Bryan G. Norton and Robert E. Ulanowicz

Scale and Biodiversity Policy: A Hierarchical Approach

A hierarchical approach to natural systems, which assumes that smaller subsystems change according to a faster dynamic than do larger systems of which they are a part, is advocated as a useful means to conceptualize problems of scale in determining biodiversity policy. It is argued that conservation biology is a normative science that, like medicine, is shaped by a goal of protecting and healing ecosystems. The goal of sustaining biological diversity over multiple human generations implies that biodiversity policy must be set at the landscape level of the ecosystem. Since ecosystems can be described at many levels of organization, conservation biologists must model ecosystems on a scale appropriate to the crucial dynamic that supports the sustainability goal. This dynamic, the *autopoietic* feature of ecosystems, supports and sustains species across generations. The value of these ecosystem processes is measured as the avoided costs of sustaining species in zoos or highly managed habitats. The protection of the health of these landscape-level processes should therefore be the central goal of biodiversity policy.

INTRODUCTION

There exists a broad consensus supporting the protection of biological diversity; but the exact meaning of this consensus for policy is not clear. In the United States, for example, the *Endangered Species Act* emphasizes protection of species. But this emphasis has led to the question: Since approximately 99% of all species that have existed on earth are now extinct, how can it be so urgent that we reduce anthropogenic species extinctions? The standard answer to this question—that extinction itself is not bad, but rather that the accelerated *rate* and broadened *scale* of extinctions is unacceptable—likewise raises more questions than answers. One might ask, what would be an "acceptable" rate of extinctions? If species are not sacrosanct, what then *is* the proper target of protection? These questions are important because our inability to answer them indicates huge gaps in our understanding of environmental management and of biodiversity protection: It is not clear at what scale the problem of biodiversity loss should be addressed; Nor is it clear that measuring rates of species loss is the only or best criterion for measuring the success or failure of protection efforts.

In this paper we explore the policy implications of a hierarchical approach to protecting biological diversity. The hierarchical approach, which represents a specific application of general systems theory (1, 2), models natural complexity as a hierarchy of embedded systems represented on different *scales*. A major assumption of hierarchy theory is that smaller subsystems change according to a more rapid dynamic than do larger systems (1, 3–5). We believe that this correlation between system size (hierarchical level) and rate of change introduces some conceptual order into discussions of the proper scale on which to address environmental policy goals, and we illustrate our approach by applying it to biological diversity policy.

While much of our conceptual apparatus is adapted from theoretical ecology, we do not consider our work to be scientific in the narrow sense that it consists of value-free descriptions and explanatory hypotheses. We, on the contrary, believe that conservation biology is a normative science—like medicine it is guided most basically by a commitment to important social values. Just as medical research must fulfill both a criterion of methodological rigor *and* a criterion of relevance—usefulness in healing patients—conservation biologists are likewise obligated to characterize ecological systems in ways that are not only accurate, but useful in protection and recovery programs. The goal of conservation biology should therefore be to examine dynamics that affect environmentally important goals. Social values, and our attempts to understand how to protect them, direct conservation biology by pinpointing crucial natural dynamics that should be understood and protected. Thus, while species are of course important because species are essential participants in natural dynamics, we intend to shift the focus of biodiversity policy to protecting the *health* of socially important natural processes.

This approach eschews purely scientific delineation of goals for conservation biology, and departs from the pure science paradigm. But this approach can be regarded as value-free in another and more realistic sense. Whether elements of nature are valued for themselves (intrinsically) or for future humans (instrumentally), we can provide a scientific argument that it is multi-generational, ecosystem-level dynamics that should be the target of protection policy. Because protecting ecological processes that unfold across multiple generations is the only way to sustain species diversity for future generations, and because we are committed to this policy goal, the question of whether species or future humans are ultimately valued is rendered moot.

A THEORY OF SCALE FOR BIODIVERSITY PROTECTION

Contemporary philosophy and physical theory have converged to show that there exist many consistent and coherent accounts of reality as we experience it (6, 7). One manifestation of this more general result directly affects scalar questions. Newtonian physics assumed that the world could be understood on a single, unified scale, there being no universal constants in the Newtonian system of description. "Scale therefore becomes all-important," in the words of Ilya Prigogene and Isabelle Stengers, "because the universe is no longer homogeneous, and the synoptic perspective is abandoned in favor of a hierarchically organized, multiscalar and dynamic world" (6).

Choice of system boundaries and scale are therefore an essential part of describing a system that is to be managed for a given purpose, and thus the best description of a system is one that describes dynamic processes on a scale determinative of priority social goals. We are therefore not bothered by the recognition that ecologists use the concept of an ecosystem loosely and variably. We recognize choices to bound a given system in time and space as decisions based broadly on the usefulness of certain models in understanding targeted physical processes. Since there are many useful ways to understand a system, articulated social goals must direct choices as to how natural systems are described. Choice of the proper scale on which to address an environmental problem such as species loss is therefore an interactive process in which definitions of policy goals guide choices of system boundaries, even as scientific descriptions of processes, and human impacts on them, help us to refine our understanding of policy goals. Determining the correct scale and perspective from which to address environmental problems therefore involves a complex interaction of value definition, concept formation, and scientific description–an interaction in which the articulation of environmental goals drives science (Fig. 1).

We emphasize the development of a physical scale for conservation biology, and

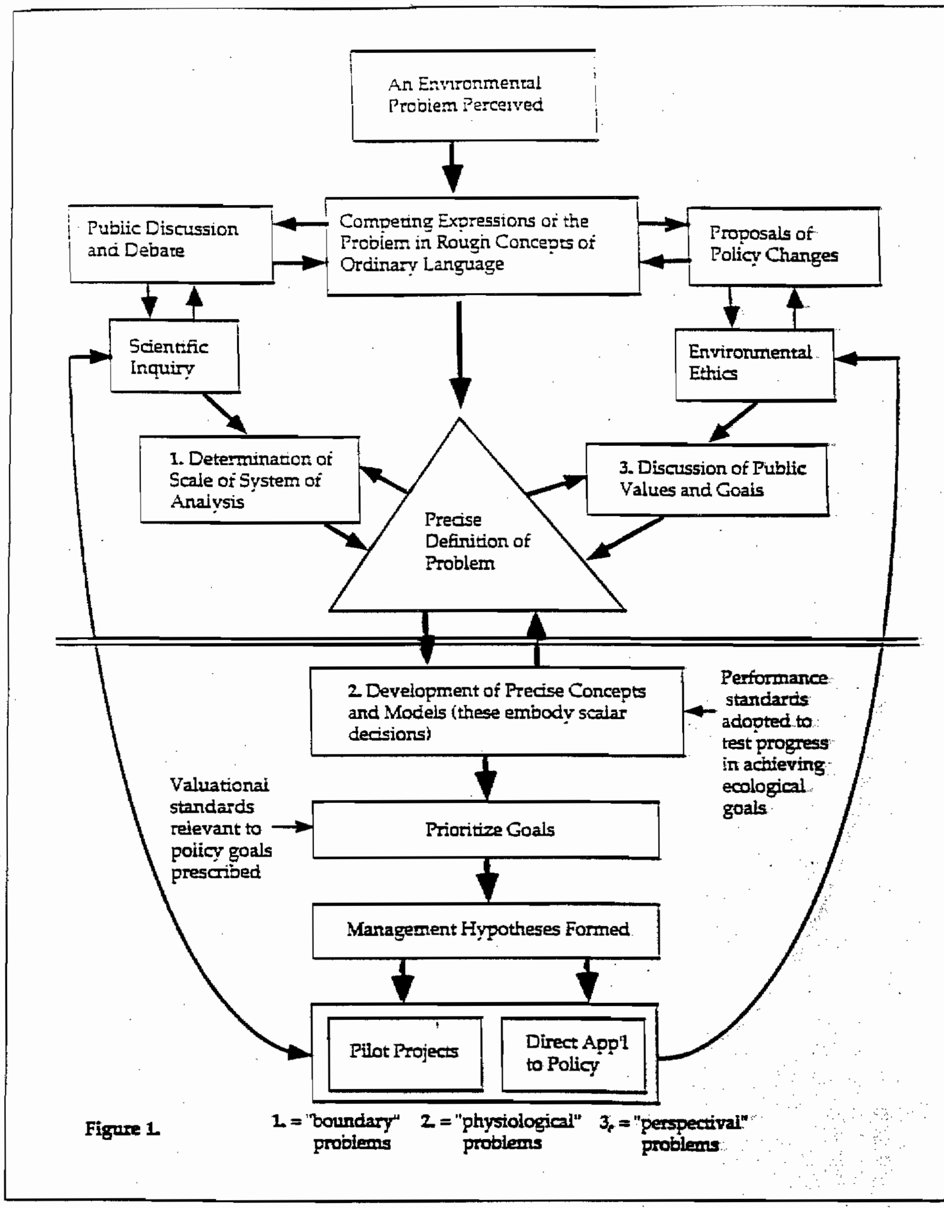

Figure 1. The Environmental Policy Process. Environmental problems are not clearly formulated when they first emerge in public discourse. Determination of the proper scale at which a problem should be "modelled" requires an interactive, public process in which public values guide scientific development of models. Once the problem is precisely defined and models developed, the process of experimentation with solutions can begin.

assume a high social value on protecting biological diversity. We proceed to combine this assumption with hierarchical principles and to explore the implications of this combination for biodiversity policy. We believe that the emerging concept of ecosystem health, understood in conjunction with hierarchy theory, should guide policy debate. The outcome of that debate, admittedly a political affair (as is any process of value articulation), should in turn guide biological diversity policy.

The difficult theoretical problem we have posed for ourselves is as follows: Given that the scale of ecosystem description is relative to choices regarding the concepts and values we operate with–and these, in turn, are relative to goals and value determinations–how can ecosystem scale and boundaries be constructed on a rational basis? Implicit in this question is the recognition that a choice can be *relative* to certain factors, including public values, without thereby becoming *subjective* (not amenable to rational analysis). Choices to employ certain concepts to describe an ecosystem, and choices to view it on a particular scale, involve tremendous latitude and depend on the goals of the researcher. Nevertheless, these decisions are in fact constrained by the goals of managers as well as those of the researcher. To understand a natural dynamic in order to protect it requires that the dynamic be modelled at a scale relevant to social values.

Scale and Biodiversity Policy

The goal of conserving biological diversity for the benefit of future generations determines the temporal horizon of biodiversity policy. Relying on hierarchy theory we reason that since the policy horizon for this social value is many generations, we must concentrate on a large-scale dynamic such as the dynamic that determines total diversity over landscape level systems. This approach squares with what we know biologically: landscapes are essentially patchy. Many populations of plants and animals are ephemeral and we cannot save every population of every species, nor can we save every species. As the scale of human activities on the earth increases and human dominated landscapes prevail more and more it is inevitable that the rate of ecological change will accelerate. The goal of policy should be to maintain the health of the dynamics that support and retain diversity on a large geographical scale. The proposed approach therefore agrees with advocates of species protection in most cases, although for different reasons. Policies should usually protect species because an accelerating rate of species loss is the best available benchmark of illness in ecological systems. According to our approach, however, the value of species is mainly in their contribution to a larger dynamic, and we do not believe huge expenditures are always justified to save ecologically marginal species. The problem, of course, is to specify what is too large an expenditure and to define "ecologically marginal". On the approach developed here, these definitions must be built upon a theoretically adequate conception of system scale, one that is also useful in guiding protection and restoration efforts and in communicating with the public as it articulates goals and values.

The limits to any dimensional description of a system have been formalized in the discipline of *dimensional analysis*, for which the Buckingham-Pi Theorem provides the foundation (8). This theorem states that there are a limited number of dimensionless groupings of the physical parameters of a system (expressed in terms of fundamental dimensions of the system) that are sufficient to control the dynamics of the system. A corollary of the Buckingham-Pi theorem, which states that only those dimensional groupings near order unity are important to the dynamical system description, is of special relevance here. That is, if any of the characteristic parameters becomes disproportionate with respect to the scale of the other system phenomena, then it becomes irrelevant to the system description. Either it is so slow as to appear constant or so fast as always to be in equilibrium with other limiting factors. Thus, in a real and quantitative way, the Buckingham-Pi theorem allows us to circumscribe the domain of applicability—the focal level in a hierarchy—for any given system feature.

Let us, for example, look at how the Buckingham-Pi theorem would apply to a specific management problem. German foresters of the 19th century emphasized production of timber and converted huge areas of the German forest to monocultural spruce. Initially, yields of high-quality timber increased. After three or four iterations, however, yields plummeted. Young trees could not penetrate the soil with their roots and a condition called soil sickness developed (9). Analysis showed that soil composition had been altered because essential microorganisms had been lost. In this example, descriptions at a particular scale—the scale of economic forestry—had been assumed to provide a complete and unique

Litter decomposing fungi (*Marasmius* sp.). Photo: N. Nykvist.

description of reality. Failure to recognize that timber production is a process that exists as a part of a system that has evolved over centuries and that that system is supported by processes existing on a longer scale than is registered in the language of production forestry resulted in a serious management failure.

The Buckingham-Pi theorem provides a tool by which we can pinpoint the proper scale at which to formulate policy in cases such as this. Suppose at the outset that we are ignorant of the actual dynamics of litter decay and wish to determine which parameters of the system, at what scale, are pertinent. We could list the following parameters as candidates: D_o, the initial density of litter on one square meter of forest floor; F, the rate of litter fall per year; B_o, the initial density of bacteria among the litter; r, the instantaneous rate of litter decay; L, the characteristic length of the patch we are observing; and h, Planck's constant. There are three fundamental dimensions (mass, length, and time) among the six parameters. The Buckingham-Pi theorem says that there will be 3 (= 6–3) dimensionless groupings that characterize the system dynamics. Without going into the details about how they are determined, those three groupings (pi numbers) may be taken as B_o/D_o, $D_o r/F$ and h/FL^4.

Now we go into the field and laboratory and actually measure these parameters. Our (hypothetical) estimates are:

D_o 1.2 Kg m^{-2}
F 0.5 Kg $m^{-2} y^{-1}$
B 0.00009 Kg m^{-2}
r 0.41 y^{-1}
L = 1m
h = 2.09×10^{-26} Kg m^{-2} y^{-1}, Planck's constant which means that:

B_o/D_o 7.5×10^{-5}
$D_o r/F$ 0.99
h/FL^4 4.18×10^{-26}

As one could have guessed, the grouping that contains Planck's constant, h, is much less than one, and the corollary to Buckingham-Pi says that this grouping will not influence the dynamics we are observing to any visible extent. That is, phenomena at the submolecular level occur so fast and over such a small space that we need not concern ourselves with those details. What is less obvious is that the first pi number, B_o/D_o, is also very small, so that one need not be concerned with following bacterial concentrations. What this result implies is that some unknown factor (e.g., nitrogen concentration, soil moisture, soil temperature, aeration rate, etc.) is limiting the breakdown of the litter. The bacteria themselves grow very quickly, and their densities will rise and fall in very short order to track the unknown limiting factor.

The dynamics of forest litter are best described in this case by the second grouping, $D_o r/F$, which characterizes the ratio of the decay rate to that of the supply. That the two are very comparable indicates that litter buildup should be a slow process. In fact, one can calculate a characteristic time for the process by dividing the difference between the supply and decay rates by the stock of litter present, i.e.

$(F-D_o r)/F \quad 0.00667y^{-1}$

The reciprocal of this accretion rate is 150 years, which accords with our intuition that soil buildup is a very slow process. The slowness of that process explains how, by concentrating on forest production of timber in a single cycle of planting and harvest (8–40 years), the relevant scale for economics, the German foresters ignored a crucial factor in sustainable forest use and, in the process of simplifying the system, actually impoverished it on a longer scale of time. The scale relevant to a policy of intergenerational sustainability correlates very closely with the ecological parameter of soil build-up because this parameter is associated with maintaining both the diversity and the productivity of the system over multiple generations. According to this hypothetical example, a public concern long-term sustainability of forest prod and for maintenance of forest health imp an approximate horizon of 150 years policy horizon of this length is suggeste the recovery time from damage to soil c position and we arrive at a scale based the production function for leaf litter, crucial variable if our public concern is definite intergenerational sustainability forest productivity. The characteristic namic of forest development is that of bon retention and the rate of soil build-u probably the rate-limiting factor most evant to maintaining and encouraging lo term forest productivity. In this way, an derstanding of the production function fecting a public value of intergeneratio sustainability, when coupled with a hie chical understanding of ecosystem struct and functions, determines the proper sc for addressing an environmental problem

WHOLE ECOSYSTEM MANAGEMENT

The goal of biological diversity policy sho be, given the long time horizon of the pol of intergenerational sustainability, to pro *total diversity at the landscape level ecological organization.* While we do intend to reify any given system-descript as complete and uniquely correct, we believe that one can scientifically determ ecosystem boundaries and membra *provided a priority social goal such protecting biodiversity* is specified. E system-level management is distinguis by its concern for characteristics of wh systems—characteristics that cannot reduced to aggregated characteristics of parts. The decision to emphasize wh ecosystem management is a decision employ hierarchical, rather than aggregat models—it is to seek models that integr policy goals on multiple levels or scal rather than simply counting bottom-line co and benefits (5, 10, 11). To add a whole e system level to a management plan is resolve to manage, in addition to managi components of the system for resou production, the system as a system. Succe ful ecosystem management will necessar be management that has conceptualized system in a way that focuses attention on central features of the system—features t are important to supporting important pub values. The intuitive idea of ecosystem hea is valuable because it focuses attention the larger systems in nature and away fr the special interests of individuals and grou Competing and special interests, and goals they articulate, must be integrated i the larger-scale goal of protecting the hea and integrity of the larger ecological syste (12). While decisions regarding particu elements of the landscape, especially tho in the private sector, will be manag according to economic goals and criter biodiversity policy focuses on the larg scale. The regulative idea of a healt ecological system organizes, tests, a integrates these special interests on landscape level of organization. A prior goal of conservation biologists must educating the public toward a better understanding of ecological management, and in helping citizens to articulate their values and to express those values in management decisions.

But the analogy of ecosystem health/integrity is best understood as an intuitive guide, rather than as a specific determinant of policy choices (13), because, like all analogies, it eventually breaks down. The strength of the medical analogy is that it focuses attention on the overall organization of the system: just as a good physician would not treat a specific organ without paying attention to impacts on the health of the entire organism, whole ecosystem managers must constantly monitor impacts of human activities on the larger ecosystems that form the human environment. The medical analogy is important in emphasizing the importance of systems thinking, and of a recognition of multiple levels and scales on which systems change dynamically (14). But the medical analogy has an important drawback (5). Whereas human medicine and veterinary medicine focus on individual organisms and are guided by the unquestioned goal of protecting the health of patients, ecosystems are multi-scalar and have no obvious identity. No prior, overriding consideration like the Hippocratic oath determines which level of the complex hierarchies of nature should be considered the "whole", organismic level of the system. Managers have considerable latitude in choosing the boundaries, and hence the scale, of the systems they monitor and manage. We believe that choices within this latitude will remain indeterminate until a viable consensus regarding management goals has been articulated. In cases where public goals have been clearly formulated, scientific description of the internal functioning of ecological systems will provide guidance regarding the location of boundaries, and regarding which internal compartments/membranes of the system to emphasize (Fig. 1). A whole ecosystem is a system whose boundaries include essential elements of a dynamic relevant to important social values for a region.

Ecosystem health/integrity therefore stands as the central policy concept to guide ecologically understood environmental management; and, we are arguing, public values–aesthetic, economic and moral–all depend on protecting the processes that support the health of larger-scaled ecological systems. These systems create the context for those activities, and in this sense are crucial elements in their value (5, 11, 15). The local, cultural goal of protecting the capacity of systems to react creatively and productively to disturbance, whether footprints of hikers or harvests by oystermen, therefore can sometimes take precedence over the short-term goals of individuals and economic interest groups.

AUTOPOIETIC SYSTEMS

Whole ecosystem management must be understood as management of a self-organizing system–a system that creates and maintains itself by homeostatic and homeorhetic responses to changing conditions. We describe the creative feature of ecosystems as *autopoiesis* (from the Greek term meaning "self-making"). (16–18). Emphasis on autopoiesis implies that the macroscalar boundaries separating the system from its surroundings as well as the smaller-scaled boundaries that separate the system into subsystems or "organs" are chosen to accentuate dynamics essential to sustaining biodiversity. It is not claimed that the features we emphasize are the only features of ecosystems that could be spotlighted, it is claimed only that the scalar choices (boundaries and membranes) represent conceptualizations (models) of the system that are *managerially relevant* and *naturally appropriate* given the goal of protecting healthy ecosystems and their elements over many generations.

Management of forest production of timber in a single short-term cycle of planting and harvest of one or two species rarely accounts for the dynamics of long-term forest litter and soil build-up. Ignoring crucial dynamics, and reducing species diversity in the forest system, actually impoverish the system. Sustainable use of forests recognizes that timber production exists as a part of a continuously evolving system supported by processes taking place on a longer scale. Litter in a Swedish deciduous forest. Photo: N. Nykvist.

Diversity must be understood dynamically in terms of ecosystem processes rather than merely as maintenance of current elements of the system. Wood anemones are beautiful and appreciated flowers, but they are also parts of the system contributing to its health. Photo: F. Eberhardt.

While we agree with those, such as Botkin (14), who emphasize the dynamism of natural systems, we recognize also that dynamically creative change requires a certain amount of stability in the form of larger, slower-changing systems that provide "stable" backgrounds for the processes of iteration and reiteration that allow evolutionary development. Evolutionary creativity on long scales requires creative solutions to environmental constraints that are essentially "fixed" on the scale of individual specimens.

A commitment to ecological sustainability, the resolution to protect complex and creative ecological systems for future generations, assumes the possibility of stability across multiple generations. Stability, here, is treated as a "well-founded illusion of scale." It is an illusion because the system on all levels is constantly dynamic. But this illusion, from a human perspective, is nevertheless well founded because large-scale ecosystems have historically changed sufficiently slowly that there existed continuity of landscape across human generations.

From the environmental standpoint a most important attribute of self-supporting units is their ability to adapt to new circumstances in *creative* ways. This creativity supports the ability of natural systems to rebound in response to heavy economic exploitation and also explains their ability to absorb human wastes. As human activities become ever more intrusive in the systems of nature, these creative adaptations will become even more crucial. Creativity has been perceived as relevant only to conscious, goal-forming agents. But as new developments in physical theory have made clear, the process of creation is ubiquitous in the universe and at times can even transpire in systems not containing living members (6). Ulanowicz (19) has argued that the capacity for creativity constitutes the crux of what is normally referred to as *ecosystem health*. But the capacity for creativity is too often misperceived, which comes as no surprise, given the difficulties in describing it in semantic, much less quantitative terms. The emerging consensus (19–21) indicates that creative action is contingent upon two mutually exclusive properties of the performing system.

First, it is necessary that any system capable of solving a novel problem possess a requisite amount of ordered complexity. Order implies constraints–events impinging upon the system or subsystem must initiate a channeled sequence of reactions (which may be and probably must be reflexive to some extent) that culminate in the response of the system to that input, e.g. compensation, indifference, counteraction, co-option, etc. Without such coherence, creativity is impossible, and Atlan (20) demonstrates how thresholds in ordered complexity must be surpassed before a system is capable of creative action. This side of creativity is widely understood. It is unquestioned that an organism or system must possess enough "apparatus" before creativity is possible. But some of the most tightly ordered objects in the universe are machines—artifacts that are incapable of truly creative actions, primarily because they lack an adequate degree of inherent disorder.

It is not so universally acknowledged (or, in many cases, even suspected) that incoherence is also a prerequisite for creative action. Before creativity is possible, a system must possess a potential "reservoir" of stochastic, disconnected, inefficient features that constitute the raw building blocks of effective innovation. In the course of normal functioning such disutility appears as an "overhead" or an encumbrance. However, when faced with a perturbation or problem, it is this background of dysfunctional repertoires that is utilized to meet the exigency. Background species or marginally extant trophic pathways–system redundancies–can be activated in response to a disruption of the normally dominant means an ecosystem employs to process material and energy. If the disturbance is recurrent or persistent, the new response eventually will be incorporated into permanent coherent structure. This idea of freedom resonates in public values with the emphasis on wilderness protection and with the importance placed on protecting wildness wherever possible and appropriate (5, 22).

The concepts of order and incoherence may seem subjective to some, but Ulanowicz (23) has suggested that it is possible to employ results from information theory (quantitative epistemology) to estimate the relative amounts of each of these attributes possessed by a given system. To attach numbers to these system properties, it is necessary first to describe the system as a collection of subunits linked together by processes that can be quantified. For example, ecosystems are often described as a collection of species or other aggregations of organisms linked one to another by exchanges of material or energy. These exchanges can be assigned physical units and measured or otherwise estimated in the field or laboratory.

Once the ecosystem has been bounded and then characterized as a network of palpable flows, one can employ information theory to quantify the diversity of flows in this ensemble as if each flow were independent of all others. Of course, the exchanges do not occur in random, unconnected fashion. There is an order in the pattern of trophic connections and temporal sequences. Such order gives rise to a component of the overall diversity of flows as computed by a variable called the average mutual information of the network topology (24). Ulanowicz (25) has given the name *ascendancy* to a scaled version of the mutual information. Systems with more clearly defined pathways of cause and effect will exhibit higher values of ascendancy. One can rigorously prove that the mutual information and linkages can never exceed the measure for the diversity of flows. This condition has led Ulanowicz (25, 26) to call the latter term the system *capacity* for growth and development. System capacity obviously is tightly coupled with the biodiversity of the system. We are here hypothesizing that this idea may also serve as the link between the intuitively understood policy concept of ecosystem health and the more precise, quantitative disciplines of systems theory and information analysis.

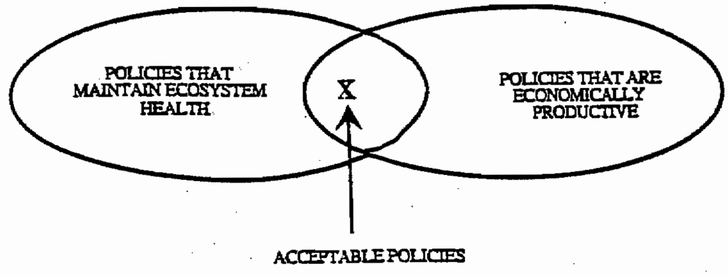

Figure 2. A hierachical system of analysis does not seek a single, synoptic "bottom-line" determination of the best policy from every perspective, but rather defines (through public debate and political processes) policies that will protect ecosystem health and policies that fulfi essential ecological *and* economic criteria. If no such policies have been proposed, there shoulc be an intense effort to develop them.

The amount by which the capacity exceeds the mutual information has been called the system *overhead*. All those system features which contribute nothing to its order and coherence by definition add to its overhead. These include redundant and inefficient pathways, stochastic and ill-phased events, etc.

In terms of these three concepts–ascendancy, capacity, and overhead–one can enumerate the requirements for a system to act creatively in response to a novel circumstance: (i) The system must have a high capacity for growth and development, i.e. its biodiversity and complexity must remain high. (ii) Most of this capacity needs to be expressed as ordered and coherent ascendancy. (iii) Some capacity must remain as unstructured and incoherent overhead to afford the system the degrees of freedom necessary to respond to novel environmental stimuli.

A biotic system satisfying all three requirements can be termed "healthy" (19). Thus, we can suggest a definition of ecosystem health for public policy consideration: "An ecological system is healthy and free from 'distress syndrome' if it is stable and sustainable, i.e. if it is active and maintains its organization and autonomy over time" (27). The goal of sustaining ecosystem health so defined therefore involves maintaining a capacity for autopoietic activity on the scale relevant to many human generations.

THE VALUE OF BIODIVERSITY

One advantage of the approach to scale and policy goals sketched here is that it bypasses intransigent value questions and focuses attention on concrete and achievable goals. It does so by reversing the usual valuational methods of utilitarians and economists, who place a price-value on species and then aggregate toward a total value for ecosystems. On our approach, the policy-driving value are ecosystem-level processes; we save species *both* because we value them directly (a least in many cases) *and* because of their role in ecosystem processes. But since the processes must in the long run protect the species, the question of ultimate value, species or ecosystems, will arise only in those cases where large expenditures are required to save an ecologically marginal species.

If we are committed to saving species/biodiversity for future generations and wish to introduce dollar figures into policy debates, we should estimate the total value of the ecosystem dynamic that protects species to be equivalent to costs that would be incurred to maintain individual species in alternative ways. If we do not protect species in the wild, they must then be protected in zoos or other artificially managed areas. The cost of artificial protection would be prohibitive for more than a few species. We therefore adopt the intermediate goal—which is instrumental to the goal of protecting ecosystem processes—of protecting as many species as possible. But this is not to say that one would never declare a particular species too expensive to save, given its ecological role. The obligation to protect species is therefore best understood in the terms of the *Safe Minimum Standard* as formulated by Ciriacy-Wantrup and developed by Richard Bishop (28, 29). Endangered species policy should be governed by the rule: protect all species, as long as the costs are bearable.

This approach to valuation also suggests a new sort of partnership between biologists, economists, and the public. Emphasis on the self-perpetuating features of ecological systems and their role in achieving social goals such as species preservation implies highest priority for studies that promise to characterize the structures, functions, and processes that make an ecological system a habitat capable of perpetuating species for many generations. Economists also have important roles. By developing new methods of valuation for deciding policy priorities and by determining costs of various alternatives for maintaining functioning habitats, economists can make protection efforts more efficient. Especially, they must develop incentive systems that will encourage healthy economies that are compatible with protecting ecosystem health. Since ecosystem health is as much an evaluation as it is a descriptive concept, both economists and ecologists must work to inform the public about management options and work to develop scientific models that both express and, through an interactive process, improve values. It is therefore a high priority to develop new methods of valuation that are sufficiently interactive to contribute to the dynamic process of defining and protecting ecosystem health.

CONCLUSION

Ecosystematic, hierarchical management recognizes that many choices we make, both individually and collectively, will introduce disturbances on a local scale; as when a field is plowed, a fire set, or a forest plot harvested. The recommendation that we manage for ecosystem health as well as for productivity in the various cells of the system implies that, when we disturb a wetland, for example, we will look also at the impacts of the disturbance on the larger level of the landscape. This approach would recognize that, in managing *particular* fields or wetlands, we usually seek to maximize productivity and economic efficiency. One might call management on this cellular level *resource management.* But the hierarchical approach also recognizes more inclusive levels of management, levels where we are concerned about the healthy functioning of the creative systems of nature and about the continued existence, across the landscape, of indigenous species and distinctive ecological communities—what is popularly called "biodiversity". We have emphasized that a hierarchical, whole ecosystem approach to management recognizes multiple levels of system organization; the scale on which an environmental problem is addressed must depend on the public goals that are given prominence.

Because the public derives many values—economic, cultural, and aesthetic—from the landscape, no single ranking of environmental goals can be adequate to guide public policy. Hierarchical thinking helps us to avoid policy gridlock, however, if we recognize that successful policy will encourage a patchy landscape. On the level of field or farm, economic criteria will predominate, while on the ecosystem level we must manage for total diversity and complexity. Here, macroscalar criteria must guide the development of incentives that protect ecosystem health. This general approach seeks integration of levels; it places priority on finding new and various methods and procedures, and on arranging economic incentives to encourage economic development that has minimal negative impact on large ecological systems. This process will be political. A variety of economically efficient policies will be delineated; simultaneously, expectations will be set for maintenance of the health of the larger system that perpetuates complexity and total diversity. Good policies will be those that fulfill key criteria on both levels (Fig. 2).

The political process of developing a biodiversity policy for any given region should be guided by three central principles.

I. Efforts at maintaining biodiversity should be directed at maintaining the total diversity of the landscape over multiple generations. Landscape-level goals must be defined more precisely by increased articulation of biodiversity values within a locale. Good management will require public dialogue as much as expert opinion because the definition of goals and development of scientific understanding is an interactive and experimental process.

II. Diversity must be understood dynamically, in terms of healthy processes, rather than merely as maintenance of current elements of the system. The development of landscape-level models will involve choosing a scale and a perspective from which to both understand and manage large ecological systems. Dimensional analysis, combined with information theory and applied to hierarchical models, can provide techniques to help pinpoint dynamics associated with important public values and their support.

III. Economic activities that complement and enhance, rather than oppose and degrade, ecological processes are to be preferred and encouraged. Recognizing that natural systems will react creatively to change, we should develop economic incentives to encourage economic development that mimics natural disturbances (30).

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Bryan G. Norton was trained in the philosophy of science at the University of Michigan, specializing in conceptual change in scientific disciplines. Since 1978 he has worked in environmental ethics, environmental policy, and conservation biology. He has been a research associate at the University of Maryland Institute for Philosophy and Public Policy, was chosen as a Gilbert White Fellow at Resources for the Future (1985–86), and is currently a professor in the School of Public Policy at the Georgia Institute of Technology. He is a member of the Environmental Economics Advisory Committee of the Science Advisory Board of the US Environmental Protection Agency. He is author of two books on biological diversity. His address: School of Public Policy, Georgia Institute of Technology, Atlanta, GA 30332. Robert E. Ulanowicz received his bachelor of Engineering Science (1964) and PhD in Chemical Engineering from The Johns Hopkins University (1968). He has taught Chemical Engineering at Catholic University in Washington, D.C. Since 1970, he has worked at Chesapeake Biological Laboratory in Solomons, MD, where he is professor of estuarine science. He is interested in the structure of trophic exchanges in ecosystems and how these relate to other fields of study. His address: Chesapeake Biological Laboratory, Box 38, Solomons, MD 20688 U.S.A.