1993. *Restoring and Protecting the Great Lakes: Progress Report from 1991*. Toronto, ON: Ministry of Environment and Energy.

Ontario Ministry of Natural Resources. 1997. *Lake Erie fisheries report, 1996*. Toronto, ON: Ministry of Natural Resources, Fish and Wildlife Branch. Canadian Research Index, 97-05824, microfiche.

Openshaw, S. 1983. *The Modifiable Areal Unit Problem*. CATMOG No. 38. Norwich, UK: Geo Books.

Openshaw, S., and P.J. Taylor. 1979. A million or so correlation coefficients: Three experiments on the modifiable areal unit problem. In *Statistical Applications in the Spatial Sciences*, ed. N. Wrigley, 127–144. London: Pion Limited.

Orr, D.W. 1992. *Ecological Literacy: Education and the Transition to a Postmodern World*. Albany: State University of New York Press.

Oxley, K.A. 1997. Education in support of the ecosystem approach at the Huron Natural Area. M.E.S. thesis, Department of Environment and Resource Studies, University of Waterloo.

Parson, E.A. 1995. Integrated assessment and environmental policy making: In pursuit of usefulness. *Energy Policy*, 23(4/5): 463–475.

Persson, L., and L.B. Crowder. 1998. Fish-habitat interactions mediated via ontogenetic niche shifts. In *The Structuring Role of Submerged Macrophytes in Lakes*, ed. E. Jeppesen, M. Søndergaard, M. Søndergaard, and K. Christoffersen, 3-23. New York: Springer-Verlag.

Peters, R.H. 1991. *A Critique for Ecology*. Cambridge: Cambridge University Press.

Petrie, S. 1998. Waterfowl and Wetlands of Long Point Bay and Old Norfolk County: Present Conditions and Future Options for Conservation. Report prepared for the Norfolk Land Stewardship Council. Simcoe, ON.

Pickering, A. 1995. *The Mangle of Practice: Time, Agency, and Science*. Chicago: University of Chicago Press.

Pimm, S.L. 1984. The complexity and stability of ecosystems. *Nature*, 307: 321–326.

Poff, C. 1996. Long Point Area Monitoring Assessment Project (LPAMAP). Report prepared for the Long Point World Biosphere Reserve Foundation. n.p.

———. 1998. Letter to Dr. Anthony Hopkin, Canadian Forest Service, Sault Ste. Marie, 8 June.

Price, M.F. 1996. People in biosphere reserves: An evolving concept. *Society & Natural Resources*, 9: 645–654.

Ravetz, J.R. 1971. *Scientific Knowledge and its Social Problems*. Oxford: Clarendon Press.

Ray, G.C., and B.P. Hayden. 1992. Coastal zone ecotones. In *Landscape Boundaries: Consequences for Biotic Diversity and Ecological Flows*, ed. A.J. Hansen and F. di Castri, 403–420. New York: Springer-Verlag.

Redner, H. 1987. *The Ends of Science: An Essay in Scientific Authority*. Boulder, CO: Westview Press.

Regier, H.A., and J.J. Kay, 1996. An heuristic model of transformations of the aquatic ecosystems of the Great Lakes–St. Lawrence River Basin. *Journal of Aquatic Ecosystem Health*, 5: 3–21.

Reiser, O.L. 1958. *The Integration of Human Knowledge: A Study of the Formal Foundations and the Social Implications of Unified Science*. Boston: Porter Sargent.

Richardson, G.P. 1991. *Feedback Thought in Social Science and Systems Theory*. Philadelphia: University of Pennsylvania Press.

Robinson, N.A., ed. 1993. *Agenda 21 & the UNCED Proceedings, Volume IV*. New York: Oceana Publications, Inc.

Robertson, A. 1995. Integrated international monitoring: Strategic design. Paper presented at the North American Workshop on Monitoring for the Ecological Assessment of Terrestrial and Aquatic Ecosystems, Mexico City, 18-22 September. CIS/Envirofiche, 97–11737, microfiche.

Rosen, R. 1977. Complexity as a system property. *International Journal of General Systems*, 3(4): 227–232.

———. 1978. *Fundamentals of Measurement and Representation of Natural Systems*. New York: North–Holland.

———. 1985. *Anticipatory Systems: Philosophical, Mathematical & Methodological Foundations*. Oxford: Pergamon Press.

———. 1991. *Life Itself: A Comprehensive Inquiry into the Nature, Origin, and Fabrication of Life*. New York: Columbia University Press.

Rosenberg, A. 1994. *Instrumental Biology, or the Disunity of Science*. Chicago: The University of Chicago Press.

Ross, A. 1991. *Strange Weather: Culture, Science, and Technology in the Age of Limits*. London: Verso.

Rouse, J. 1996. *Engaging Science: How to Understand Its Practices Philosophically*. Ithaca: Cornell University Press.

Salthe, S.N. 1985. *Evolving Hierarchical Systems: Their Structure and Representation*. New York: Columbia University Press.

Scheffer, M., and E. Jeppesen. 1998. Alternative stable states. In *The Structuring Role of Submerged Macrophytes in Lakes*, ed. E. Jeppesen, M. Søndergaard, M. Søndergaard, and K. Christoffersen, 397–406. New York: Springer.

Schneider, M. 1997. *Spatial Data Types for Database Systems: Finite Resolution Geometry for Geographic Information Systems*. New York: Springer-Verlag.

Schön, D. A. 1983. *The Reflective Practitioner: How Professionals Think in Action*. New York: Basic Books.

———. 1993. Generative metaphor: A perspective on problem-setting in social policy. In *Metaphor and Thought*, ed. A. Ortony, 137–163. 2d ed. Cambridge: Cambridge University Press.

Schön, D.A., and M. Rein. 1994. *Frame Reflection: Toward the Resolution of Intractable Policy Controversies*. New York: Basic Books.

Scott, W.B., and E.J. Crossman. 1975. *Freshwater Fishes of Canada*. Bulletin No. 184. Ottawa: Fisheries Research Board of Canada. Original edition, Fisheries Research Board of Canada, 1973.

Sellers, P.J., and F.G. Hall. 1992. FIFE in 1992: Results, scientific gains, and future research directions. *Journal of Geophysical Research*, 97(D17): 19,091–19,109.

Sellers, P.J., F.G. Hall, G. Asrar, D.E. Strebel, and R.E. Murphy. 1992. An overview of the First International Satellite Land Surface Climatology Project (ISLSCP) Field Experiment (FIFE). *Journal of Geophysical Research*, 97(D17): 18,345–18,371.

Selman, P. 1996. *Local Sustainability: Managing and Planning Ecologically Sound Places*. New York: St. Martin’s Press.

Shackley, S., B. Wynne, and C. Waterton. 1996. Imagine complexity: The past, present and future potential of complex thinking. *Futures*, 28(3): 201–225.

Shklar, J.N. 1964. Decisionism. In *Rational Decision*, ed. C.J. Friedrich, 3–17. Nomos VII. New York: Prentice-Hall, Atherton Press.

Simon, H.A. 1960. *The New Science of Management Decision*. New York: Harper & Row.

———. 1962. The architecture of complexity. *Proceedings of the American Philosophical Society*, 106(6): 467–482.

Smith, B.C. 1996. *On the Origin of Objects*. Cambridge, MA: MIT Press.

Solecki, W.D. 1994. Putting the biosphere reserve concept into practice: Some evidence of impacts in rural communities in the United States. *Environmental Conservation*, 21(3): 242–247.

Søndergaard, M. and B. Moss. 1998. Impact of submerged macrophytes on phytoplankton in shallow freshwater lakes. In *The Structuring Role of Submerged Macrophytes in Lakes*, ed. E. Jeppesen, M. Søndergaard, M. Søndergaard, and K. Christoffersen, 115-132. New York: Springer-Verlag.

Stafford, S.G., J.W. Brunt, and W.K. Michener. 1994. Integration of scientific information management and environmental research. In *Environmental Information Management and Analysis: Ecosystem to Global Scales*, ed. W.K. Michener, J.W. Brunt, and S.G. Stafford, 3–19. London: Taylor & Francis Ltd.

Star, S.L. 1989. The structure of ill-structured solutions: Boundary objects and heterogeneous distributed problem solving. In *Distributed Artificial Intelligence: Volume II*, ed. L. Gasser and M.N. Huhns, 37–54. London: Pitman Publishing.

Star, S.L., and J.R. Griesemer. 1989. Institutional ecology, ‘translations’ and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907–39. *Social Studies of Science*, 19: 387–420.

Stowell, F., and D. West. 1994. *Client-Led Design: A Systemic Approach to Information System Definition*. Maidenhead, UK: McGraw-Hill.

Suchman, L.A. 1987. *Plans and Situated Actions: The Problem of Human–Machine Communication*. Cambridge: Cambridge University Press.

Thompson, M., and M. Warburton. 1985. Decision making under contradictory certainties: How to save the Himilayas when you can’t find out what’s wrong with them. *Journal of Applied Systems Analysis*, 12: 3–34.

UN Department for Policy Coordination and Sustainable Development. 1997. *Assessment of Progress in the Implementation of Agenda 21 at the National Level*. Report E/CN.17/1997/5. Available [Online]: <gopher://gopher.un.org:70/00/esc/cn17/1997/off/97--5.EN> [14 April 1998].

UNESCO. 1972. *International Co-ordinating Council of the Programme on Man and the Biosphere (MAB): Final Report of the First Session held in Paris 9-19 November 1971*. MAB Report Series No. 1. Paris: UNESCO.

———. 1984. Action Plan for Biosphere Reserves. *Nature and Resources*, 20(4): 11–22.

———. 1987. *International Co-ordinating Council of the Programme on Man and the Biosphere (MAB): Final Report of the Ninth Session held in Paris 20-25 October 1986*. MAB Report Series No. 60. Paris: UNESCO.

———. 1993. *International Co-ordinating Council of the Programme on Man and the Biosphere (MAB): Final Report of the Twelfth Session held in Paris 25-29 January 1993*. MAB Report Series No. 63. Paris: UNESCO.

———. 1996. *Biosphere Reserves: The Seville Strategy and the Statutory Framework of the World Network*. Available [Online]: <http://unesdoc.unesco.org/images/0010/001038/103849e.pdf> [1 November 1998].

———. 1998. The Statutory Framework of the World Network of Biosphere Reserves. Available [Online]: <http://www.unesco.org/mab/frameuk.htm> [2 May 1999].

United Nations Environment Programme. 1994. First Meeting of the Earthwatch Inter-Agency Working Party: Report of the Meeting. UNEP/EAP.MR.94.3. Available [Online]: <http://www.unep.ch/earthw/Ewwp1rpt.htm> [26 August 1998].

———. 1997. *Global State of the Environment Report 1997*. Available [Online]: <http://www.grid.unep.ch/geo1/ch/toc.htm> Select: Executive Summary—The Way Ahead [26 August 1998].

UN Secretariat. 1995. Information for decision-making and Earthwatch. Report of the Secretary-General, E/CN.17/1995/18. Available [Online]: <gopher://gopher.un.org:70/00/esc/cn17/1995/off/95-18.en> [25 August 1998].

U.S. General Accounting Office. 1994. Ecosystem Management: Additional Actions Needed to Adequately Test a Promising Approach. Report to Congressional Requesters, GAO/RCED-94-111. Washington, DC.

Vickers, G. 1965. *The Art of Judgment: A Study of Policy Making*. New York: Basic Books.

———. 1983. *Human Systems Are Different*. London: Harper & Row Ltd.

Wackerbauer, R., A. Witt, H. Atmanspacher, J. Kurths, and H. Scheingraber. 1994. A comparative classification of complexity measures. *Chaos, Solitons and Fractals*, 4(1): 133–173.

Walsham, G. 1993. *Interpreting Information Systems in Organizations*. Chichester: John Wiley & Sons.

Weaver, W. 1948. Science and complexity. *American Scientist*, 36(4): 536–544.

Weick, K.E. 1995. *Sensemaking in Organizations*. Thousand Oaks, CA: Sage Publications.

Weick, K.E., and D.K. Meader. 1993. Sensemaking and group support systems. In *Group Support Systems: New Perspectives*, ed. L.M. Jessup and J.S. Valacich, 230–252. New York: Macmillan Publishing Company.

Weinberg, G.M. 1975. *An Introduction to General Systems Thinking*. New York: John Wiley & Sons.

Weiner, J. 1995. On the practice of ecology. *Journal of Ecology*, 83: 153–158.

Wells, M.P., and K.E. Brandon. 1993. The principles and practice of buffer zones and local participation in biodiversity conservation. *Ambio*, 22(2/3): 157–162.

Wenger, E. 1998. *Communities of Practice: Learning, Meaning, and Identity*. Cambridge: Cambridge University Press.

Wessman, C.A. 1992. Spatial scales and global change: bridging the gap from plots to GCM grid cells. *Annual Review of Ecology and Systematics*, 23: 175–200.

Westley, F. 1995. Governing design: The management of social systems and ecosystems management. In *Barriers and Bridges to the Renewal of Ecosystems and Institutions*, ed. L.H. Gunderson, C.S. Holling, and S.S. Light, 391–427. New York: Columbia University Press.

Whillans, T.H. 1985. Related long-term trends in fish and vegetation ecology of Long Point Bay and marshes, Lake Erie. Ph.D. diss., Department of Zoology, University of Toronto.

Whitley, R. 1984. *The Intellectual and Social Organization of the Sciences*. Oxford: Clarendon Press.

Wiens, J.A. 1989. Spatial scaling in ecology. *Functional Ecology*, 3: 385–397.

Wilcox, K., and R. Knapton. 1994. *An ecosystem approach to management of an internationally significant waterfowl staging area: Long Point's inner bay*. Long Point Environmental Folio, Technical Paper No. 5. Waterloo,ON: Heritage Resources Centre, University of Waterloo.

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

Wynne, B. 1992. Carving out science (and policy) in the regulatory jungle. *Social Studies of Science*, 22(4): 745–758.

———. 1996. Misunderstood misunderstandings: social identities and the public uptake of science. In *Misunderstanding Science? The Public Reconstruction of Science and Technology*, ed. A. Irwin and B. Wynne, 19–46. Cambridge: Cambridge University Press.

Yaffee, S.L, A.F. Phillips, I.C. Frentz, P.W. Hardy, S.M. Maleki, and B.E. Thorpe. 1996. *Ecosystem Management in the United States: An Assessment of Current Experience*. Washington, D.C.: Island Press.

Yearley, S. 1996. Nature's advocates: putting science to work in environmental organisations. In *Misunderstanding Science? The Public Reconstruction of Science and Technology*, ed. A. Irwin and B. Wynne, 172–190. Cambridge: Cambridge University Press.

Yin, R.K. 1989. *Case Study Research: Design and Methods.* rev. ed. Newbury Park, CA: Sage Publications.

Yule, G.U., and M.G. Kendall. 1965. *An Introduction to the Theory of Statistics*. 14th ed. (4th impression). London: Charles Griffon & Company.

Zorn, P., and D. Upton. 1997. Ecological Integrity Monitoring Plan, Part I: Ecological Indicators. Department of Canadian Heritage, Parks Canada. Available [Online]: <ftp://nhb.com/~eimpd/eee.exe> [1 June 1998].

Biosphere reserves

Canada/MAB Program
<http://www.cciw.ca/mab/mab.html>
Canadian Biosphere Reserve Association
<http://www.cciw.ca/cbra/english/main.html>
The Seville Strategy
<http://www.unesco.org/mab/stry-1.htm>
UNESCO Man and the Biosphere Programme (MABnet)
<http://www.unesco.org/mab/home.htm>
World Network of Biosphere Reserves
<http://www.unesco.org/mab/wnbr.htm>

Environmental monitoring and assessment

Canadian Environmental Assessment Agency
<http://www.ceaa.gc.ca/agency/agency_e.htm>
Center for Environmental Information and Statistics (U.S. EPA)
<http://www.epa.gov/ceisweb1/ceishome/ceis_home.html>
Earthwatch (UNEP)
<http://www.unep.ch/earthw.html>
Ecological Monitoring and Assessment Network (Canada)
<http://www.cciw.ca/eman-temp/intro.html>
Environmental Change Network (U.K.)
<http://www.nmw.ac.uk/ecn/>
Environmental Monitoring and Assessment Program (U.S.)
<http://www.epa.gov/emap/>
Global Environmental Outlook–1 (UNEP report)
<http://www.grid.unep.ch/geo1/ch/toc.htm>
Global Hierarchical Observing Strategy (GHOST)
<http://www.wmo.ch/web/gcos/pub/ghost.html>
Global Terrestrial Observing Network (GT-Net)
<http://www.fao.org/gtos/Home.htm>
International Geosphere-Biosphere Program
<http://www.igbp.kva.se/>
SI/MAB Program (Smithsonian Institute)
<http://www.si.edu/ripley/simab/aboutsimab.html>
U.S. Global Change Research Program
<http://www.usgcrp.gov/usgcrp/GCRPINFO.html>
World Climate Change Research Programme
<http://www.wmo.ch/web/wcrp/wcrp-home.html>

Online journals and document collections

The Earth Observer (NASA's Earth Observing System)
<http://eospso.gsfc.nasa.gov/earth_observ.html/>
International Institute of Applied Systems Analysis: archive
<http://www.iiasa.ac.at/Publications/Catalog/PUB_ONLINE.htm>
Parks Canada: policies, manuals, and reports
<http://parkscanada.pch.gc.ca/library/indexe.htm>
Santa Fe Institute: working papers
<http://www.santafe.edu/sfi/publications/working-papers.html>
UN reports & sessional documents
<gopher://gopher.un.org:70/>
UNCED documents & agreements (the 1992 "Earth Summit")
<gopher://gopher.undp.org:70/11/unconfs/UNCED/English/>
UNESCO archive
<http://unesdoc.unesco.org/ulis/ged.html>
U.S. Environmental Protection Agency: archive
<http://www.epa.gov/ncepihom/nepishom/>

Programs, organizations, and institutes

Canadian Council of Ministers of the Environment
<http://www.mbnet.mb.ca/ccme/>
Committee for the National Institute for the Environment
<http://www.cnie.org>
Earth Council's Earth Network
<http://www.ecouncil.ac.cr/>
International Institute for Sustainable Development
<http://iisd1.iisd.ca/>
Millennium Eco-Communities Program (Environment Canada)
<http://www2.ec.gc.ca/eco/main_e.html>
National Center for Ecological Synthesis and Analysis
<http://www.nceas.ucsb.edu/>
National Center for Geographic Information and Analysis
<http://www.ncgia.ucsb.edu>
Ramsar Convention on Wetlands
<http://www.ramsar.org>
Santa Fe Institute
<http://www.santafe.edu>

Ecosystem initiatives

Chesapeake Bay Program
<http://www.chesapeakebay.net/>
Ecosystem initiatives in Canada (Environment Canada)
<http://www.ec.gc.ca/ecosyst/backgrounder.html>
Panel on the Ecological Integrity of Canada's National Parks
<http://parkscanada.pch.gc.ca/ecol/main_e.htm>
Rocky Mountain Ecosystem Coalition
<http://www.rmec.org>
San Francisco Bay-Delta Ecosystem Project (USGS)
<http://sfbay.wr.usgs.gov/>
South Florida Ecosystem Restoration Task Force
<http://www.sfrestore.org/indexold.html>

Great Lakes region

Great Lakes Atlas (3rd ed., 1995)
<http://www.cciw.ca/glimr/data/great-lakes-atlas/intro.html>
Great Lakes Information Management Resource (GLIMR)
<http://www.cciw.ca/glimr/>
Great Lakes Information Network (GLIN)
<http://www.great-lakes.net/>
International Joint Commission
<http://www.ijc.org/ijcweb-e.html>
Niagara Escarpment Commission
<http://escarpment.org>
Remedial Action Plans
http://www.cciw.ca/glimr/raps/
State of the Lakes Ecosystem Conference (SOLEC)
<http://www.cciw.ca/solec/>

Sustainability

Compendium of sustainable development indicator initiatives
<http://iisd1.iisd.ca/measure/compindex.asp>
Earth Network for Sustainable Development
<http://www.ecouncil.ac.cr/>
International Council for Local Environmental Initiatives
<http://www.iclei.org/>
International Institute for Sustainable Development (IISDnet)
<http://iisd1.iisd.ca/>
UN sustainable development web site
<http://www.un.org/esa/sustdev/>
Virtual library: sustainable development
<http://www.ulb.ac.be/ceese/meta/sustvl.html>