

A SYSTEMS APPROACH TO BIODIVERSITY CONSERVATION PLANNING

NINA-MARIE E. LISTER

*School of Urban and Regional Planning, Faculty of Environmental Studies, University of Waterloo,
Ontario, Canada. E-mail: nm.lister@utoronto.ca*

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Abstract. With a recent media-fueled transition from a scientific to a political perspective, biodiversity has become an issue of ethics and ensuing values, beyond its traditional ecological roots. More fundamentally, the traditional perspective of biodiversity is being challenged by the emergence of a post-normal or systems-based approach to science. A systems-based perspective of living systems rests on the central tenets of complexity and uncertainty, and necessitates flexibility, anticipation and adaptation rather than prediction and control in conservation planning and management. What are the implications of this new perspective? This paper examines these challenges in the context of biodiversity conservation planning. The new perspectives of biodiversity are identified and explored, and the emergence of a new ecological context for biodiversity conservation is discussed. From the analysis, the challenges and implications for conservation planning are considered, and a systems-based or post-normal approach to conservation planning and management is proposed. In light of the new perspectives for biodiversity, conservation planning and management approaches should ultimately reflect the essence of living systems: they should be diverse, adaptive, and self-organizing, accepting the ecological realities of change.

Key words: adaptive management, biodiversity, conservation planning, ecosystem planning, post-normal science

1. Introduction

Biodiversity literally refers to the variety, distinctiveness and abundance of life forms and processes. It is within this literal context that Kuhnian normal science operates; e.g. ecologists' long intrigue with and debate over the role of biodiversity in ecosystems and biologists' systematic classification of taxa. Figuratively, biodiversity has become one of the most recognized environmental slogans of the decade. The notion of biodiversity moved beyond the comfortable realm of science following the global media coverage of the 1992 United Nations Conference on Environment and Development – the 'Earth Summit' – in Brazil¹. Joining the ranks of sustainable development, ecosystem health and other environmental heralds, biodiversity has become more than a literal scientific description of environmental phenomena and has entered the murky context of political and social debate².

¹ The negotiation and signing of the *United Nations Convention on Biological Diversity* was a major focus of the Earth Summit. The 'Rio Convention' has provided impetus for signatory parties to develop biodiversity policies.

² Here understood in the broad socio-cultural sense, including social, political, and economic phenomena.

Biodiversity must now be considered from both a literal scientific perspective and a figurative political perspective.

With this transition, biodiversity has necessarily become an issue of ethics and ensuing values, beyond its traditional ecological roots. Furthermore, the traditional perspective of biodiversity³ is being challenged fundamentally by the emergence of a post-normal, systems-based science. This new perspective, the hallmarks of which are uncertainty and complexity, reveals ecological realities that force consideration of broader perspectives and multiple contexts for biodiversity.

Thus, the tools for biodiversity conservation planning are no longer limited to those of normal science but include those of systems-based, post-normal science. What are the implications of these new biodiversity perspectives and contexts? This central question is explored: first, through identifying emerging perspectives of biodiversity; and second, through tracing the emergence of a new ecological context for biodiversity conservation. From this analysis, the challenges and implications for conservation decision-making are considered, and a systems-based approach to conservation planning and management is proposed.

2. Perspectives on Biodiversity

2.1. CONVENTIONAL DEFINITIONS

A closer look at the nature of biodiversity reveals that many conventional definitions are simplistic and problematic. The issues of scale, measurement, and boundaries in observation pose major obstacles in defining biodiversity. Furthermore, most definitions do not deal with the complexity and uncertainty inherent in the biodiversity concept. Accordingly, it is essential to develop a richer, more illuminating definition.

Biodiversity definitions in the literature fall within three general categories. The most prevalent focus is on ecological structure (form); followed by a focus on function (ecological processes); and an implicitly value-oriented focus on wealth or richness (resources). There is an emerging broader perspective of biodiversity as information (Lister, 1994), influenced by systems science, which is addressed in the following section. The most prevalent conventional definitions of biodiversity focus primarily on ecological structure, and to a lesser degree, on function⁴.

The United Nations' *Convention on Biological Diversity* (UNEP, 1992) and *Agenda 21* (UNCED, 1992) as well as major national policies (Biodiversity Working Group, 1995; DASET, 1992; USNRC, 1992) derive their definitions from two sources: McNeely *et al.* (1990) and the *Global Biodiversity Strategy* (WRI, IUCN, and UNEP, 1992). These documents define biodiversity structurally and functionally according to the common ecological hierarchy elaborated by Allen and Hoekstra

³ Traditionally, it has been focused on and limited to ecological structure and function in the context of ecosystem stability. This perspective will be elaborated later.

⁴ The range of definitions for biodiversity, illustrated with examples, is discussed in Lister, 1994.

Table I
Perspectives on biodiversity: Range of scales and contexts

Perspective	Scale	Context	Measures/Tools
Conventional: Structural and functional	Genetic	DNA: genes; alleles	Various; incompatible between scales; e.g.: <i>Conservation biology</i> : – species richness – Shannon-Weaver/ Simpson indices – minimum viable population – species-area curves – relative abundance <i>Landscape Ecology</i> : – patch dynamics – relative patchiness – network analyses – correspondence analysis
	Species	species, taxa	
	Population	populations of species	
	(Hierarchical; Scale-dependent)	Community	
	Landscape	landscapes; ecosystems (observer-defined)	
Emerging: Cultural and informational	All scales (except genetic)	human culture, ethology	Heuristic; qualitative notion
	All scales	information: genetic, behavioural, cultural, self-organizational [see also Table IV]	
(Holarchical; System-wide)			

Sources: Forbes, 1993; Forman and Godron, 1986; Lister, 1994; O'Neill *et al.*, 1986; Regier, 1993; Solbrig, 1991a; Woodley, 1991.

(1992) and O'Neill *et al.* (1986). The ecological hierarchy stipulates three general levels or scales: genes, species, and ecosystems⁵ or landscapes. In short, the traditional (structural) perspective is that 'biodiversity is the totality of genes, species and ecosystems in a region' (WRI *et al.*, 1992, p. 2), where: genetic diversity is the variability of the genetic code within a species and among constituent populations (considered the 'building block' of biodiversity, facilitating fitness, adaptation and evolution); species diversity is the variety of genetically similar organisms present in a given spatial unit; and ecosystem or landscape diversity is the variety of large-scale ecosystems or distinct landscape patterns in a given region.

⁵ Here, biodiversity refers to the third level of the ecological hierarchy and is often used synonymously with 'landscape' level. I do not find the notion of an 'ecosystem level' illuminating; I deem it a heuristic, useful in envisioning a living system at any scale – whether a cell, an organism, a community or the earth. I prefer the use of the term 'landscape' to denote specifically the third level of the ecological hierarchy.

Table I depicts both the conventional and the emerging perspectives of biodiversity within a range of scales and contexts according to the ecological hierarchy. The most tangible scale and the most common (but implicit) focus of conservation efforts is at the species level. In contrast, landscape diversity is the most complex scale (subsuming and constraining genes, species, populations and communities), and therefore, difficult to measure.

The concept of hierarchy⁶ is important here, because it facilitates the recognition of scale-dependency, i.e. the uniqueness of structure, function and ensuing measures or analytical tools to each ecological scale. For example, to measure species richness (a structural perspective at the species scale), one would use an index unique to that phenomenon; this measure could not in any useful way be compared to genetic diversity, relative abundance or connectedness at the landscape scale. Thus, there is no single convenient method of 'measuring' biodiversity. As Nowicki (1993, p. 65) notes,

'the condition of being different or having differences does not provide a good yardstick with which to measure diversity. It is more convenient to define diversity as a complexity of systems... Diversity does not imply that all components of the system are complex; it only implies that the system itself is complex'.

The measurement or analysis of biodiversity is dependent on scale and the measurement tool, but also on the observer of the system. Specifically, the decision of scale, boundary determination, the measurement and scope⁷ of the data to include in research or policy, are all significant means by which biodiversity is rendered dependent on the observer. Conventional definitions of biodiversity, limited to either one level of the hierarchy (e.g. species) or one perspective (e.g. structure), are problematic when they fail to recognize *explicitly* the scale and observer-dependency of the diversity concept.

Finally, even at the species scale of diversity, for which rudimentary measures and absolute counts of individuals exist, there is a staggering degree of uncertainty. Wilson (1992) puts the number of currently known (described) species at 1.4 million, yet conservative estimates of the total number of Earth's species are between 10 and 30 million. Wilson (1992) concedes that a more probable estimate

⁶ Koestler (1978) introduced the notion of 'holarchy'. Some prefer this term because it conveys a sense of synergistic interaction between system subsystems (or holons), rather than the dominance of one hierarchical level or scale over another. However, Kay (*per. comm.*) indicates that hierarchy theory does not imply 'control or dominance' of one scale, but rather 'constraint and influence' between scales. In hierarchy theory (or a holarchy), holons or subsystems are nested within the overall system, giving rise to the notion of a 'nested living system' (Günther and Folke, 1993). Recognition that living systems consist of nested holons (or Kay's (1994) notion of 'systems within systems within systems...') is critical to understanding the implications of observer- and scale-dependency.

⁷ Allen and Hoekstra (1992, p. 19) use 'extent' to refer to the 'highest level of organization that can be accessed'.

lies between 10 and 100 million species. Even at this level of diversity, about which we have the most complete knowledge, the total scope of diversity is unknown to within an order of magnitude.

2.2. EMERGING PERSPECTIVE ON BIODIVERSITY

Despite the complex nature of biodiversity, major management strategies and policy reports⁸ continue to use a definition limited to structural description according to three hierarchical scales. Similarly, scientific papers often fail to define the perspective or context in which they use the term, and the conclusions are often extended, by implication, to another level of the hierarchy⁹. Such definitions do little to assist decision makers in developing effective conservation plans. Consequently, a broadened emerging definition – explicitly incorporating the vital notions of scale and context, and the qualities of uncertainty and complexity – is proposed here. In addition, a pluralistic perspective of biodiversity is advocated to include *information* and *culture*. Through these enrichments, it is intended that the notion of biodiversity become a *heuristic*, and therefore useful in guiding conservation planning and management.

The analogy of a library, in which biodiversity acts as an information reserve is an emerging perspective in the literature. Janzen (1988) suggests that genes and species are analogous to books containing vital information, and landscapes or large-scale ecosystems are akin to a library which houses the books. Similarly, Ehrlich and Wilson (1991, p. 760) observe that ‘biodiversity is a precious ‘genetic library’ maintained by natural ecosystems’. In this broad sense, biodiversity as information essentially encompasses the capacity for a living system to renew and reorganize itself as part of a dynamic life cycle. As noted in Table I, information phenomena are system-wide, affecting all scales from genes to landscapes. This notion of an information perspective, to be developed more fully in Section 2, holds potential for biodiversity conservation planning by virtue of its permeation through the whole living system, rather than a single selected scale.

Similarly, the rarely recognized cultural perspective of biodiversity is essential to include in a heuristic definition. Typically thought of in its anthropological sense as ‘the unique character or way of life of a community’ (Baeker, 1994, p. 1), culture is absent in most¹⁰ definitions of biodiversity, thus implicitly separating humans from nature. Including a cultural perspective recognizes a vital linkage between humans and nature, where culture and nature are mutually intertwined, each influencing the other. The World Resources Institute (WRI *et al.*, 1992, p. 5) notes that,

⁸ E.g. Biodiversity Working Group, 1995; DASET, 1992; UNEP, 1992; USNRC, 1992; WRI *et al.*, 1992.

⁹ See e.g. Burton *et al.*, 1992; Margules *et al.*, 1988; Tilman and Downing, 1994 among others who, investigating species diversity, draw conclusions for the larger ecosystem scale, usually in the context of stability.

¹⁰ Notable exceptions being the National Round Table (1992) and the WRI *et al.* (1992) documents.

‘this linkage has profoundly helped determine cultural values. Most of the world’s religions teach respect for the diversity of life and concern for its conservation. Indeed the variety of life is the backdrop against which culture itself languishes or flourishes’.

Furthermore, the depletion of natural biodiversity is generally accompanied by, and is a partial result of, the loss of cultural diversity (Shiva, 1993; WRI *et al.*, 1992). It is important to realize that the homogenization of nature and the creation of biological monocultures have been a consequence of the domination of white, Western (mono)culture over many indigenous cultures – a phenomenon Shiva (1993) calls ‘monocultures of the mind’. Through further pluralizing biodiversity to include its cultural aspect, we recognize and validate the variety of humanity. In so doing, we legitimize a place for other cultural values and knowledge of biodiversity in planning for its conservation.

Through these emerging perspectives, the following heuristic definition of biodiversity is proposed:

Biodiversity is the variety, distinctiveness and complexity of all life on Earth, including its structures, functions, cultures, and information at all scales (from genetic to global) and in all its contexts (from DNA to self-organization).

2.3. THE NATURE OF SYSTEMS-BASED, POST-NORMAL SCIENCE

What is meant by systems-based, post-normal science? The explanation begins with a look at normal, conventional science and its socio-political context. Kuhn (1962) defined ‘normal science’ as research built upon a foundation of past achievements, involving theoretical activity and fact-gathering through experiments and observations. Past achievements constitute Kuhn’s notion of a ‘paradigm’ if they are sufficiently unprecedented and open-ended so as to attract a dedicated following to continue the line of research. Hence, normal science is paradigm-based (Kuhn, 1962). Normal (or conventional) science in Western society is based on the paradigm established during the Scientific Revolution of the late Sixteenth and Seventeenth centuries. The mechanistic, deterministic world view of Galileo, Bacon, Descartes, Adam Smith, and Newton form the ideological roots of conventional normal science and positivism. Positivism, characterized by the belief in reductionist science to deliver a knowable, unified and objective Truth, is still reflected in today’s institutions. Our present institutional arrangements and structures rely largely on conventional science to achieve their management goals through prediction and control.

The last hundred years have been marked by new discoveries in science – from quantum physics to complex systems theory – that have resulted in a collectively emerging view of the world as contingent, diverse, complex, dynamic and uncertain. Influenced in large part by Complex Systems Theory, the ‘new science’ has been

Table II
Conventional and new scientific inquiries: comparison of key features and basic beliefs

Conventional science (normal)	Conventional world view	New science (post-normal)	New, emerging world view
<ul style="list-style-type: none"> • Truth exists, knowledge = Truth • Order, structure, certainty • Domination, control over parts • Clockwork nature, mechanical universe • Deterministic predictable nature • Nature evolves to a static climax • Reductionist, collection of parts • Values hidden (in hypothesis) • Expert-driven, exclusive to peers 	<ul style="list-style-type: none"> • Truth • Simple • Hierarchy • Mechanical • Determinate • (Most often) Linearly causal • Assembly • Objective • Expert 	<ul style="list-style-type: none"> • Truth ('t') is plural, context-dependent • Order, disorder, uncertainty • Hierarchy as constraint, scales • Self-organization, information, lumps • Unpredictability inherent • Non-linear, synergy discontinuity, dynamic • Complex systems, nested holons • Values explicit, essential to inquiry • Extended Peers, inclusive of others 	<ul style="list-style-type: none"> • Truths depend on the observer • Complex, uncertain (chaos?) • Heterarchy, holarchy • Holographic, self-organizing • Indeterminate, unpredictable • Mutually causal, synergistic • Morphogenic, emergent complexity • Perspectival, contextual • Participatory, interdisciplinary

Sources: Funtowicz and Ravetz, 1991, 1993b; Kuhn, 1962; Schwartz and Ogilvy, 1979.

so-called¹¹ because its main tenets are so radically different from and diametrically opposed to those of conventional, normal science, as depicted in Table II. This new, systems-based science is also referred to as 'post-normal' (Funtowicz and Ravetz, 1991, 1993b) in contrast to Kuhn's normal science, in an even broader socio-political context.

It is worth emphasizing that post-normal science is not about holism¹² (in opposition to reductionism) but about a plural 'systemism' in which both the parts and the whole, and analysis and synthesis are necessary elements – hence the term 'systems-based science'. Similarly, the notion of relationships or connectedness is important; i.e. the observer and observed cannot be separated as they are mutually influencing (e.g. in quantum mechanics, complex systems theory, ecosystem hierarchy theory). Furthermore, there is no underlying 'either/or' ideology, because this science is plural, and thus, inclusive of many elements of conventional science. Funtowicz and Ravetz (1994) summarize that post-normal science involves the management of uncertainty through the democratization of knowledge via

¹¹ E.g. Drucker, 1989; Francis, 1995; Regier, 1993; Wheatley, 1992.

¹² Holism, in the sense that the whole is considered greater and implicitly more important than the sum of its parts, is by virtue of its exclusionary nature, an example of reductionism. I refer to holism in this sense only.

an extended, inclusive peer community, and the recognition of a multiplicity of legitimate perspectives and values. However, despite these fundamental shifts in scientific thinking, we still cling to the dominant conventional view of a predictable, clock-work universe. As Norgaard (1987, p. 107–108 emphasis added) notes,

‘Our current social order is rationalized by the Newtonian paradigm with its emphasis on static systems of mechanically related atomistic parts. This atomistic-mechanical view of a system, especially as it is reflected in our economic thinking, is inconsistent with the evolutionary view of a system... (e.g. the emerging) model of ecological systems consisting of tightly co-evolved parts and relations’.

Such inconsistencies are elaborated in the following section. From this, the challenges of a systems-based approach to biodiversity conservation are explored.

3. Ecological Contexts for Biodiversity Conservation

3.1. INTRODUCTION

Before conservation planning is undertaken, it is necessary to establish a context for such action. Accordingly, a brief summary of the current state of biodiversity and the major causes for its demise is useful. Given that there exists no single measure of biodiversity, establishing a reasonable estimate of loss or decline is problematic, if not impossible. Crude estimates are generally confined to the structural perspective of diversity at the species scale, yet are still tenuous since the total number of species on Earth is unknown. It is generally agreed that species loss has been increasing steadily over the past 400 yr – since humans began colonization – and that present rates are significantly greater than background extinction¹³.

Norgaard (1987) attributes the human-induced loss of biodiversity to three macrophenomena: increasing human population, technological change (resource extraction, industrial pollution, agricultural technologies etc.), and social organization based on a Newtonian, positivist paradigm. The clearest direct cause of biodiversity loss (at all scales, but most noticeably at the landscape level), is habitat destruction as a result of population growth and technological change (Ehrlich, 1988; Ehrlich and Wilson, 1991; McNeely *et al.*, 1990; Reid and Miller, 1989; WRI *et al.*, 1992). In tropical moist forests, areas considered hyperdiverse or ‘hot spots’ of (especially genetic, species and community) biodiversity, habitat destruc-

¹³ Extinction, usually balanced by the evolution of new species, is a normal on-going process, loosely estimated at a ‘background rate’ of 90 vertebrate species per 100 yr and 1 higher plant species per 27 yr (McNeely *et al.*, 1990). Periodic mass extinctions (e.g. during Cretaceous/Tertiary boundary) also seem to occur roughly every 26 million years according to the geologic record (Jablonski, 1991).

tion is usually irreversible and occurring at the fastest rate¹⁴. A secondary cause of biodiversity loss related to habitat destruction is fragmentation – the process of reducing contiguous natural landscape cover to isolated, disconnected patches¹⁵.

Biodiversity conservation is a normative endeavour. Like medicine, the science that is used to support biodiversity conservation is motivated by an ethic (Norton and Ulanowicz, 1992); indeed it is almost analogous in the desire to ‘heal and cure’ pathologies. Consequently, in the conventional sense, there can be no strictly scientific ‘ecological’ basis for conservation¹⁶. Rather, there exists a range of value-orientations resulting from ethics that underlie conservation motivation. Interestingly, the current literature makes much of the ‘scientific values’ for biodiversity¹⁷ – a particularly revealing oxymoron where conventional Newtonian science is concerned. However, it is possible to consider this a ‘trespass of semantics’ for the moment because ecology is divided between a reductionist and systems-based approach.

3.2. OVERVIEW OF ECOLOGICAL PERSPECTIVES

During the development of ecology as a science¹⁸ (confined here to the 20th century), the perspective of biodiversity and the resulting contexts for its conservation have been influenced by the dominant themes in ecological thinking. A key factor in the way biodiversity is perceived has to do with the schism that characterizes ecology. This schism has as its genesis the fact that ecology developed along two divergent routes: population ecology and ecosystem ecology. Both routes share three main areas of investigation which are designed to answer questions of ‘what’, ‘how’ and ‘why’: structural ecology (concerned with description, classification and natural history), functional ecology, and evolutionary ecology (Krebs, 1994; Smith, 1992). The development paths of ecology have become schismatic because population ecology has remained fixed in a reductionist approach, while ecosystem ecology has recently begun to embrace a systems approach. Table III provides

¹⁴ Ehrlich and Wilson (1991) record that tropical forests remain at only 55% of original coverage and that the rate of destruction doubled between 1979 and 1989. Remaining forest is being lost at an estimated 1.8% per annum – an absolute amount greater than the area of Costa Rica (Ehrlich and Wilson, 1991; Wilson, 1988).

¹⁵ There is a plethora of studies indicating the negative impacts of habitat fragmentation on species, population, community, and landscape diversity. See e.g. Harris, 1984; Lovejoy, 1986; MacArthur and Wilson, 1967; Wilcove *et al.*, 1986.

¹⁶ All so-called ‘scientific’ bases for conservation are ultimately motivated by an underlying, implicit set of values for biodiversity and an associated set of moral principles. For example, a commonly recognized ‘scientific basis’ for conservation is the life-support functions of the biosphere (Reid and Miller, 1989). However, this has nothing to do with science; it is an anthropocentric value for biodiversity, in that humans perceive some value to staying alive. This is discussed in detail in Lister (1994).

¹⁷ See e.g. Reid and Miller, 1989.

¹⁸ Here understood in the broad sense as the study of the relationships between organisms and their environment.

an overview of major developments in ecology, highlighting the schism and its differing perspectives of biodiversity.

The reductionist/systems schism in ecology may be due in part to the fact that it was not considered a 'real' (i.e. reductionist) science until the late 1960s. With its acceptance into the fold of normal science, the volume of ecological research has increased significantly.

Given that the majority of research has been established in an era of growing environmental concern, ecology has been linked to environmentalism – in both the media and by scientists themselves – and therefore, to normative science (MacIntosh, 1976). Furthermore, there is a broad spectrum of explicitly ethical contexts and bases for biodiversity conservation. Although not discussed here, the ethical contexts for conservation are eloquently explored in a rich and growing literature.

3.3. BIODIVERSITY IN ECOLOGICAL SCIENCE

Both of the major ecological doctrines, population and ecosystem ecology, have for many years debated the role of biodiversity in ecosystems, and there is no rigorous theory of biodiversity (Solbrig, 1991a, b). However, it is generally recognized that biodiversity has strong feedbacks to ecosystem structure and functional processes, although cause-effect relationships are not well understood and are rarely quantifiable¹⁹. Both ecosystem and population ecologists, although frequently divided in approach, perceive two general classes of roles for biodiversity in ecosystems: ecosystem stability and ecosystem function. These two classes of roles arise from investigations in structural and functional ecology, but it is argued here that the information role may hold the greatest potential as a basis for conservation.

3.3.1. *Biodiversity and Ecosystem Stability*

That biodiversity is connected to ecosystem stability is an old and dominant theme in ecology. Stability, the conventional generalization that there is an inherent 'balance' or equilibrium in nature, is linked to successional theory: as systems become more diverse during succession²⁰, it is believed that they become more stable. The maintenance of 'ecosystem stability' is a pervasive theme in the literature, and is frequently advocated as a basis for conservation²¹. However, the diversity-stability connection may be considered a flawed premise for three reasons: First, it is not a rigorously defensible theory; second, there is a wide range of contrasting

¹⁹ The Hubbard Brook Study (Bormann and Likens, 1979) is one of the best known examples of empirical research in ecosystem function.

²⁰ Here meaning the process of ecosystem development in which species assemblages are successively replaced by other colonizing species, becoming progressively more permanent. Early successional theories (e.g. Clements (1916) and Gleason (1926) though different in perspective) held that succession was a linear process, ending in a static, mature 'climax' stage. Ecosystem ecology (Holling, 1986; Odum, 1993) now recognizes that succession is a dynamic and cyclic process occurring at many scales – a concept that will be elaborated later.

²¹ Among many articles, see e.g. Burton *et al.*, 1992; Tilman and Downing, 1994.

Table III (continues on next page)
 Selected developments in 20th century ecology influencing the perception of biodiversity

Key figures	Year	Development	Biodiversity perspective
Clements	1916	Community Succession	Holistic, community-as-organism
Gleason	1926	Individualism, Niche Concept	Reductionist, focus on species/individual
Elton	1927	Animal Population Ecology	Reductionist, pop'n, natural history
Tansley	1935	The Ecosystem Concept	Systemic, multi-scaled, heuristic
Lindeman	1942	Community Trophic Relationships	Systemic, functional components
Watson and Crick	1953	Discovery of DNA Discovery of DNA	Genetic basis for diversity
MacArthur	1955	Food Webs + Stability	Reductionist, species/community
Hutchinson	1959	Diversity – Stability Hypothesis	Reductionist, species/populations
Margalef	1963	Diversity = Stability Theory	Reductionist, species/populations
Paine	1966	Food Webs + Species Diversity	Reductionist, species/populations
MacArthur	1969	Island Biogeography Theory	Reductionist, species/populations
Odum, E.P.	1969	Ecosystem Analysis, Homeostasis	Systemic, ecosystem 'physiology'
Lewontin	1970	Population Stability	Reductionist, predictive
Wilson	1970s	Sociobiology	Reductionist, genetic determinism
Odum, H.T.	1971	Ecosystem Energetics	Systemic, energy flows
May	1974	Population Modelling	Reductionist, predictive
Slobodkin	1974	Criticism of Math/Theoretical Ecol.	Reductionist, but less predictive
Bormann, Likens	1970–79	Forest Processes, Functions	Systemic, functional, community focus
Pickett	1978	Patch Dynamics	Reductionist, community-scale
Lovelock	1979	Gaia Hypothesis	Holistic, Earth-as-organism

Table III
Continued

Key figures	Year	Development	Biodiversity perspective
Soulé	1985	Conservation Biology	Reductionist: species, populations
Forman, Godron	1986	Landscape Ecology	Systemic, community-landscape
Lovejoy, Wilcove	1986	Habitat Fragmentation Studies	Reductionist, species/pop'n/community
Noss	1986	Corridor, Network Theory	Reductionist, species/pop'n/community
Holling	1986	Disturbance, Adaptive Mng't	Systemic, ecosystem function
Petraitis	1989	Diversity + Disturbance	Reductionist, community
Allen, O'Neill	1986, 92	Hierarchy Theory	Systemic, multi-scaled
Kay, Schneider	1992–94	Ecosystems as Complex Systems	Systemic, multi-scaled

Sources: Bocking, 1994; Golley, 1993; MacIntosh, 1976; Real and Brown, 1991.

interpretations for both terms; and third, post-normal science holds insights that fundamentally challenge the view of living systems upon which it is based. For these reasons, it is argued here that the diversity-stability association constitutes a weak basis for the conservation of biodiversity.

MacIntosh (1976) writes that the direct association of diversity with stability came about with the postulation that stability is imparted by increasing the number of links in the ecological food web. Kay and Schneider (1994) note that this idea, put forth by MacArthur (1955, in Kay and Schneider, 1994), was misinterpreted by Hutchinson (1959, in Kay and Schneider, 1994), elaborated by Margalef (1963, in Kay and Schneider, 1994) and led to the eventual codification of the diversity-stability hypothesis²². Along with May (1974) and others who refuted the diversity-stability hypothesis on mathematical grounds, Goodman (1975) analyzed its foundation and showed that there is no robust basis for the hypothesis. In addition to these counter-arguments, there is continuing field evidence which shows mature forests contain fewer species than transitional (seral) forests. Despite the evidence against it however, the diversity-stability hypothesis has become 'almost axiomatic to some biologists' (MacIntosh, 1976, p. 366), and is still cited in many ecology texts today. Yet, as Real and Brown (1991, p. 188) surmise,

²² For a detailed account of the development of the diversity-stability hypothesis, see Kay and Schneider, 1994; MacIntosh, 1976; Pimm, 1991; Schneider and Kay, 1994.

‘[t]oday we realize that the whole debate about diversity and stability is flawed to a large extent by the imprecision in definition these terms... Depending on the definition one chooses for these terms, one can obtain diametrically opposed results.’

It is for this reason that the author devoted space to the analysis of the definitions for ‘diversity’ at the outset of this paper. Yet stability is also a fuzzy concept which, until recently, was rarely defined. Pimm (1984, 1991, 1993) has written extensively on the range of interpretations of stability, arising from five distinct meanings: strict (mathematical) stability, resilience, variability, persistence, and resistance. He notes that in general, the meanings are related to the similarly abstract notion of ‘balance’ in nature (Pimm, 1991). Kay (1991a) observes that stability is generally meant to convey that ecosystems are ‘well-behaved’ although a more formal definition is problematic. In the strict mathematical sense, stability is defined as a numerical function (a state point) having constant value to which the system tends and returns following disturbance (Kay, 1991a). Although the classical definition harkens intuitively close to the elusive ‘balance of nature’, Schneider and Kay (1994) are quick to ask which state function should be measured to determine stability; they emphasize that the choice of one function – whether net productivity or food web complexity – represents only one aspect of stability, not the view of the whole system. Clearly, the juxtaposition of two complex and abstract concepts – diversity and stability – poses a simplistic and tenuous context for conservation, especially given the political pressure put on ecologists to provide rigorous management rules in the context of conservation.

Nevertheless the diversity-stability connection is still advocated as an ecological basis for conservation. Wilson (1992, p. 12 emphasis added) paraphrases the essence of the still popular diversity-stability hypothesis:

‘Biological diversity is the *key to the maintenance of the world as we know it*. Life in a local site struck down by a passing storm springs back quickly: opportunistic species rush in to fill the spaces. They entrain the succession that circles back to *something resembling the original state of the environment*.’

The notion of the ‘balance of nature’, a return to equilibrium, is implicit in Wilson’s conclusion and reflects the underlying dominant view of ecosystems: that there exists an ideal stable state, and its maintenance depends at least in part on some ‘level’ of biodiversity. As Solbrig (1991b) observes, the notion of equilibrium in nature has persisted because the dominant perception has been that ecosystems could be described according to Newtonian deterministic laws. Yet, in a strictly thermodynamic sense, living systems cannot be at equilibrium: an organism at thermodynamic equilibrium with its surroundings is dead. Even in the purely physical sense of balance (where all forces acting are equal), equilibrium is not a useful substitute for stability, as living systems are characterized by fluctuations

– weather, populations, biomass etc. As noted by Schneider and Kay (1994), these ecosystem functions are now recognized as dynamic, i.e. they are not stable themselves and thus cannot be used to measure even strict stability.

Post-normal science, and complex systems science in particular, have provided a new perspective of living systems, fundamentally different than the Newtonian-based perspective outlined earlier. Notably, in the context of the diversity-stability debate, living systems are shown to have multiple steady states, leading to what Kay (1994) and others have termed a ‘shifting steady state mosaic’. Thus, the idea of a single optimum and homeostatic state is replaced by the reality of multiple steady states²³. The fact that ecosystems may ‘shift’ or diverge from any one of a number of steady operating points is a critical revelation of research in the new science. Furthermore, Holling (1986, 1992) has shown that divergence from a given operating point or state by means of natural catastrophe, such as fire, pest outbreak or human-induced perturbation, is a *normal* and usually *cyclic* event. With these insights from systems-based science, it is clear that the diversity-stability hypothesis is an out-dated paradigm.

3.3.2. *Biodiversity and Ecosystem Function*

Another key class of roles for biodiversity may be found in ecosystem function. The essential processes of living systems – nutrient cycling, carbon and water cycling, productivity, etc. – are certainly dependent to some degree on the diversity of genes, species, populations, communities, landscapes and information, whose structures and composition perform these functions. Furthermore, the *diversity of functions themselves* is undoubtedly critical to the maintenance of ecosystems, and ultimately, the earth’s life support system (Odum, 1993). We consider only the role of (structural) biodiversity in ecosystem function, focusing first on the species level, and second, with evidence from systems science to the macro community/landscape or ecosystem level. The role of functional diversity in ecosystem function is not explicitly considered as this demands a level of complexity that is beyond the realm of current ecology²⁴.

It is a dominant proposition in the literature (Ehrlich, 1988; Naeem *et al.*, 1994; Schulze and Mooney, 1993; Wilson, 1985; Mooney *et al.*, 1996) that the loss of structural and functional biodiversity (largely through habitat destruction

²³ There are two types of mathematical stability. Ecosystems possess multiple stable or steady states; i.e. they occupy a *domain* around an equilibrium point, known as an attractor. This contrasts with strict stability in the other sense, in which homeostatic systems occupy a single stable *point*, to which they return following perturbation (the conventional view of ecosystems). The key difference in the revised view of ecosystems is that, as non-homeostatic systems, they return to the general *domain* – not to the exact same *point*. (Except in the case of catastrophic disturbance, where the system may flip to the domain of another attractor.) A detailed discussion of ecosystems as complex systems is found in Jørgensen, 1992; Kay, 1991b; Schneider and Kay, 1994.

²⁴ Holling *et al.* (1995 p. 48–49) note that, although ‘changes in functional diversity will have immediate and profound effects on ecosystem performance... function is more difficult to identify and measure, and does not easily lead to an ordered hierarchical classification. [Thus,] ecologists have so far been unsuccessful in their attempt to develop an ordered functional classification’.

and fragmentation) impairs ecological systems and their ability to continue self-maintenance. Although diversity-function feedbacks are generally poorly understood and rarely quantified (Solbrig, 1991a), the premise that ecosystem function is dependent on biodiversity is advocated as a basis for conservation in key policy reports (McNeely *et al.*, 1990; Reid and Miller, 1989; WRI *et al.*, 1992). Concern for the maintenance of unimpaired ecosystem function lies in the assumption that it is ultimately integral, at the biospheric level at least, to the provision of human life-support. Accordingly, there is a growing body of literature that attempts to link structural diversity to ecosystem processes. Such research has been generally confined to groups of organisms whose specific functions are known, such as nitrogen-fixing bacteria, although broader studies have been undertaken in Schulze and Mooney (1993) and Naaem *et al.* (1994).

Of the plethora of possible diversity-function links, this analysis is confined to a conventional premise that connects species to ecosystem functions. Paine (1966) introduced the idea that certain species, termed 'keystone species', are largely responsible for 'community integrity' (here meaning stability) and have an effect on the survival of other species. The notion of keystone species has since become a major platform for the connection of biodiversity to ecosystem function. Bond (1993, p. 237) argues that keystone species 'should be conserved because they have a disproportionate effect on the persistence of all other species' through their actions which may be directly or indirectly tied to ecosystem functions²⁵. Westman (1990) observes that certain species, particularly among decomposer microorganisms and litter invertebrates, may be directly tied to ecosystem function, and that these 'critical link species' are rarely considered for conservation action. The discussion over keystone species has become a debate among ecologists in the determination of which species play vital roles in maintaining ecosystem functions and thus, which should be targeted for priority conservation action.

Erhlich and Erhlich (1981) contend that all species play a small but significant role in ecosystem function, and if conservation emphasized only those species considered keystone species, it would be a serious mistake²⁶. The opposing view

²⁵ E.g. keystone species include: large carnivore predators, selected herbivores (e.g. elephants, rabbits), pathogens, and parasites, all of which suppress competitor populations; mutualists such as pollinators and dispersers which facilitate effective reproduction; system processors such as nitrogen fixers and mycorrhiza which affect rates of nutrient transfer; and earth-movers such as gophers and termites which facilitate other functions (soil aeration, water percolation, nutrient-freeing etc.).

²⁶ Erhlich and Erhlich (1981) created the 'rivet-popper' problem to illustrate this contention. Species may be considered analogous to rivets in an airplane. When one or two rivets are popped (or species lost) no serious damage is done due to the redundancy in fail-safe design. However, if rivets are continuously lost, some threshold is crossed and the plane loses its air worthiness and crashes, analogous to eventual ecosystem collapse if enough species are lost. Walker (ND in Baskin (1994)) counters the rivet popper problem by suggesting that the redundancy of fail-safe design in aircraft is analogous to ecosystems, which, he contends, have considerable built-in redundancy. Thus, according to Walker, redundant species are more akin to passengers rather than rivets on an aircraft. Yet neither of these perspectives is helpful in a pragmatic sense because ecologists cannot determine which species are 'rivets' and which are 'passengers'.

is that most species are redundant and only a small set of keystone species and processes is critical to ecosystem structure and function (see, e.g. Baskin, 1997 and Holling *et al.*, 1995). However, both these perspectives leave conservation planners with a fundamental conundrum: the threshold of functional collapse will likely be crossed before it is known how many or which species can be considered expendable.

The on-going debate over the role of species in ecosystem function is a classic example of reductionist ecology's search for an 'either/or' truth; it is typical of the search for simple rules to describe complex systems from which conservation and management policy can be derived. It is the author's contention that asking 'which species play which role' is the wrong question. Rather than being an issue of 'either keystone/or redundant', it is far more likely that species play *both roles*, although at different times in different ecosystem states or contexts. Thus, it is not a matter of 'either/or', but 'when'. This contention is based in part on insights from systems science (see e.g. Allen and Hoekstra, 1992; Jørgensen, 1992; Kay and Schneider, 1994) which reveal that the use of simplistic 'rules' established at one level of the hierarchy, or in one specific ecological context, can not be transferred meaningfully to another scale or context to make generalized statements about the role or function of biodiversity. Thus, there can be no universal 'magic number' or threshold for any scale of diversity let alone the whole system. Although it is reasonable that *some* level of biodiversity is critical to proper system function, it would almost certainly be unique to each discernible system at each observer-defined scale. Recent research by Naeem *et al.* (1994) indicates that the theoretically possible identification and conservation of select keystone species would be limited to a specific context, which if altered through pest outbreak or climate change, would leave nothing as 'back up'. Encouragingly, there is growing recognition in the literature (see e.g. Noss, 1990; Pimm, 1991; Solbrig, 1991a) that ecological research must be carried out on multiple spatial and temporal scales, using reductionist (e.g. population ecology) and systemic (e.g. ecosystem ecology) approaches if a deeper understanding of ecosystem function and diversity is to be achieved and an operational context for conservation planning derived.

3.3.3. *Biodiversity and Information*

The third major class of ecological roles for biodiversity lies in information. It has been recognized that there is an informational role for biodiversity in terms of genetic structure and function²⁷. Genes are often seen as a 'library' of information (Ehrlich and Ehrlich, 1992; Janzen, 1988) which essentially drives evolution and adaptation. Biologists, from Darwin to Wilson, have traditionally held that the gene is the root of life's information, driving natural selection through random processes of chance mutation, and thus, acting as the motor of adaptation and evolution (and social behaviour in the extreme sense of sociobiology). Armed

²⁷ E.g. Margalef (1993, p. 3) considers biodiversity as 'non-redundant genetic information contained in any segment of the biosphere'.

with the theory of natural selection and the discovery of DNA as the essence of genetic information, some reductionist biologists, lead by Neo-Darwinists such as Dawkins (1986, 1989), effectively consider the ‘mystery of life’ to be solved. According to Dawkins (1986), all that remain are questions of detail. Yet, this assumption is simplistic and does not consider the perspective of self-organizing living systems offered by systems science. There is an emerging, much broader role for biodiversity in an informational context, and this role, supported by post-normal science, may hold great potential as a basis for conservation planning.

Kay (1984) and others have shown that living systems are open and self-organizing, i.e. they are capable of self-renewal or regeneration following disturbance²⁸. This perspective, arising from Prigogine’s (in Kay, 1984) work on dissipative systems, is relatively new and was not a consideration for Darwin and Spencer – the founders of natural selection theory. As part of systems-based science, self-organization theory allows for the spontaneous creation of order from disorder. In living systems, the result of self-organization is life itself²⁹. Kauffman (1991) observes that self-organization provides a new basis for evolution beyond conventional natural selection. However, he is quick to emphasize that Darwinism (natural selection) is not wrong *per se*; only that it is *incomplete* (Kauffman 1994). Similarly, Wesson (1991) calls for a modernization of Darwinism and looks to complex systems theory for a synthesis. Wesson (1991, p. 36) suggests that ‘self-organization is the essence of the origin of life and its complexification, that is, evolution’. Given this, the gene can no longer be the ‘driver’ of evolution in an information context. In this new perspective, Kay (1984; Kay and Schneider 1994) observes that genes *constrain* the process of self-organization. That is, in an information sense, the role of the gene is to bound the structuring process in living systems, remembering fitness and facilitating adaptability and evolution.

A hallmark of self-organization (and thus complex systems) is the emergence of new structures, properties, functions and behaviours. Solbrig (1991b) defines emergent properties as those qualities of ecosystems *which are not present in the constituent parts* (genes, species, populations, or communities), yet are a result of

²⁸ The notion of living systems as open and self-organizing is important. As open systems, they do not contradict the 2nd Law of Thermodynamics as was once thought. Rather, they have been characterized (Jørgensen, 1992; Kay, 1984; Kay, 1991b; Schneider and Kay, 1995; Schneider and Kay, 1994) as non-equilibrium thermodynamic, dissipative systems; i.e. they are maintained some distance from thermodynamic equilibrium. When pushed from a present steady state through the application of a gradient (e.g. incoming energy), living systems will degrade the gradient (i.e. the exergy, or the amount of energy available to do work) and in doing so they build structure, i.e. they further organize themselves. As structure is built and organization is increased, so is the ability to more efficiently degrade applied gradients and exergy. The role of dissipative systems, thermodynamics and complex systems is discussed in detail in the references cited above.

²⁹ Living systems have been dubbed to exist ‘on the edge of chaos’ since the ordering process of self-organization occurs between periods of chaos, or disorder (Lewin, 1992). Self-organization occurs in a ‘window of vitality’ (Ulanowicz, 1993 *per. comm.*; Kay, 1994) when a gradient of sufficient *but not too much* exergy is available: too little exergy means that self-organizing structures will not appear, whereas too much exergy results in system chaos (Kay, 1994). The ‘edge of chaos’ is unique in that it results in both complexity and limited predictability in its self-organized structures.

Table IV
Biodiversity as information

Genes	Species, populations, communities	Landscapes, whole systems
<ul style="list-style-type: none"> • DNA is the genetic blueprint and primary information source; the basis for evolution through variability and mutation due to self-regeneration. 	<ul style="list-style-type: none"> • Variety and distinctiveness within species and populations are forms of historical information; a link to the past through the evolutionary record encoded in the genome. 	<ul style="list-style-type: none"> • In open, self-organizing systems (e.g. ecosystems), information may emerge without a pre-established blueprint. This contrasts with information decay and loss in closed systems.
<ul style="list-style-type: none"> • Genetic materials are sources of both present and future information and may be considered 'information reserves' which allow for future options through adaptation to new situations. Folke's (1994) notion of 'insurance' for ecological self-renewal. 	<ul style="list-style-type: none"> • Expression of the genome includes the emergence of complex epigenetic information, as in behavioural and adaptive responses. Such emergent information is not predictable from the genetic code alone. 	<ul style="list-style-type: none"> • Diversity, or information, at the systems-level requires but does not rely solely on the genetic information level. Emergent information, such as cultural diversity and behaviour are a feature at this level.
<ul style="list-style-type: none"> • Kay's (1984) notion that genes act as a <i>constraint</i> on the organization of life at all levels of the ecological hierarchy, from individuals to complex living systems. 		<ul style="list-style-type: none"> • Community structure and adaptive responses, especially in a landscape mosaic, include feedbacks of natural and cultural information. This may also be seen as emergent complexity.

Adapted from Lister (1994) using: Folke, 1994; Holling *et al.*, 1995; Kay, 1984; Regier, 1993; and Schneider and Kay, 1994.

interaction between system components and the self-organization process. (Examples are trophic and niche structure, seral stages, and system complexity itself.) Funtowicz and Ravetz (1993a) emphasize that emergent complexity is a defining feature of living systems, rendering them literally 'more than the sum of their parts'. In this respect, biodiversity can be seen as emergent information. Specifically, the creation of new information (and diversity) occurs at all ecosystem scales and contexts during self-organization and the ensuing processes of ecosystem self-renewal/regeneration. This idea can be extended throughout the living system, with a role for biodiversity in an informational sense at each scale.

Table IV depicts this informational perspective of biodiversity as applied to the three standard ecological hierarchical scales. Through self-organization and related themes in systems science, a whole new role for biodiversity as information unfolds.

If biodiversity acts as information at scales beyond the genetic, what might be its primary role in the life cycle and functions of living systems? Recent work (Holling, 1986; Holling, 1992; Holling *et al.*, 1995) in complex systems science has shown that ecosystems follow cyclic (rather than linear) paths of development, regularly punctuated by sudden, unpredictable and rapid episodes of change to a variety of other possible states. Disturbance, or perturbation from a seemingly steady state (by means of fire, storm, pest outbreaks etc.) is now known to be a normal and integral part of living systems occurring on a more or less regular basis³⁰. Therefore, the ability of species, populations, communities and whole systems to recover, reorganize and adapt in the face of regular change is critical to survival.

It is in this context that biodiversity, in an informational sense, is vital to system function. To illustrate, let us return briefly to the earlier discussion of species as keystone or redundant. It was emphasized that it was not a matter of 'either/or', but a question of when a species acts in which role. Given the propensity for systems to move between multiple operating states, it is reasonable to expect that keystone species in one ecosystem state may be redundant in another. Folke (1994) has used the term 'insurance species' rather than 'redundant' to convey the notion that species are likely to perform different functions under differing circumstances, and therefore, in different contexts. As Holling *et al.* (1995, p. 67) note, 'the [keystone] role of species may only become apparent every now and then under particular conditions that trigger their key [organizing and] structuring function'. Furthermore, our understanding of species-function links is weak even in present – let alone future – ecosystem states. Holling *et al.* (1995) suggest that the dominant conviction that only a few species are keystone (or critical to the structuring processes that result in ecosystem function) may be based on the limited choice of variables that researchers have modeled. Since we do not know whether our conclusions about the role of species in ecosystem function are a consequence of the models or of actual ecosystem dynamics, the notion of 'insurance' species, or biodiversity as 'information' in a broad sense becomes an important consideration for conservation decisions.

In keeping with the lessons learned from hierarchy theory³¹, it should be stressed that it is not useful to reduce information to a single scale. Although theoretically it may be possible to measure biodiversity in an information context, it would require simplification of system phenomena to the point where the emergent complexity is no longer apparent; i.e. to the point where the system can be predicted and controlled. In doing so, Schneider and Kay (1994, p. 19) observe that the 'very phenomena that ecology seeks to understand' would be lost. Furthermore, the issue of context is essential to any discussion of biodiversity conservation in an information sense. Because biodiversity information acts in the bio-physical environment

³⁰ Work in this area began with Holling (1986) but is now found throughout the ecological literature. See, e.g. Hansen *et al.*, 1991; Petraitis *et al.*, 1989; Ricklefs, 1987; Solbrig 1991b.

³¹ See notes 6 and 7.

for which it is adapted, it must be conserved *in situ* if the information is to have meaning in a regenerative sense (Kay and Schneider, 1994).

Figure 1 depicts the dynamic cycle of ecosystem development (modified from (Holling *et al.*, 1995; Kay, 1994)). As systems evolve, they do so discontinuously (creating 'lumpy' geometry and distribution of elements). Following inevitable and sudden disturbance, the system reorganizes to 'renew' or regenerate itself to a similar or perhaps new state. It is at this stage, immediately following disturbance, that information is most critical: the volume and type of information available in the diversity of a system's structures and functions (e.g. species) will determine its ability and direction of regeneration through reorganization. In this way, the informational aspect of biodiversity serves to facilitate the essential, life-giving process of self-organization. Clearly, given the pattern of ecosystem development offered by systems science, it is not a matter of redundant diversity, but of what might be termed 'investment' diversity that should be the basis for precautionary conservation planning. Despite the uncertainty about 'how much' diversity is enough, it may be more helpful to consider biodiversity as an investment for the future: i.e., biodiversity protection is essential because ecosystem change is an *inevitability*, not a contingency³².

Biodiversity as information provides us with broad, systems perspective, in which the diversity of life is characterized by complex *interactions* rather than a collection of individuals. Thus, as a library of historical and emergent information, biodiversity provides not only a multiplicity of evolutionary and adaptive pathways for future development of life on earth, but the *essential regenerative capacity for all living systems* (Lister, 1994). Although the emerging notion of biodiversity as an investment is not widely recognized, it holds significant potential as a heuristic for conservation policy. Specifically, the adaptive and regenerative information capacity of biodiversity can illuminate trade-offs necessary in the conservation planning process.

4. The Challenges of Post-Normal Science

A systems-based, post-normal perspective of science accepts uncertainty, complexity and diversity as natural phenomena. Thus, in the absence of 'Truth' or certainty, scientific inquiry should illuminate choices and trade-offs, which planners must consider in conservation goal selection – the process of which is value-driven. However, current conservation decision making relies largely on the traditional scientific context of biodiversity to *determine policy and planning choices*, rarely considering values explicitly. This continues to be the case because planning is still

³² The analogy of biodiversity as an 'investment' may also be more powerful as a (heuristic) basis for conservation than the notion of biodiversity as 'ecosystem insurance' put forth by Holling *et al.* (1995) because it is unlikely that conservation planners will be able to argue successfully for costly 'insurance', based on the perceived contingency of ecosystem change.

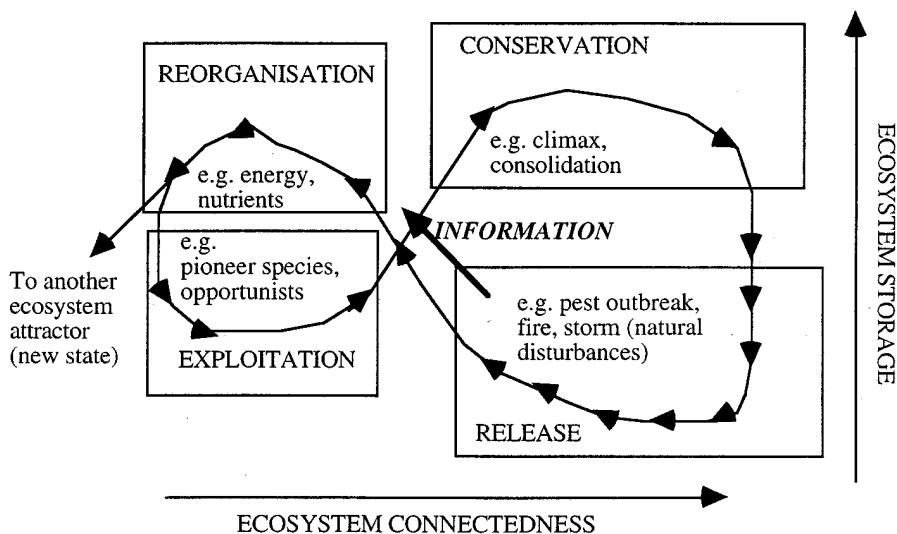


Figure 1
HOLLING'S MODIFIED FIGURE-EIGHT:
A CONCEPTUAL MODEL OF ECOSYSTEM DYNAMICS

- The model depicts the dynamic cycle all ecosystems follow: *growth* (exploitation), *maturity* (conservation), *death* (release), and *renewal/birth* (reorganization). This representation is a further modification of Kay (1994), showing a critical stage for *biodiversity* (information) following disturbance, during reorganization.
- The arrows indicate the speed of the flow in the ecosystem cycle, where arrows in close proximity indicate rapid change and arrows spaced farther apart indicate a slower process of change. The Y-axis arrow indicates increasing storage of nutrients and carbon and the X-axis arrow indicates increasing connectedness between ecosystem variables.

Figure 1. Sources: Holling, 1986; Holling *et al.*, 1995; Kay, 1994.

widely practiced on an expert-driven, rational model using economic choice to lead to pre-determined ends (Dalton, 1986). In fact, the problem of biodiversity loss itself can be partially attributed to decision-making which has fragmented, manipulated and controlled natural systems and has ultimately resulted in the homogenization of landscapes and diversity³³. Therefore, the challenge of post-normal science in the context of biodiversity conservation is to reform decision making from control-oriented, predictive and interventionist *management of the environment* to adaptive, flexible and participatory *management of human activities*.

Systems-based science has shown that living systems are open, self-organizing, hierarchically nested, and highly complex – they develop in inherently unpredictable ways and have a plurality of operating states from which they regularly, and suddenly diverge. Most importantly, it is understood that ecosystems are not

³³ This concept is explored by Merchant, 1980; Shiva, 1993.

homeostatic and they do not operate along a smooth and continuous path to a single optimum state. The ‘lessons’ learned from a systems perspective on ecological realities emphasize central tenets of uncertainty, complexity, and diversity. These ‘lessons’ can be put into a generalized context for conservation planning and management and might be summarized as follows³⁴:

1. Expect the unexpected: change is normal but can’t be predicted with certainty.
2. Live with change: structures come and go but processes endure.
3. Look around: you can’t see the whole picture by looking at only one piece.
4. Don’t generalize: ‘rules’ established in one context can’t be applied meaningfully elsewhere.
5. Truth is observer-dependent: the perspective and values of the observer shape the perception of what is ‘real’.
6. More is better: a collection of tools and approaches is necessary since one can’t do the job alone.
7. Life is complex: don’t expect simple answers to complex problems.

A key challenge of post-normal science is to recognize that control-oriented management of diversity often reduces diversity – a paradox identified by Ehrenfeld (1991). In moving toward adaptive rather than control-oriented management, conservation decision makers must focus on ecosystem processes. ‘Because ecosystems are self-organizing and creative... management must have as a central goal the protection of the system’s creativity’ (Norton, 1992, p. 37). This means that conservation of biodiversity (as insurance for system regeneration) is essential despite the uncertainty about how much is enough. The challenge for conservation decision making is how to invoke the precautionary principle. Insights from complex systems science assure us that the unexpected will occur. Thus, with respect to biodiversity conservation, decision makers are clearly challenged to invest in the future: they must plan adaptively for inevitable ecosystem change.

A cornerstone of post-normal science is the meaningful and explicit inclusion of a variety of voices and values into the planning process, particularly in the goal-setting stage of any conservation plan. However, the ability to do this requires enlightened conservation managers who are open to a broad set of informed scientific and ethical perspectives on biodiversity. In essence, conservation planning must become a participatory and cooperative endeavour. The need for both reductionist and systemic approaches to research is emphasized by Jørgensen (1992) who notes the plurality of perspectives needed in complex ecological systems theory. Because conventional science cannot adequately describe ecosystems or biodiversity, a cooperative and interdisciplinary approach to research is essential.

In this regard, Funtowicz and Ravetz (1994) call for the ‘democratization of science’ in which the pursuit of quality – rather than ‘Truth’ – becomes paramount.

³⁴ With ideas from Funtowicz and Ravetz, 1994; Kay and Schneider, 1994.

Quality assurance is achieved through the extension of peer communities beyond the conventional experts to include, e.g. traditional knowledge of indigenous cultures, landowners, and natural historians. In this way, shifting the focus of science to 'quality assurance' to deal with uncertainty, a role for broader participation in the decision making process is validated. Furthermore, the need for cooperation and participation is extended to decision making in terms of which research is employed, fostered and ultimately factored into the value-driven conservation planning process.

In dealing with uncertainty and complexity, conservation values must be made explicit if planning goals are to reflect the desired ecosystems states (and hence biodiversity) to which decision making and management are ultimately targeted. Notably, this also entails legitimizing values of biodiversity beyond conventional anthropocentric ethics. Given that systems-based science demands a recognition of humans as part of a mutually-constraining living system – rather than externally dominant or controlling – there emerges the need to validate a new class of ethics. Des Jardins (1993) articulates the need for ethical holism; i.e. the extension of moral consideration to whole living systems. Such ethical considerations should necessarily be built into a framework for biodiversity conservation planning. Harper and Stein (1992; 1993) observe that normative ethical theory has an inherent role in planning and, although relevant to contemporary planning practice, remains largely ignored. Reiterating a key lesson of systems science, Wheatley (1992, p. 151) observes: '[w]e cannot expect answers. Solutions, as quantum reality teaches, are a temporary event, specific to a context, developed through the relationships of persons and circumstances.'

Thus, ecological science can only illuminate options. This point provides a solid basis for the re-marriage of ethics and planning practice wherein the identification of conservation choices – in a democratic political context – will be determined by value-driven planning goals.

5. Building a Systems Approach

At the Earth Summit, Canada became the first signatory party of the *United Nations' Convention on Biological Diversity*. In 1995, in keeping with the commitment to develop policies for the conservation and sustainable use of biodiversity (as stipulated in the Convention), the Canadian federal government released the *Canadian Biodiversity Strategy* (Biodiversity Working Group 1995). The planning process for implementation is underway, shaped to a large extent by conventional ecological science. The post-normal perspective of ecosystems as open, self-organizing, and complex is generally not being advocated for research and policy support. If this trend continues, it is reasonable to expect that the Canadian institutional response to biodiversity will remain focused at only one level of the ecological hierarchy and will not adequately reflect the ecological complexity that characterizes

biodiversity³⁵. This being the case, it is essential that new insights from ecological science and a broader socio-political context for biodiversity are brought explicitly into the conservation planning process.

How should a planning framework for biodiversity conservation differ from the existing modern, normal-science based approaches? The key lies in reflecting on the new perspectives of ecological science and an awareness of the resulting implications for decision making. Briefly, this requires an appreciation of complexity and uncertainty in ecological realities, and an approach to planning that is based on diversity – in the post-normal context. The implications for decision making discussed in the previous section effectively form the basis for a planning framework for conservation. For example: systems science challenges decision makers to become less concerned with prediction and control, and to move toward more organic, adaptive and flexible management. In the absence of certainty and predictability, the implication for decision making is that greater participation in the process is necessary – decisions will be negotiated rather than pre-determined by rational choice. Thus, a key element in a conservation planning framework must include deeper participation, and in fact, collaboration with an extended peer group. Using this rationale, the remaining key heuristic elements can be identified in summary as follows:

1. *Empowerment* of an ‘extended peer group’ who will participate in the decision-making and judge the quality of the process. (These may not necessarily be the same people.)
2. *Participation* of an extended peer group in the decision-making process lends ‘quality assurance’ to the process. The extended peer group which judges ‘quality’ should include both experts and local citizens, managers, stakeholders and interdisciplinary scientists.
3. *Cooperation* among and between reductionist and systems research suppliers, public and private sectors, experts and non-experts, planning jurisdictions, and institutions.
4. *Negotiation* of four key elements:
 - A. a systematic, defensible and accountable methodology for the decision-making process;
 - B. the criteria for quality;
 - C. values to determine planning goals; and
 - D. conservation planning goals and objectives.
5. *Inclusion* of multiple perspectives, values, ideas and experiences into the conservation goal-setting process, to be determined through negotiation.

³⁵ The majority of current biodiversity research is focused at the species level of the ecological hierarchy.

6. *Collaboration* among participants to deepen the meaning of participation and to shift the balance of power from experts to an extended peer group in the face of uncertainty and complexity.

This conceptual approach is iterative: each element feeds information into another and the process shifts in a cyclic pattern as feedbacks result in directional adjustment. The approach is also a holarchy: no single element can lead the other, yet all impose constraints on one another.

Given our preference for neat, simplified and quick fixes, it is reasonable to question whether there exists the political will to implement such an open approach. Clearly, the precautionary principle should apply, and every effort should be made to adjust to the realities of uncertainty and complexity before conservation managers are forced – and inadequately prepared – to do so. In a post-normal sensibility, the above systems-based approach is conceptual and generalized. It is deliberately generalized as a set of guidelines rather than a specific recipe, because it *must* be shaped according to each unique conservation planning issue. To devise a ‘new model’ with elaborate detail and advocate it as the preferred planning model would be missing the point completely. In the absence of a single ‘best model’ provided by conclusive ecological science, the logical approach to conservation planning is to search for a set of *common elements* that work in a majority of similar cases.

6. Conclusions

With insights from systems-based, post-normal sciences, a broader role for biodiversity in ecosystem dynamics has emerged. This is not to say that a ‘new science’ has replaced an ‘old’ or outdated science, but rather that the newer perspective of ecosystems requires a *broader set of tools*. Clearly, the standard approach to conservation management through prediction and control is well-suited to closed, mechanical systems and to smaller-scale, well-understood environmental problems with a few, controlled variables. The post-normal, systems-based perspective of biodiversity challenges conservation planners and managers to move away from prediction and control-oriented strategies and move toward more adaptive management of human activities. Coming to grips with uncertainty and complexity demands an iterative process of change, between individuals and institutions. For practical purposes this means that we must look to more adaptive management approaches with less emphasis on prediction, control and efficiency, and more emphasis on building adaptive capacity for change, built-in flexibility, collaboration with a variety of interest groups, and an appreciation of ecological scale, context, and historical change. In short, a systems approach to conservation planning demands that we *expect uncertainty, embrace complexity, and celebrate diversity*.

Appendix – A Systems Approach in Practice

What would an adaptive, systems-based approach for biodiversity conservation look like in operation? How can this be accomplished in practice? Although clearly in its infancy, I propose the following set of guiding principles as the basis for an adaptive planning approach. I do not pretend that such an open, inclusive framework will be easy to implement in either attitude or practice. Rather, this approach is intended to *stimulate discussion* and *motivate alternative conservation initiatives*, from grassroots to national levels. With help from creative and innovative conservation advocates in science and policy, this systems approach to conservation may provide a route to navigate the waters of uncertainty and complexity.

In practice, an adaptive, systems-based approach would require collaboration by a broad, representative and interdisciplinary ‘conservation community’ of scientists, planners, managers, and citizens. The approach requires that the conservation community:

- ESTABLISH A RIGOROUS YET FLEXIBLE DECISION MAKING PROCESS

A systematic, accountable management process includes rule systems for participation³⁶, a defensible methodology, and criteria for judgment of ‘quality’ of the process³⁷. The process established in one context may not be the same in another; it will be (to some degree) a function of the individuals and their interactions around the table.

- CHOOSE A VISION FOR THE FUTURE

The conservation community must first specify a long-term vision for conservation. This requires explicit acknowledgment and recognition of biodiversity *values*, articulated by a clear statement of these values (e.g. What is desirable? For whom? Which species, functions or systems to protect? etc.). The vision and value statements can then be used to select a specific plan of action according to options deemed ecologically feasible through surveys and monitoring (field work).

- ASSUME LONG-TERM ENVIRONMENTAL CHANGE

Systems science has clearly demonstrated that ecosystems are dynamic, open, and self-organizing, and as such, conservation planners and decision makers must assume that environmental change is normal. Furthermore, we must now *also* assume that normal ecosystem changes will likely be exacerbated by long-term global environmental change. For example, greenhouse warming in the 21st century

³⁶ Rule systems facilitate ownership of the process yet help prevent hijacking of the process by one special interest.

³⁷ See, e.g. Funtowicz and Ravetz, 1994; Kay and Schneider, 1994.

may result in a mean global temperature increase of 2 to 4 degrees Celsius, and be accompanied by sea level rise, inundation of many coastal zones, and increased aridity in continental interiors (among other profound effects on ecosystems). See, e.g., IPCC, 1996.

- **DIVERSIFY PLANNING AND MANAGEMENT STRATEGIES: USE A BROADER SET OF TOOLS FOR MORE FLEXIBILITY**

Conservation planners should use both legislative (or regulatory) as well as voluntary (or non-regulatory) planning methods. For example, a combination of legislated parkland conservation in conjunction with private stewardship or land trusts may be more effective than either approach alone³⁸.

- **FOCUS ON INCLUSIVE COLLABORATION**

Collaboration is critical in setting planning goals through both visioning and the use of scientific support. The conservation community will need to be vigilant to ensure that no single interest co-opts another or that a special interest dominates. This differs from conventional 'citizen participation', in which one powerful interest permits limited input from others (usually non-experts). This input may be used or disregarded at the discretion of the dominant power at the table. A collaborative process differs in that decision making power should be distributed equally around the table, or at least allocated by consensus during the process design stage.

- **MAKE VALUES EXPLICIT IN AND CENTRAL TO THE PLANNING PROCESS**

The recognition of the full range of conservation values is critical to the process. Only through explicit recognition can all values be legitimized and then considered by participants. This is a vital step which enables conservation planners to deal more effectively with conflicts which arise in the process.

- **EDUCATE AND LEARN FROM ONE ANOTHER**

Scientific, policy and participatory literacy is vital to an effective process. Without a general willingness to learn, or in particular, an 'ecological literacy requirement' for planners, it is conceivable that a conservation plan may do more harm than good. For example, biodiversity may actually be hindered through the domination of a special interest or one class of values that is not in the best interest of long term ecosystem function. Similarly, 'experts' or technical information providers need to understand the collaborative process; they must respect that non-expert values are

³⁸ See, e.g. Lister (1992).

legitimate and must be negotiated before a plan can be implemented – even if these values are contradictory³⁹.

- DEMAND COMMITMENT FROM PARTICIPANTS

There should be ‘no free ride’: the conservation community will have an increased chance of success if members buy into the process they develop and feel a sense of ownership in the resulting conservation plan. Rules for participation and criteria for commitment can be determined by consensus at the outset of the process.

- CONSIDER A SPECTRUM OF SCIENCE

Use alternative ecological paradigms and hypotheses, including, for example, reductionist, scale-appropriate biology, holistic community approaches, and ecosystem-wide studies of energetics and dynamics.

- MOVE FROM STATIC PRESERVATION TO DYNAMIC CONSERVATION

To be adaptive, conservation plans must focus on enduring ecological functions (e.g. ecosystem self-organization) instead of solely on static structures (endangered species, etc.). Scientific support can be used to educate participants on ecological realities, and eventually, shift the focus of conservation values to protecting viable ecosystems⁴⁰.

- RECOGNIZE SCALE AND CONTEXT

Conservation planners must clearly identify the ecological scale(s) relevant to the plan, and learn historical context. The support of field scientists is critical to determining appropriate scale, while local citizens, naturalists and native people are often the best sources of historical context, e.g., localized patterns of ecosystem change.

- LEARN BY DOING: EXPERIMENT, MONITOR RESULTS, MODIFY PLANS

Feedback from the lessons learned is essential to long term success of conservation plans. Decision makers must establish and implement a monitoring framework, including specific criteria, indicators and parameters for monitoring both existing and emergent features of the ecosystem under conservation. To use learned input

³⁹ Without community support and buy-in to the process, a conservation plan will not succeed. In theory, ecological literacy of all participants should eventually result in conservation values which are in the best interests of long-term ecosystem viability, and thus, biodiversity. Clearly, there will be some conservation plans that explicitly trade-off long term function for individual species protection in the case of highly endangered species with significant cultural appeal, for example.

⁴⁰ See, e.g. Funtowicz and Ravetz, 1994; Kay and Schneider, 1994.

successfully, plans should favour 'safe-fail' options (Francis, 1994) and reversible strategies where possible.

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