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SYSTEMS PREDICTION: THE INTEGRATION OF DESCRIPTIVE, EXPERIMENTAL AND THEORETICAL APPROACHES[1]

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The most critical aspects of an environmental impact analysis is the determination of whether or not ecological change means ecological stress. As Chairman of the Michigan Environmental Review Board (MERB) for the last three years, I have had the opportunity to debate the relationship between change and stress for a large number of environmental issues covering a wide variety of impacts, including Project Seafarer, the Department of Navy's 3,000 square mile communication antennae which would emit low frequency, electromagnetic radiation; the thermal effluent impact from electrical generation plants on the shore of Lake Michigan; the environmental impacts of polybrominated biphenyls (PBB) in ecological food chains; the ecological change anticipated with the establishment of the Gypsy moth in Michigan; and the ecological impact of oil exploration and development on the elk herd in the Pigeon River Country State Forest. All of these case studies came to MERB as a major environmental concern based on the belief that physical, thermal, chemical and biological alterations of the existing conditions would constitute a stress to the ecology of Michigan.

The data required to evaluate the ecological response to a potential stressor is similar to that required by the FDA to evaluate the toxicology of some food additive. The difficulties of obtaining direct observations of dose-response curves under controlled conditions for populations, communities and ecosystems is, however, a most difficult task. In real life situations, decisions are based on some logic, some descriptive data and some social relevance of the anticipated impacts. Many times the significance of an impact is judged not in quantitative characteristics, but as shifts in qualitative impacts. The measurable contaminants of kepone in Chesapeake Bay bluefish, polychlominated Bipheyls (PCB) in Lake Michigan lake trout, and PBB in Michigan dairy cattle did not affect the demographic properties of the populations. Rather, the major impacts were to preempt the social utility of these biological resources.

In order to determine significance of change either quantitatively or qualitatively, one must first establish a reference point for an ecological base-line and then determine the *natural* variations that one would observe without the presence of an outside stressor. The normal rigors of a biological system coupled to a stochastic environment will generate a certain level of *stress*. This amount of uncontrolled perturbation is one of a number of environmental constraints to which ecosystems have evolved a number of buffers. What we really need is to determine the amount of additional stress imposed by human induced activities and how much resistence the ecological system contains. The impact of incrementally increasing the total amount of stress agents is to incrementally decrease the resistence to withstand the infrequent extremes of naturally induced stressors. The results of increasing this vulnerability would only become apparent under extreme and unlikely combinations of environmental conditions.

The baseline pattern and the inherent variation varies tremendously with type of environment and level of biological organization. Populations, communities and ecosystems have differing structural

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configurations and differing mechanisms for behavioral compensation. The dynamics of materials and energy have generic properties, but the formulation, storage, transport and expression of information is very different at each level of organization. Recently, the concept that ecosystems are analogous to ***super organisms*** has been re-emphasized. This allows one to consider ecosystem pathologies similarly to human disease. In the same way that protein content of urine is utilized to determine gross pathologies, soil-water ion concentration could be utilized to determine ecosystem stress. One must be very careful as to how these results are interpreted. There are no unique relationships between behavioral output and system performance. Furthermore, one must design the experiment so as to allow the ecosystem to compensate internally and re-establish acceptable levels of materials. Quantitative deviations in ion concentrations are not unique and significant determinants of stress.

From purely ecological aspects, one can approach the problem of determining reference levels of means and variances from 3 perspectives: theory, experimentation and descriptive characterizations of existing conditions. Considerable theory exists at the level of population dynamics. The theoretical basis of community and ecosystem ecology is poorly developed. Since most ecological theories are based on or constrained by evolutionary concepts, the logic of going from population interactions to community dynamics is not an easy step. Most community formulations are derived by taking traditional two-way competition and/or predation models and expanding them to n-dimensional arrays (May 1973). The resulting questions of the exsistence of single equilibrium conditions versus multiple stability points, the impacts on alternative equilibrium arrays as species composition changes, the degree of determinism associated with community succession, and the possible existence of differing equilibrium arrays, for each of a variety of differing environmental conditions, all relate to the relationship of change versus stress.

For any given level of environmental uncertainty, there exists the option of selecting for alternative patterns of life history strategies. The resiliency of communities is partly due to the opportunity to adjust to environmental change by the substitution of alternative species within any ecological guild. The species taxonomies can be altered considerably without any significant change in functional performance.

In short, we must think of baseline patterns that are adaptive and dynamic. Steady state solutions are mathematically tractable but not ecologically realistic. To determine theoretically the parametric values of means and variances of community characteristics, a goal toward which many ecologists are working, one would have to quantitatively determine the interaction of 4 factors: competition, predation, spatial heterogenity and temporal heterogenity. The heterogenity factors include both biolocial and environmental properties of the ecosystem that modify the interaction of competition and predation.

The most direct approach is to initiate controlled and replicated experimentation. These experiments can be performed in controlled environmental chambers or with free-ranging field experiments. The trade off between precision and robustness is a well known design problem. Recently, the use of replicated microcosms as experimental units has increased in interest. This is partly motivated by the requirements of the new Toxic Substance Act to test potentially toxic substances at the community and ecosystem level. Neill (1975) took over one year to establish 40 replicated microcosms that stabilized through systematic ross migration. Once each unit was isolated, the units drifted apart so rapidly that the experimental stress (addition of fish predator) effects had to be measured within a few months. Taub (1974) summarized the results of many years of microcosm research. Little can be obtained from these results to help determine the baseline levels of means and variances for community characteristics.

Field experimentation is probably the most direct method of establishing various patterns of community dynamics under semi-controlled conditions. Unfortunately, the time, effort and monies required for this type of hypothesis testings limits its use. The experiments reported by Paine (1966) and Dayton (1971) with intertidal communities, Simberloff and Wilson (1970) with Mangrove Islands, Harper (1969) with terrestrial island communities, Hall *et al* (1970) with replicated fish ponds and Borman *et al* (1970) with experimental watersheds all represent examples of community and ecosystem manipulations. In the long run, we must develop experimental ecosystems prototypes that are large enough to stabilize the patterns of interactions and yet small enough to allow adequate manipulative control.

Most of the field experiments were done with ecological systems that were chosen for scientific purposes. In most cases, these systems were not the same as those involved with environmental impact assessments. With the advent of the NEPA Act, a tremendous number of environmental assessments have been performed. The majority of these deal solely with on-site descriptive data of usually only 1 or 2 years duration.

The range of ecological parameters that could be utilized as stress indicators is broad and the associated detailed comparisons of sensitivity and reliability have not been accomplished. Taxonomic indices such as species numbers, species diversity, indicator species and species frequency distribution curves have all been utilized. Functional characteristics such as ratios of predator and prey abundances, physiological processing of specific portions of the biogeochemical cycles, species packing and niche breadth determinations, and life history strategies resulting from "r" and "k" selection have also been utilized to characterize communities in harsh versus benign environments. Others have utilized integrative variables such as total O_2 fluctuations, total CO_2 changes, soil water ion concentrations or total organic carbon to characterize community conditions.

In all of the above, the lack of controls and the multiple confounding factors reduce the resulting analysis to something of an art form. Short term shots at characterizing long term oscillations generate an impossible situation for objective, parametric analyses. The recent use of neutral models to obtain baseline estimates of means and variances for community parameters (Caswell 1976) illustrates the need for extreme caution. Multivariate pattern analyses requires a considerable amount of adequate data collected from a well designed protocol. Most environmental assessments fail miserably in all of the ecological requirements mentioned above. Because of this, it is very difficult to determine natural steady state versus unsteady state dynamics of communities and ecosystems. The distinction between change and stress is, therefore, seldom made.

The tradeoffs of utilizing structural versus functional characteristics to identify and quantity stressed ecosystems relate to the cost and ease of measurement versus the interpretive relevance of the significance of observed deviations. The most observable changes are not necessarily those related to the most serious stress agents. We are all told that the Lake Erie ecosystem is stressed through eutrophication. The carp and alewives don't appear to be very stressed and the secondary productivity of the *trash fishery* appears very healthy. On the other hand, the introduction ot sea lamprey, alewive and many salmoid species into Lake Michigan has probably generated a more serious source of irreversible stress in this lake eocystem. The significance of a given change has more often been judged in social terms of human utility than in ecological terms of resiliency, resistence and stability. Ecological cost/benefit and risk/benefit analyses are not conducted in the same fashion and with the same parameters as analyses of social tradeoffs.

It is obvious from our experiences with toxic material crisies in the last few years that nobody can predict ahead of time the next stress agent that will become a major issue. The research and development efforts in the the area of stressed ecosystems must be oriented towards generic properties. Community and ecosystem mechanisms for compensation and adaptation must be understood. The limits of resiliency and resistence must be quantified as a function of the class of stress agents, the intensity of the insult and the frequency of repeated insults. It will be a long time before adequate computer based models exist to analyze for sensitivity and rbustness. In the meantime, physical prototypes should be developed and the ecological hypotheses tested through direct experimentation.

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