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CAN STRESS ECOLOGY ADEQUATELY INFORM ENVIRONMENTAL ETHICS?

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ABSTRACT

Stress ecology represents the field of ecology that measures and evaluates impacts of perturbations on the structure and function of ecosystems. Many human ecologists and philosophers maintain that environmental ethics should be predicated upon holistic ecological principles. Specifically, this implies the successful application of stress ecology to environmental problems. However, few thoroughly discuss the extent to which stress ecology is capable of serving as a basis for environmental ethics, nor do they make substantial reference to the scientific literature which examines this question. A number of factors constrain the successful development and application of stress ecology, and its usefulness as a basis for a holistic environmental ethics. These factors include: 1) lack of consensus about the definitions of stress to organisms or ecosystems, 2) insufficient knowledge about causes of environmental perturbations (e.g., pollutants), 3) inadequate ecosystemic knowledge, and 4) lack of integration of ecosystem and scoioeconomic systems into formal approaches of systems analysis. Accordingly, stress ecology will not fulfill the goals of a holistic and ecologically based environmental ethics.

Many human ecologists and environmental ethicists increasingly advocate for an ethic based upon holistic ecological principles. Stress ecology represents the field of study within ecology that attempts to measure and evaluate the impacts of natural or foreign perturbations on the structure and function of ecological systems. Stress ecology has some application for almost every type of environmental problem. For an applied environmental ethic, the degree to which stress ecology is presently holistically developed or likely to develop must be known by human ecologists and ethicists. Although many philosophers maintain that ethics should be predicted upon holistic ecological

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principles, few (if any) thoroughly discuss whether ecology is capable of serving as a basis for environmental ethics; nor do they make substantial reference to the scientific literature which examines this question. Ecologists increasingly maintain that environmental management be holistic in approach, yet they do not implicitly or explicitly make reference to the philosophical debate concerning the ethics of environmental holism. Development of ethical theory by philosophers cannot take place independent of ecological knowledge for it to have practical value. Likewise, the development of stress ecology in an ethical context can only occur if ecologists are knowledgeable about the content and directions of environmental ethics.

In this article I examine a number of factors which constrain the development of a suitable holistic stress ecology. To ensure a balance between abstract theory and practicality, I discuss stress ecology and holism within the context of the problem of pollution. However, I believe my conclusions are applicable to most global and long-term environmental problems. Specific topics discussed include:

1. the philosophical bases for environmental holism and the debates concerning them;
2. the various concepts/definitions of stress ecology;
3. the adequacy of pollutant data;
4. the adequacy of ecosystemic knowledge;
5. the way we conceptualize the relationship between the environment and the economy; and
6. the nature of environmental impacts as determined from the application of stress ecology.

I conclude that stress ecology as currently practiced will not fulfill the goals of a holistic and ecologically based ethics, and although it is theoretically possible that it will in the future, it is realistically unlikely to do so. This conclusion has implications for those concerned with management of the environment according to ethical principles.

ENVIRONMENTAL ETHICS AND HOLISM

Different types of ethics about the environment exist, and the task of philosophers is to clarify the ethic(s) most appropriate to guide our relationships with the environment. Types of environmental ethics conform to one of two paradigms, that of "shallow ecology" or "deep ecology." Shallow ecology consists of traditional western traditions such as utilitarianism, deontic ethics, concepts of justice, concepts of freedom, and theism. Because shallow ecology emphasizes the relationships between individuals, it is said to be atomistic. Shallow ecology considers the values of nature to be instrumental, and is thus said to be strongly anthropocentric. Deep ecology is a more recent ethics and is receiving increased attention by environmental philosophers. One form of deep ecology is predicated upon a biocentric viewpoint, which maintains that all species have an intrinsic right to exist in the natural environment. Another form of deep ecology is predicated upon the ecosystem concept which emphasizes the interdependence of members of the biotic community, the importance of species diversity for ecological stability, the finite limits of populations and natural resources, and concern for long-term spatial and temporal effects. The ecosystem is the locus of intrinsic value rather than the individual members which comprise it. Ethical behavior is defined in terms of ecosystem consequences to the whole system rather than aggregate functions derived from the total benefits to individual members; accordingly deep ecology is said to be strongly holistic.

There is not a consensus by philosophers as to which types of ethics are most appropriate for an environmental ethic. Considerable normative, metaethical and empirical problems of philosophical justification for the various types of ethics exist [1-4]. The professional responsibility of scientists is not the resolution of such problems as this is properly the domain of philosophers. Rather, the responsibility of scientists is to consider the relevancy/adequacy of scientific knowledge to inform an applied environmental ethic. Philosophers generally assume ecological knowledge is adequate to predict the long-term environmental consequences of our actions [5]. Is this view valid?

The shallow ecology paradigm is considered by many to foster the systematic application of technology to all levels of human activity. This includes governmental and economic policies which favor growth as a central goal. Because technologies are sophisticated and large-scale, they involve governmental and corporate planning by technical specialists who favor technological goals over maximal environmental protection. Accordingly, much of the serious environmental degradation is said to occur as a consequence of the shallow ecology paradigm [6]. What is not clearly understood is whether environmental degradation is an inevitable consequence of the shallow ecology paradigm. Environmental degradation can be said to result from either an inadequate ethical system, or because peoples' behavior has an imperfect relation to their ethics. Although the shallow ecology paradigm does not mandate obligations to nature *per se,* it does permit the protection of nature, and in fact would mandate it if so doing would benefit what is alive, sentient, human, personal, or divine. Since it seems to be an inescapable conclusion that what is alive, sentient, human, or personal requires at least some of the resources and services of nature, it therefore follows that scientific knowledge is necessary for an informed applied environmental ethic.

The deep ecology paradigm has been proposed as an alternative to the shallow ecology paradigm. Proponents of deep ecology have attempted to emphasize a biocentric viewpoint and the intrinsic value of ecosystem function and processes because they maintain that the shallow ecology paradigm inevitably leads to serious environmental degradation. Deep ecology attempts to locate the constraints on human activities in the principles of ecology. What is not resolved by deep ecologists is the question that if the whole biosphere is regarded as having moral standing, then there can be a conflict between maximizing its excellence as a system and maximizing the intrinsic value of its components. Maximizing the value of the biosphere requires considerable knowledge of system properties and an assessment of species that are important for system functions. Value of individual species would be dependent on their contribution to maintenance of system functions and processes. Maximization of value of ecosystem components implies that the value of species is independent of their ecological roles. Lastly, fulfillment of the goals of deep ecology requires either that the human population be considerably below the ecological carrying capacity of the earth, so that environmental impact from human activities is minimal, or that techniques of holistic stress ecology be successfully applied such that inadvertent human environmental impact is ecologically insignificant.

CONCEPTS AND DEFINITIONS OF STRESS ECOLOGY

Environmental ethicists and ecologists commonly speak of stress on ecological systems. However, the meaning of stress is often obscure and ambiguous [7].

Stress as Cause

Stress can be defined as an independent variable, an unfavorable stimulus or input, which is external to the organism [8]. The response of an organism is selection for adaptive traits to avoid or tolerate stress; these include physiological, evolutionary, and cultural adaptations. This definition of stress recognizes that an optimum environment is not constant, but provides an optimum range and frequency of change in the environment.

Stress as Effect

Stress can be considered to be a dependent variable, internal to the organism. Accordingly, it is a response or output caused by a factor identified as a stressor. Historically, the formulation of stress as effect is developed from Liebig's law of the minimum and Shelford's law of tolerance. Liebig stated that: " . . . growth of a plant is dependent on the amount of foodstuff which is presented to it in minimum quantities" [9]. Liebig emphasized that too little of something constituted a limiting factor. Shelford extended Liebig's concepts such that the presence or absence of organisms depends on the qualitative and quantitative excesses or deficiencies with respect to factors that may approach physiological limits of tolerance [10]. Prosser [11] utilized Shelford's concepts in his significant experimental work on comparative animal physiology by recognizing that stress is induced by environmental factors above or below an organism's optimum range. Since species do not encounter optimum conditions for all of their functions, performance can be enhanced or diminished by manipulation of the environment. Selye developed the concept that stress is the organismic physiological non-specific response to an external stressor, and does not depend on specific characteristics of the stressor [12]. Although he thought of stress mainly as stimulus, he also variously defined it in terms of organism response or interaction between stimulus and response. Selye utilized mammalian systems, and from them determined that stress occurred in the three phases of alarm, resistance, and exhaustion. Alarm occurred immediately after a stimulus, resistance constituted a new steady state maintained by the utilization of metabolic energy, and exhaustion resulted as energy reserves were depleted.

Additional modifications of the above stress concepts were made by researchers as interest increased in developing quantitative methods to assess the effect of human activities on organisms in different environments. Brett defined stress for non-mammalian and invertebrate species as " . . . a state produced by an environmental or other factor which extends the adaptive responses of an animal beyond the normal range, or which disturbs the normal functioning to such an extent that, in either case, the chances of survival are significantly reduced" [13]. Brett's measurements were based upon physiological studies, and they extended the definition of stress by allowing for quantification of a normal range of responses, allowance for quantification of stress by measurements of deviations from normal states, and introduction of the concept of disadvantage to the species. Bayne utilized data from molluscan studies, and extended Brett's concepts by substituting "steady state values" for "physiological range," and by suggesting that demonstration of "disadvantage" be predicated upon the individual or the population, since survival potential of the species is difficult to determine [14]. Ivanovici and Wiebe noted that the universal distribution of adenine nucleotides and their role in energy metabolism of organisms may be useful for developing an indicator of stress that may apply across a wide range of cells and organisms [15]. They showed that adenylate energy charge values decrease as stress increases.

The significance of the above described works is that they represent a continuous broadening of the definition and applicability of stress, and in many instances yield quantifiable data. The limitation of the studies is that they were restricted to relatively few groups of organisms, and many were never meant to apply to ecosystems.

Stress in Systems

More recently, definitions of stress have included responses at the ecosystem level. Barrett defined stress as a foreign perturbation to the system, or as a natural perturbation which is applied at excessive levels [16]. However, this definition does not provide for a means of measurement, nor does it include criteria for determining disadvantage to an organism or ecosystem. Odum indicated that stress places an organism or ecosystem at disadvantage because it requires the expenditure of excess energy for maintenance of homeostasis [9]. Meier defined stress as any force that exceeds the functional limits of a critical subsystem beyond its ability to restore homeostasis [17]. Auerbach emphasized the necessity to distinguish between stressors that are part of an organism's or ecosystem's natural environment and those caused by the activities of humans [18]. Franz utilized systems theory of ecosystems and measured stress as the goodness of fit, which was determined by the difference of available necessary energy, materials, or information in the environment and the demand for them [19]. According to this concept, stress is applicable to any hierarchical level of biological organization, so long as the system is in contact with its environment only through inputs of energy, materials, and information.

Given the nature of many environmental perturbations, it is important that definitions of stress and methods for assessment facilitate the detection of low-level sublethal stress that occurs with long-term exposure to adverse environmental conditions. Further, because numerous definitions and concepts of stress exist, it is necessary to identify any common elements between them in order to formulate general phenomena of stress. For indicators of stress to be useful they must be applicable across as wide a range of organisms and ecosystems as possible. Odum [9] and Woodwell [20] have attempted to generalize ecosystem response to stress by defining such response in terms of changes in the successional stages and properties of communities. Levin and Kimball attempt to define the response of different ecosystems to toxic chemicals by assessing changes in successional characteristics at the community or ecosystem level [21]. Their work represents a major synthesis of ecosystem theory and data which strongly supports the necessity of an ecosystem perspective.

Interpretation of Stress Effects

A number of factors make interpretation of observed stress effects difficult. Consequently, extrapolation of results from one study to another problem may not be valid, and the literature on stress ecology therefore contains much data irrelevant to actual ecosystems [25]. Important factors which alter observed stress effects include:

Alteration of the stressing factor when applied under different conditions – Certain stresses may be transformed under field conditions such that the impact on a species or system differs significantly from that expected from laboratory or other field studies. For example, the pesticide DDT degrades under environmental conditions to DDD and DDE, and the predominating chemical form depends upon actual environmental conditions. Further, the toxicity of the three forms differs considerably upon the species and actual physiological conditions in question [26].

Interaction of stress effects with variable physiochemical factors – Stress effects become altered when physiochemical environmental conditions change. Sublethal stress often becomes lethal under suboptimal natural physiochemical environmental conditions. For example, some species exposed to mercury concentrations that were sublethal under optimal salinity and temperature suffered significant mortality in a short time under suboptimal temperature and salinity conditions [22]. Alternatively, stress effects may also become less severe under altered environmental conditions. The toxicity of algal poisons is reduced when sediment coarseness and organic matter content increase in natural environments [23].

Variable characteristics of tested species – Under natural conditions, species may show behavior not displayed in laboratory or controlled field tests. For example, in the natural environment fish may avoid thermal effluents and therefore not suffer increased mortality levels to elevated temperature as determined from laboratory experiments. In the natural environment, species are usually present in a number of different developmental or life stages. The sensitivity of an individual organism to stress often is highly dependent upon the actual developmental or life stage at which it is exposed to the stress. For instance, the adult stages of crabs often are more resistent to toxic metals than are the larval stages [22]. The consequence of these types of variability is that results from the laboratory or controlled field testing may differ markedly and unexpectedly from those actual occurring in natural environments.

Intraspecific and interspecific interactions – Population and community interactions such as competition, cooperation, predation, and reproductive success may interact with stresses to produce population/community changes different than those expected from laboratory data or from the testing of species in isolation. Such interactions may affect either sublethal or lethal effects of a particular stress factor. For example, an experiment involving insecticide effects on marsh crabs demonstrated that crabs that were caged to protect them from predators did not show significant changes in population density when treated with the insecticide compared to control plots. However, uncaged plots identically treated showed significant reductions in population density. Although the insecticide itself only affected the crabs sublethally, unusual mortality occurred in the presence of both insecticide and predators. Apparently, this was due to a slowing of the crabs' normal escape behavior [24].

A Consensus About Definitions

The discussion of stress definitions and concepts implies that the scientific difficulties of assessing stress are not resolved. Sufficient agreement about concepts and definitions of stress must exist for philosophers to base environmental ethics upon, and for utilization by decision-makers in environmental protection. Ecologists must attempt resolution of stress definitions in order to provide others with the most ecologically relevant definition(s) of stress. While may ecologists recognize the necessity of this, an individual's scientific approach stems from the perspectives of his/her respective disciplinary training which encompasses the subdisciplines comprising ecology. Thus, an ecologist may be specialized in, say, morphology, genetics, physiology, organism behavior, or systems analysis and will be influenced by the approaches inherent in such fields. Further, ecologists may be generalists or restrict their ecological investigations to taxonomic biological divisions such as ornithology, mammalogy, entomology, etc. While the perspective of one subdiscipline may yield knowledge which reinforces or supplements that of other disciplines, the various perspectives and data may also yield conflicting concepts in the operational sense, and emphasize different responses such as the physiological, the evolutionary, or the systems.

The various definitions of stress result not only from the perspectives of the disciplines comprising the field of ecology, but are also subject to the limitations of studying the different levels of hierarchical organization of biological matter. For example, biochemical effects tend to be highly variable, have limited application, and be difficult to interpret. Study of morphological effects is limited by slow response time, and too many structures and types exist for general application. Physiological effects require extensive study time, have inconsistent and variable responses, and are limited by a lack of baseline data. Behavioral effects are highly variable according to individual organism and are species specific. Study of higher levels such as populations, communities, and ecosystems require long study time, and interpretation is difficult. Lastly, agreement about definitions of stress are constrained by the difficulties of extrapolating results from one study or organism to another.

ADEQUACY OF POLLUTANT DATA

A number of characteristics of pollutants make application of stress ecology difficult. These include:

Number of chemicals produced – The American Chemical Society's computer registry of industrial chemicals lists 4,039,907 distinct entities, with a rate of 6000 per week. Approximately 33,000 chemicals are in common use, and 50,000 are in daily use. These figures do not include pesticides, pharmaceuticals, or food additives [25].

Exponential growth of pollutants in the environment – Environmental levels of most chemicals are increasing exponentially. Consequently, contamination levels can easily reach excessively high levels quickly, even before we are aware of a problem.

Natural delays or time lags – Typically there is a delay between the introduction of a chemical into the environment and its appearance in various environmental compartments, or between its introduction and the detection of adverse effects. The delay may range from several months to decades; toxic metals, radiation, and carbon dioxide are examples of pollutants with long time lags.

Threshold versus nonthreshold chemicals – One of the most perplexing problems in assessing environmental or organism risk from exposure is the question of whether risk is proportional to exposure, even down to very low levels; or, alternatively, whether there is a threshold level below which adverse effects are nonexistent. Empirical data do not resolve this question because they are not obtainable for low dose levels. Therefore, one must utilize theoretical knowledge and statistical extrapolations based upon less than ideal laboratory or field data. One's conclusion regarding this question is unavoidably based upon untested assumptions; specifically, whether one assumes that a threshold or nonthreshold effect should exist.

Persistance – Most synthetic chemicals, toxic metals, and radionuclides with long radioactive half-lives remain in the environment for long time periods. Waste disposal techniques must therefore be effective over the long-term. If persistent chemicals are accidently liberated they will pose a long-term hazard. The radioactive waste product plutonium-239 will have to be properly sequestered in the environment for 240,000 years before it decays to a safe level.

Biological magnification – Persistent chemicals increase in concentration as they are transferred through the food chain; concentration factors may range from two to twelve orders of magnitude. Thus, a chemical may be nondetectable in, say, the water, but may reach harmful levels in higher organisms.

Chemical transformation – Chemicals may be liberated into the environment in a harmless state but react in the abiotic or biotic environment and be transformed into toxic forms. An example is when elemental mercury becomes methylated by bacteria in sediments, thereby increasing its mobility and toxicity.

Synergistic effects – This result is due to the fact that the toxicity of a chemical may be increased in the presence of others, such that the consequence of, say, two chemicals present together is greater than the sum of the effects determined when the chemicals are present by themselves. For example, hydrogen peroxide in a concentration of 1.5 parts per million (ppm) in the presence of ozone at a concentration of 1 ppm is lethal to some animals, whereas it has only a slight effect at 200 ppm when ozone is absent.

Pervasiveness – Numerous pollutants are regionally or globally distributed, and therefore do not remain within ecosystem boundaries. This results in low-level chronic ecosystem effects, and it is often difficult to determine the specific causes of such effects. Another scientific difficulty is that it is impossible or very difficult to ascertain natural levels for many chemicals. Determination of natural levels is necessary to understand whether environmental contamination has occurred. Lead is an example of a chemical which is globally distributed such that it is very difficult to determine natural levels. A consequence is that existing lead levels in, say, humans are considered by some to be "normal," and by others to be excessively high by five orders of magnitude [26].

Analytical techniques – Valid determinations of chemical concentrations depends upon proper analytical and sampling procedures. Twenty years ago, chemical instrumentation was not as advanced as present, and many harmful chemicals present in the environment in small levels were not able to be detected. Presumably, this is also the case today. Additionally, recent improvements in analytical sampling and laboratory procedures have shown that the overwhelming majority of some chemical concentrations as published in the scientific literature may be wrong by several orders of magnitude. For example, it has recently been determined that most figures for lead concentrations are in serious error [27].

Upper limits – The consequence of the above ten points is that the level at which a chemical might first begin to cause an adverse effect is usually not known, nor is the higher level at which clearly serious and unacceptable consequences might result. For example, some researchers believe the deep ocean layers will absorb anthropogenic carbon, thereby mitigating against carbon dioxide-induced atmospheric warming. Other scientists maintain that such warming has already begun [28].

As a result of the above eleven points is that adequate data for chemicals are seriously lacking. Estimates of the quality of information available on the potential health hazards (ecosystem hazards are excluded, but are more uncertain) for selected chemicals with sales greater than 1 million pounds per year indicate that adequate information exists for 10 percent of 3350 pesticide ingredients studied, 2 percent of 3410 cosmetic ingredients studied, 18 percent of 1815 pharmaceuticals studied, 5 percent of 8627 food additives studied, and 11 percent of 12,860 commercial chemicals studied.[1]

ADEQUACY OF ECOLOGICAL KNOWLEDGE

Many maintain that a holistic ecological approach is of greatest significance for the development of environmental ethics sufficient to guide humankind's behavior. However, a holistic approach is not fully developed and consequently remains largely theoretical and descriptive. Major scientific obstacles to a formulation of a holistic stress ecology include the following:

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[1] National Academy of Science, *Toxicity Testing: Strategies to Determine Needs and Priorities,* Washington, D. C., 1984.

Characteristics to study – Ecologists have identified important organizational characteristics of ecosystems to study to promote holistic understanding. These include:

1. ecosystem processes;
2. productivity;
3. decomposition and nutrient cycling;
4. interactions between the biosphere, atmosphere, hydrosphere, and lithosphere;
5. communities;
6. community structure;
7. dynamic networks of interacting individuals and species;
8. symbiotic and mutualistic species;
9. populations;
10. individual organisms; and
11. overall homeostasis.

While these characteristics are known to be important, there is often no consensus as to which of them should be studied for a particular problem [21]. Further, measurement of numerous parameters is often required, since changes in one parameter are not necessarily coincident with changes in others or with overall ecosystem changes.

Ecosystems as dynamic systems – Substantial natural variations of ecosystem structure and functions exist. Such variations include successional change, regular and periodic change due to temporal cycles, and change which is thought of as irrelevant "noise." All variations may be essential to the continuation of species which are adapted to the predictable variation patterns, and to ecosystem processes. Essential to accurate ecological assessments is understanding of the natural dynamics of ecosystems, and the ability to separate change into that which would occur in the absence of new stress and that which is caused by stress. In general, knowledge of the kinds and magnitudes of variations increases the more the finer or lower levels of ecosystem organization are studied; large ecosystem components may sometimes appear to be static because changes can only be detected after long study times.

Ecosystem scales and operations – Ecosystems include processes that operate on widely different structural, functional, temporal, and spatial scales. There is no *a priori* single correct choice of scales for a particular ecosystem. On the structural level, a focus of study may be on individual organisms, populations, or species; alternatively, a functional study may emphasize factors such as production, nature of change in population densities with predation, or energy flow. A suitable temporal scale may be defined, in part, by factors of climate, physiology, and nutrient cycling, and may include the short- or long-term. Spatial scales may be locally or globally defined. Spatial scales may interlock with temporal ones, but there is not a necessary correspondence.

Application of stress ecology requires recognition that events are taking place on a variety of structural, functional, temporal, and spatial scales. Any particular ecological study must necessarily define bounds on the scales of interest; this operationally defines the ecosystem unit of study. In the absence of limiting the boundaries of scales, it is not possible to unambiguously define an ecosystem. All ecosystems exchange information and material with other ecosystems up to the global level. However, because ecosystems are not closed, even with boundaries established on scales ecosystems cannot be defined unequivocally. A major problem is that in many cases the scales of interest are not obvious; when scales are known, they often are better known for lower hierarchical levels of organization. For example, it is easier to understand the local and rapid exchange of nutrients between plankton and seawater than it is to understand the movements of nutrients and water masses in the ocean. Stress ecology therefore demands that structural, functional, temporal, and spatial scales be chosen carefully; yet, it is not often possible to make choices on sufficiently precise data. Excessive reliance on measuring either structural or functional characteristics often leads to an inadequate description of overall ecosystem properties and changes. For example, an accurate description of species composition may indicate changes due to pollution stress. However, such changes may not necessarily be of consequence functionally if new species replacing the old perform similar functional roles in the ecosystem. Likewise, changes in functional parameters, e.g., productivity, by themselves do not indicate whether the system has been altered, for example, by replacement or disappearance of species, changes in trophic relationships, or whether it remains structurally unchanged. Temporal responses to stress may range from the instantaneous to the long-term. Consequently, short-term measurements may not predict long-term responses, and the natural variation of undisturbed systems may mask the response of a particular system to stress.

The correct choice of a hierarchical level to study – A holistic approach recognizes that ecosystems display emergent properties that cannot properly be understood in analytical reductionistic terms. Scientific studies that have focused on lower hierarchical levels have been criticized as being too reductionistic, and therefore contributory to ecological disruption [29]. Alternatively, reductionistic approaches emphasizing lower hierarchical levels often yield more certain data and hence are more predictive, although in a more narrow sense because they do not consider whole systems. Such approaches are not necessarily incompatible with holism. Potter maintains that it is artificial to separate reductionism and holism in ecology [30]. Intimate reductionistic details from, say, molecular biology may be necessary to know because such details provide knowledge about the targets of our environmental hazards. Further, relational properties of components in holistic systems may be understood by an analytical approach which studies a system's component parts.

This recognition does not imply that all of the biological world can be explained solely in terms of fundamental chemistry and physics terms and nothing else; it recognizes emergent properties of higher hierarchical levels. Generally, ecological "how" questions are answered by reductionistic approaches, and "why" questions are answered by considering external relations of the system of study [31]. Accordingly, to an extent a reductionist approach has to be defended as a stage in the evolution of new holistic environmental ethics. What is required is to combine knowledge of lower and higher hierarchical levels of organization and then proceed to development of an ecological holism.

Concepts of stability – Ecosystem stability can serve as a standard upon which to predicate a system of environmental ethics. Ecologists have been successful in determining the relationship of some, but not all ecosystem attributes to stability. For example, it is not known whether stability is due to species diversity, or the cause of it. Further, concepts of stability can variously emphasize the resistance to disturbance of an ecosystem, the time an ecosystem requires to recover from damage, the zone from which an ecosystem will return to a stable state, the degree to which the pattern of secondary succession is not an exact reversal of the retrogression following environmental impact, and the degree to which a stable ecosystem established after disturbance differs from the original steady state [32].

It is important to note the conclusion that major scientific obstacles constrain the development of holistic stress ecology is also supported by the results of one of the most comprehensive, sophisticated, and hence unprecedented ecological studies conducted. Research funded by over $10 million dollars and conducted for over a decade, which utilized advanced ecological methodologies and models, failed to adequately assess the long-term effects of once-through cooling of power plants on striped bass and other fish populations of the Hudson River [33]. The failure of the study is instructive, for it was not due to lack of effort, but occurred because of insufficient understanding of underlying biological processes. Further, the problem of study was not nearly so complex as other environmental problems (e.g., acid rain, environmental effects of pesticides, and climate change).

The discussion so far has emphasized the purely scientific constraints towards formulation of a stress ecology. However, such constraints cannot be entirely separated from practical limitations imposed upon ecologists. Society demands that ecologists forecast environmental impacts in a reasonably certain quantitative manner. Further, decision-makers demand information in a relatively short time period, and at reasonable cost. These demands constrain the focus of most ecological studies to lower levels of hierarchical organization, the short-term, small spatial areas, and measurement of relatively small numbers of parameters. Accordingly, holistic ecosystem knowledge is difficult to obtain for practical reasons as well as the scientific.

THE INTEGRATION OF ECOSYSTEMS AND SOCIAL SYSTEMS

Stress ecology as presently practiced is a subdiscipline of ecology; generally it is viewed primarily from its biological and physical interactions. Although humans are an implied element of ecosystems, the impacts of religious, cultural, and socioeconomic traditions on ecosystems are seldomly integrated with commonly employed ecosystemic measurements. This is despite the knowledge that such traditions significantly influence environmental quality. A consequence in terms of holistic systems analysis is that if the natural environment is contained within the systems boundary, then the socioeconomic system is an external force acting upon it, and vice versa. The result is a dichotomy whereby the ecological sciences are equipped to deal only with nature and not human needs, and the social sciences are able to deal with human needs but not those of nature. Existing strategies of pollution control fail to achieve long-term environmental protection because they utilize arbitrary or incomplete boundaries. This leads to fragmented problem identification and analysis because the strategies ignore the feedbacks between the two systems. Although more holistic pollution control strategies would theoretically provide for a long-term symbiotic relationship with nature, several additional factors constrain their development.

Existing Strategies of Pollution Control

Current strategies of environmental protection pertaining to pollution control and resource use can serve as specific examples of how the environment and the economy are viewed as distinct systems and not within a common boundary of a larger system; these are shown in Figure 1. Such strategies create problems because they are not sufficiently holistic [34]. Technology is utilized to obtain and process natural resources, and to find substitutes for scarce resources, it is also used to achieve environmental protection by concentrating harmful technological by-products and dumping them in approved environmental sites such as landfills, or by concentrating such by-products and isolating them in, say, toxic waste

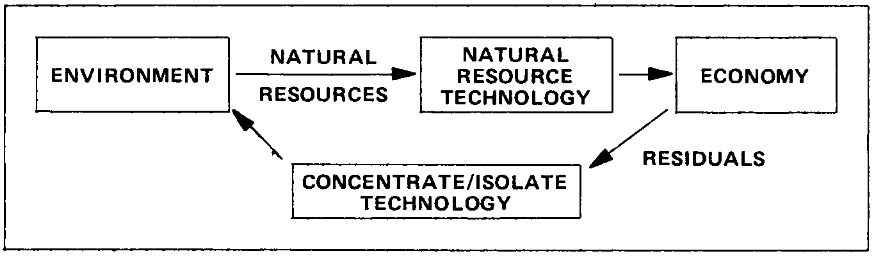

Figure 1. Existing strategies of pollution control.

disposal sites. These strategies have provided some environmental protection for the short-term. However, because they emphasize concentrating and isolating wastes, they are uphill thermodynamically. Consequently, such strategies require exponential increases of fuel and other resources, human labor, and significant monetary expenditures. Further, the concentrated pollutants have considerable potential to increase environmental impacts in the future. Environmental contamination from improperly managed or designed waste disposal sites is a growing problem to both the human and nonhuman environment. For some pollutants, such as plutonium-239, it is unlikely whether any disposal sites or isolation techniques will be adequate. Additionally, not all pollutants are controlled by abatement techniques; the residuals lead to sublethal environmental stress resulting from chronic low level exposure. Extensive reliance on pollution control technology also increases diffuse pollution, because of the mining and processing of raw materials necessary for the technology. Existing strategies of pollution control, by ignoring thermodynamic considerations, inevitably lead to higher costs for goods and services and for environmental protection, a worsening of environmental problems for the future, and significant hidden and indirect environmental impacts [34]. They will not provide for a long-term symbiotic relationship between man and nature.

Holistic Pollution Control Strategies

The identification of a functional unit which encompasses the physical, biological, and socioeconomic components of the environment would, in theory, properly evaluate stress effects in a more holistic manner. A theoretical concept which integrates ecosystems and socioeconomic systems in a holistic manner is shown in Figure 2. Included within the ecosystem component of the model are the traditionally studied levels of biological matter such as biological molecules, cells, tissues, organs, organ systems, organisms, populations, communities, ecosystems, and the biosphere; also included are the atmosphere, hydrosphere, and lithosphere. Included within the socioeconomic system component are individuals, family, groups, human populations, human communities, nations, and the socioeconomic system. The ecosystem and socioeconomic systems combined together can be said to be the "noösystem." The noösystem includes the traditional concept of the ecosystem and the religious, cultural, and socioeconomic relationships to the whole system. Such a concept lessens the anthropomorphic connotation which exists when ecosystems and socioeconomic systems are arbitrarily separated; it places humans in nature as opposed to being outside of nature. In Figure 2, the ecosystem and socioeconomic system are linked by the flow of natural resources from ecosystems to the economy, and by the flow of pollution from the economy to the ecosystems [34]. Some pollution is recycled back to the economy without undergoing degradation by ecosystems. Some recycling is intentional, e.g., aluminum, and some is unintentional, e.g.,

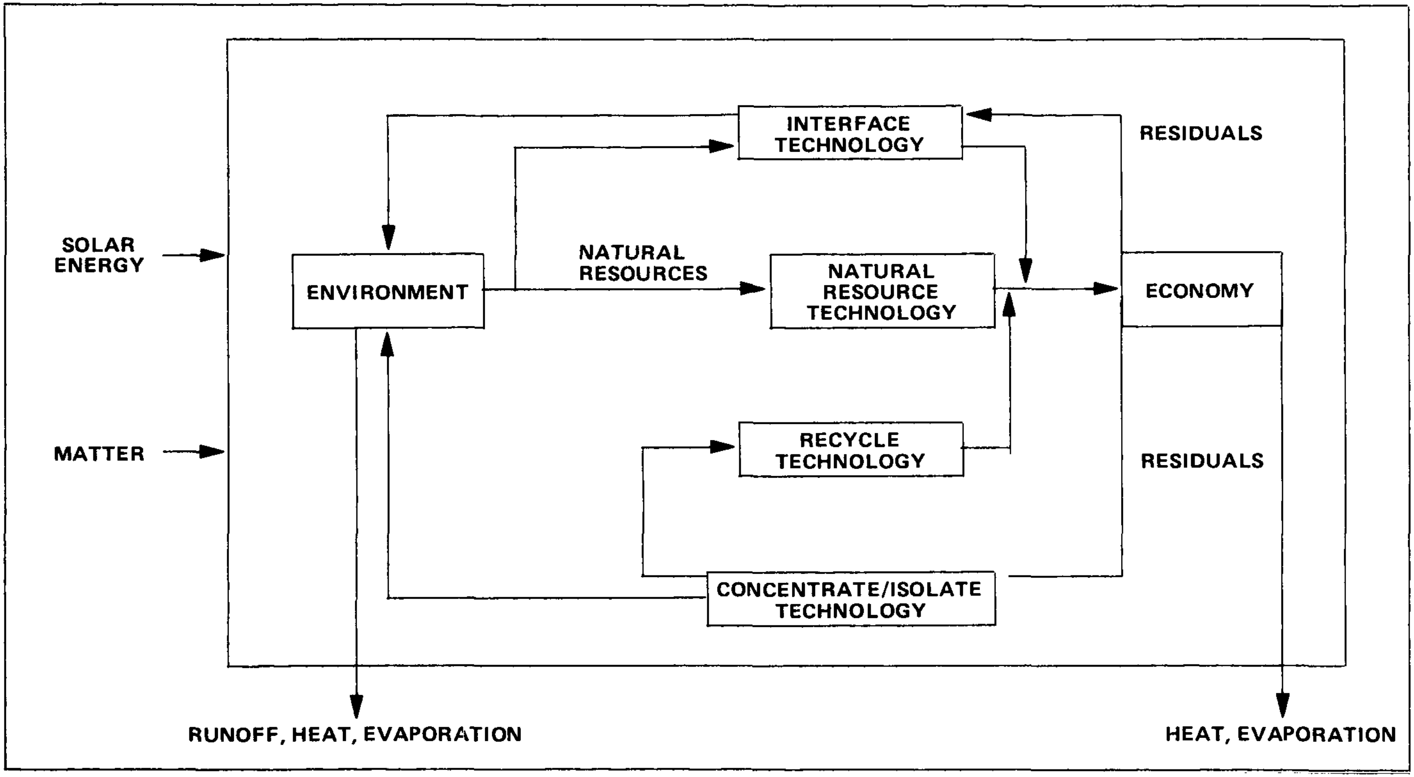

Figure 2. Integrated pollution control approaches.

acid precipitation. The "health" of ecosystems and the economy is dependent upon the flux rates of pollutants which flow between them. Natural ecosystems are capable of absorbing pollutants from the economy if the levels are not excessive; accordingly, clean natural resources are freely made available for use by the economy without the expenditure of money or increased utilization of raw materials for pollution control technology. In theory, the concept suggests that a long-term symbiotic relationship between the environment and the economy can persist. However, if pollution levels are excessive, natural resources must be cleansed before use by the economy; this requires monetary expenditures and consumption of raw materials.

The alternative strategies shown in Figure 2 have been applied only to a limited extent. A strategy emphasizing concentration and recycling reduces some environmental impacts of materials production and conserves natural resources. However, it is not clear whether the concentrate and recycling strategy ameliorates many of the disadvantages described for Figure 1. Recycling utilizes a high technology and centralized approach to environmental protection, and is expensive in terms of dollars and energy consumption; it also produces concentrated toxic residues that require adequate long-term disposal or isolation. The interface strategy couples some pollutants with an environment that is already adapted to utilizing the pollutants. Examples of interface systems include land application of waste water, use of greenbelts for extracting air pollutants and for flood control, and once-through cooling of power plants. In the interface approach, environmental resources are one of the inputs to environmental control technology. The approach produces resources that are desired by the economy and that are utilized by the environment itself; it requires that the donor of a pollutant and the recipient of that pollutant be considered as one integrated interface. The overall aim is to establish and manage a complex of natural ecosystems for the purpose of transforming the by-products of technology into more benign forms prior to release to the environment or the economy. An interface approach would mitigate some disadvantages associated with a concentrate or isolation strategy. An interface approach substitutes natural environmental resources for raw materials, fuel, and labor required for pollution abatement technology, and produces by-products that are less toxic than the by-products which it treats, because pollutants are thermodynamically closer to their endpoint state. Further, diffuse pollution and hidden costs of abatement are lessened because consumption of raw materials and fuel needed for pollution control are reduced. The major problem with the interface approach is that it is likely that some pollution is too large in amount and too concentrated to make interfaces feasible. Most importantly, an interface approach would require sophisticated ecological and engineering knowledge for the design of interface environmental systems; such knowledge is not yet available [34].

Several additional factors need to be considered in a holistic pollution control strategy. These include:

1. population size;
2. population distribution;
3. resource use per person;
4. pollution per unit of resource used;
5. economic system;
6. political system;
7. administrative efficacy; and
8. ethical system.

Although each of these factors is known to be relevant to the pollution problem, they are only generally understood, and there is no consensus on which are most important.

CONCLUSION

Holistic stress ecology can, in theory, be used as a basis for "shallow" or "deep" ecology. Successful application of holistic ecology can support the shallow ecology paradigm because it enables society to make more efficient use of natural resources to best serve anthropocentric interests. Application of holistic stress ecology according to the shallow ecology paradigm would require extensive modification and design of many natural ecosystems. If it is assumed that a human population operating according to deep ecology ethics will cause environmental impact (although an impact less than exists under a shallow ecology paradigm), then application of holistic stress ecology is also necessary to support the deep ecology paradigm because it could indicate, for example, when unintended environmental effects were occurring [35].

The development of applied environmental ethics predicted upon holistic stress ecology requires that scientists and decision-makers be informed of ethical thought, so that decisions about the environment are made in the most ethical manner possible. Scientists need to provide ethicists with ecological meaningful information so that philosophers can develop ethical theory in accord with ecological facts. Unfortunately, while holistic ecological thinking is often advocated as a basis for environmental ethics, the philosophical literature on environmental ethics does not contain a rigorous discussion of the adequacy of holistic stress ecology, nor does it provide references from scientific literature which support a contention that stress ecology is sufficiently developed for predication of an holistic environmental ethic. The consequence is that development of ethical thought is not congruent with the state of the art of holistic ecological knowledge, and hence is destined to remain largely theoretical instead of becoming suitable for application. My assessment of the status of stress ecology is that it is not sufficiently developed to support, for the long-term, either the shallow or deep ecology paradigm in any reasonably certain and predictive manner.

A variety of definitions of "stress" exist; these are due to reasons pertaining to the historical development of the field of stress ecology and also to scientific and practical factors which constrain study to certain types of organisms, particular levels of hierarchical organization, relatively short time periods, and relatively small regional boundaries. Further, interpretation and extrapolation of stress effects is difficult. Accordingly, there is not a consensus on which definition of "stress" is the most ecologically meaningful.

It has not been possible to adequately test but a small fraction of the tremendously large number of anthropogenic chemicals in the environment. Our knowledge about their environmental and human health effects remains woefully inadequate. Further, the production and utilization of new chemicals continues to grow faster than our ability to conduct proper tests.

Although ecological knowledge can be used to support the idea that we should, perhaps, think holistically, the application of stress ecology is seriously limited. First, there is no consensus as to what ecosystem properties to measure. Second, although it is known that certain species play fundamental roles in the structure and functioning of ecosystems, it is not possible to develop generic lists of critical species. Third, ecosystem boundaries are arbitrary. Depending on how ecosystems are defined, each can be said to be unique. If each ecosystem is regarded as unique, then environmental regulation is a hopeless task. Alternatively, it is also thought possible to classify ecosystems by common characteristics and therefore implement adequate environmental protection measures for similarly classified ecosystems. However, it is recognized that fundamentally there is only one ecosystem, that of the biosphere. Because of the problems of, say, non-point and transboundary pollution, protection of air, water, or species may not be sufficient unless the biosphere as a whole is considered. Environmental protection at the biosphere level requires agreement about problems and their solutions at the international level; this is not likely.

An environmental ethic predicated upon holistic stress ecology requires integration of ecosystems and socioeconomic systems. Systems analysis is the formal application of holistic ecology, and is still very theoretical. Not only is ecosystem knowledge inadequate, but there is little conclusive understanding of the most important socioeconomic factors which influence pollution. Such information is required for application of systems analysis. Further, even if such knowledge were available, it is possible that the most commonly proposed holistic approaches for pollution control would not be adequate due to requirements of high technology and energy use, and sophisticated ecological and engineering knowledge.

Several additional implications of my analysis exist for scientists concerned about informing environmental ethics.

First, scientists must decide whether to devote their expertise to the shallow or deep ecology paradigm; the demands made upon scientists by the respective paradigms are different. Shallow ecology requires application of science to the task of economic management by developing the insights and information society needs to manipulate, control, and convert ecosystems to provide the goods and services society utilizes. Alternatively, deep ecology requires scientists to provide the insights and information society needs to understand how ecosystems function in the absence of significant human intervention. Scientists would, accordingly, assist policy makers in deciding what ecosystem components should be preserved and why, based upon evolutionary and biological characteristics. Importantly, the way ecology develops will depend upon whether scientists emphasize the shallow or deep ecology paradigm, and how they reach a compromise between a research agenda which serves the purposes of management and an agenda which promotes maximum environmental protection. Should science emphasize the shallow ecology paradigm, it will increasingly contain descriptions of situations which facilitate prediction and control of ecosystems. If the deep ecology paradigm prevails, the ecological sciences will increasingly evolve a scientific framework in which society can appreciate ecosystem qualities and evaluate policies concerning them.

Second, ecosystem modeling is frequently used in applied stress ecology to predict how ecosystems will change if certain modifications are made. Ecosystem managers sometimes pay more attention to models and what they are supposed to do than to the state of real ecosystems. Unfortunately, few ecological models have been rigorously tested for use as sources of prescriptions for management of stressed ecosystems. Further, models range from relatively simple regressions to large mechanistic models. Ecosystems are complex units with many variables, all of which interact sometimes to produce counterintuitive behavior. Simple models often do not contain sufficient detail to be convincing or extrapolated beyond the original data used to construct them, whereas large detailed models are difficult to construct, operate, validate, and interpret. Additionally, part of ecosystem complexity is a property arising from the interaction of the system with the observer [36]. Levels of complexity incorporated into the observer's objectives guide the degree of complexity involved in ecosystemic analysis. To what extent should models be used as a basis for management, given their deficiencies and the fact that not all likely effects can be evaluated? Although, theoretically, models facilitate the ordering of information, they do not necessarily provide information on what rate of stress-induced change is acceptable, nor which components of an ecosystem should be managed and which should not.

Third, many politicians, industrialists, and some segments of the general public are asking for hard field data on which to base pollution control legislation. Accordingly, it is held that society should move slowly in imposing new emission controls until the cost-benefit relationship is quantified. What role should stress ecologists play when decisions, as yet, cannot be made on scientific certainty? One approach is for stress ecologists to use circumstantial evidence as the basis for their best informed judgment. This approach is sometimes resisted by scientists because they often are reluctant to speak out on issues without having hard data. However, what must also be considered is that excessive reliance on stress ecology may not be practical given the scientific uncertainties, other than for it to suggest extreme caution in our dealings with the environment. The demands of a large human population and the consequences of modern technology permit little margin for error. If stress ecology will not sufficiently inform either shallow or deep ecology about long-term environmental impacts, then what alternative exists for environmental ethics that require predictive scientific information? What seems necessary is for the human population to be significantly below the earth's carrying capacity. The environment would therefore be buffered against both our willful and inadvertent actions. Consequently, the management need for more certain predictive ecological data would be lessened and a greater margin for error would exist.

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