A Problem-Solving Approach to Resource Management

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To assess stress in a given system, resource management must take into account socioeconomic as well as biological and physical factors. The 19-step algorithm presented here should help applied ecologists tackle management problems holistically, objectively, and systematically.

Ecological systems are frequently exposed to a wide array of ubiquitous perturbations (e.g., acid rain, increased CO_2, and pesticides). The response of these systems to stress has become a fertile field of investigation. For example, Darnell (1970) noted that an ecosystem's response to stress usually reflects the intensity and duration of the stress agents imposed and the ability of a particular system to respond. Hurd and Wolf (1974) proposed a model of ecosystem stability in response to stress, defining stability as the ability of a system to retain or return to some ground state after being perturbed. They pointed out that one can design experiments to test stability in terms of a system's response to an external perturbation measured as a deflection from ground state. My colleagues and I (Barrett et al. 1976) outlined a series of guidelines for testing perturbations at the ecosystem level. Odum et al. (1979) presented a subsidy-stress gradient model and pointed out that a systems approach based on energy flow models can clarify many cause-and-effect relationships. Pimentel and Edwards (1982) described how pesticides influence essential ecosystem functioning by, for instance, changing patterns of energy flow and nutrient cycling. And a recent book (Barrett and Rosenberg 1981) focuses upon the effects of perturbations on both terrestrial and aquatic ecosystems and suggests new approaches for evaluating such perturbations at the ecosystem level.

Thus, a variety of studies have considered holistic approaches to the investigation and management of stressed ecosystems. However, we need new integrative units of investigation and new research approaches for our understanding and management of these large and complex systems to advance even more rapidly in the immediate future.

In this article I suggest that a new unit of study (the noosystem) and a new research approach (a problem-solving algorithm) will not only further our understanding of ecosystem structure and function, but also permit applied ecologists to make resource management decisions in a systematic and scientific manner.

THE NOOSYSTEM CONCEPT

Previously (Barrett 1981, 1984a) I have argued that the noosystem, rather than the ecosystem (Evans 1956), should be recognized as the basic unit of study for integrating biological, physical, *and* socioeconomic parameters within a holistic, systems framework. (See Birx 1972, Naveh and Lieberman 1984, Teilhard de Chardin 1966, and Vernadsky 1945 for a review of the noosphere concept.) Naveh and Lieberman (1984) especially call attention to the importance of noospheric-cultural influences and impacts on resource management in the emerging field of landscape ecology. At one end of the spectrum, ecologists have all too often studied ecosystems without regard to human impacts. At the other end of the spectrum, decision makers and environmental scientists frequently make resource management decisions that are not based on sound ecological theory or fact. Thus, ecologists ignore the human systems; decision makers ignore the ecological systems.

Applied science must be integrated with basic science as research, educational philosophies, and personnel needs continue to change (Barrett 1981, 1984b). Indeed, applied ecology could be an

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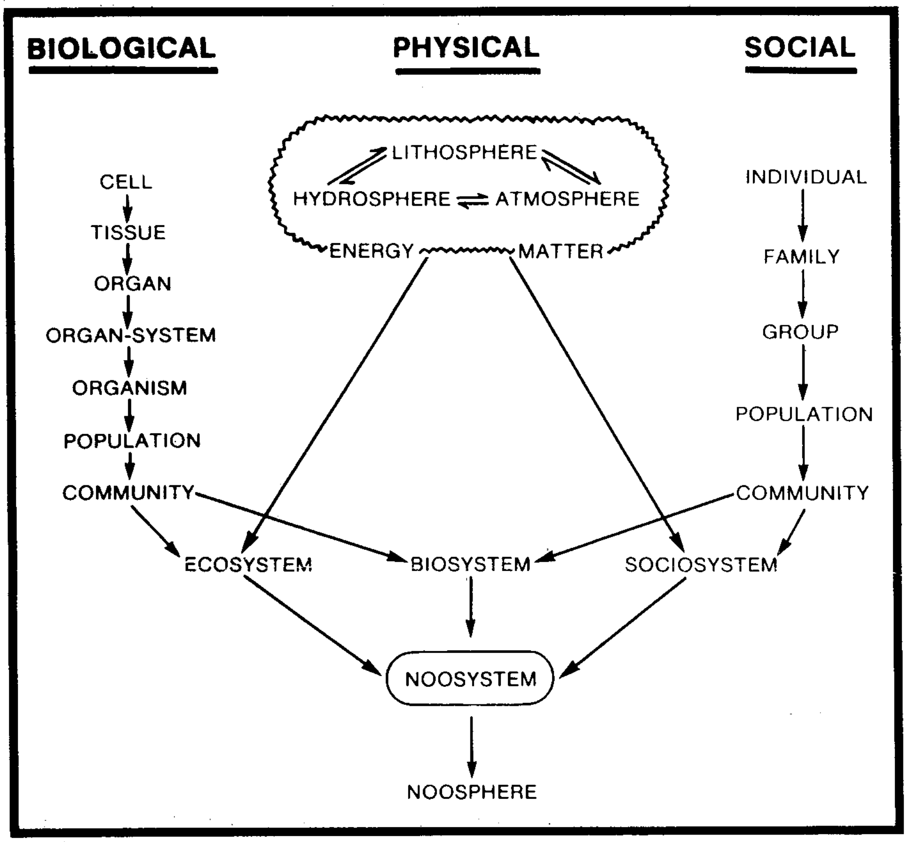

Figure 1. A diagram depicting the noosystem as the basic unit of study for applied ecology. Modified after Barrett (1981).

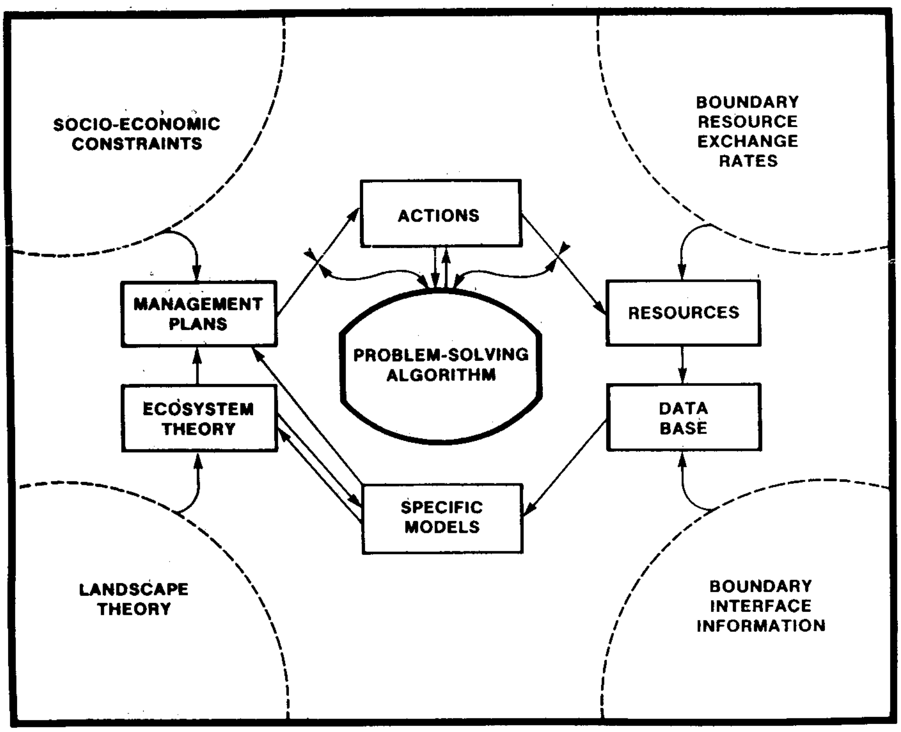

Figure 2. Diagram incorporating a problem-solving algorithm for resource management within a national park.

integrative paradigm for merging such research and training needs (Barrett 1984a, Redfield and Barrett 1983), and the noosystem could serve as a basic unit for such an integrative approach (Figure 1). The influence of socioeconomic systems on ecosystem dynamics can no longer be ignored; neither should resource management decisions continue to be made that are not based on sound ecological theory. The noosystem concept would, therefore, include not only a study of the structure and function of ecological systems, but also the social, economic, and cultural influences on such systems. A holistic approach to the management of stressed ecosystems urgently needs to be developed along these lines.

A NOOSYSTEM MODEL

Figure 2 depicts a landscape-level noosystem, namely a national park. Any long-term management plan needs to be based not only on sound ecosystem or landscape theory, but also on socioeconomic constraints like budget appropriations. Although national parks have traditionally been viewed as ecosystems (e.g., Houston 1971), management plans have frequently failed to combine ecological and socioeconomic components in long-term decision making.

Ecologists have often failed to recognize that several research approaches (including algorithms, scientific method, cost-benefit analysis, net energy, cybernetics, and problem solving) are available for efficient and cost-effective impact assessment and resource management. Unfortunately, problems associated with impact (stress) assessment—road construction, acid rain, prescribed burning, and disease control, for example—frequently are attacked only in a site-specific manner (the stress is analyzed via a reductionist rather than a holistic approach); they may be viewed at an incorrect scale of resolution (the stress is evaluated in terms of the population or single ecosystem rather than the landscape); or they may be analyzed by only a single research design (the stress is assessed only in terms of short-term financial costs rather than a mechanistic and long-term perspective). Thus, for real-world resource management, one may need to use an array of research approaches, often simultaneously.

This paper describes a problem-solving algorithm that takes a holistic (landscape), quantitative approach to decision making (see also McCormich and Barrett 1979). I hope this algorithm will provide a new approach and integrative perspective for large-scale problems.

THE PROBLEM-SOLVING ALGORITHM

This problem-solving algorithm is important because it encourages a systematic, interdisciplinary approach to complex problems and opens the decision-making process to the public for inspection and/or participation. The algorithm can also be used for education (e.g., an interdepartmental seminar or class project) in fields like applied ecology, resource management, impact assessment, landscape ecology, and environmental science. The 19-step algorithm (Figure 3) is particularly well suited to siting major construction projects (e.g., power plants, reservoirs) or corridors (highways, power lines). Please note that in some instances, managers may need to loop back to an earlier step to make the process as specific as possible.

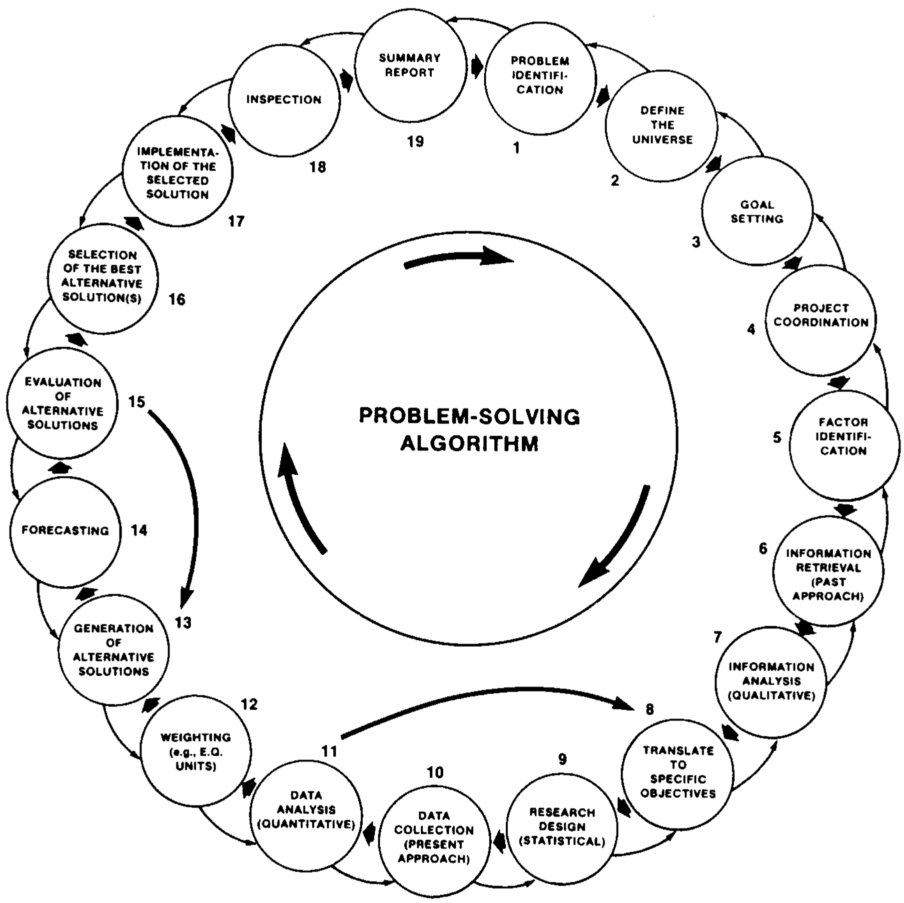

Figure 3. The 19-step problem-solving algorithm.

1. *Problem identification.* This first step is also one of the most difficult. Problems can arise from natural phenomena (the eruption of Mount St. Helens, on the cover), passing of federal legislation (impact assessment required by the National Environmental Policy Act [NEPA]), or anthropogenic effects (acid rain). A hierarchy of smaller problems growing out of a larger problem area can also appear. To illustrate the algorithm, let us assume that we need to locate an environmental-awareness center in one of our national parks; this need is related to problems associated with increased demands for environmental education, recreation, resource management, ecological research, and socioeconomic planning.

2. *Define the universe.* A universe must be defined for each problem. Boundaries for certain problems, depending on scale and management constraints, may correspond to total watersheds, park boundaries, or the political units within which such systems are located. For our environmental awareness center, the limits are the recognized park boundaries, including visitors and park management personnel.

3. *Goal setting.* Goals are normally stated in utopian terminology (Baldwin et al. 1975, Barrett and Puchy 1977), for example, "To locate the environmental awareness center for maximum public benefit with minimum degradation of the natural environment."

4. *Project coordination.* Normally at this step in the algorithm a steering committee is assembled to coordinate the total problem-solving process, although the team may be appointed earlier depending upon the scope of the problem or the scale of the system. This group must recognize that the approach is interdisciplinary, and all steps, including those using ecological lexicon, must be understood by all (Barrett et al. 1976). The steering committee is *to coordinate* the process, not to make quick or final decisions.

5. *Factor identification.* All major factors need to be identified at this step via public hearings (as required by NEPA for federal projects), state laws, questionnaires, or other means. All factors, regardless of their hypothetical significance, should be considered equally important during this step. Factors related to an environmental awareness center would likely include project costs, transportation, reduction in biotic diversity, aesthetics, nutrient loss, water supply, sewage disposal, proximity to historical sites, jobs created, and primary productivity lost.

6. *Information retrieval (past approach).* The purpose of this step is to collect and catalogue past (existing) research information. Here the emphasis is on information retrieval and on establishing efficient computer storage systems. Information reservoirs will likely include scientific publications; governmental reports; historical archives; related environmental impact statements; soil surveys; and relevant local, state, and federal laws. Human and financial resources should not be spent on conducting basic research if satisfactory basic research data are already available.

7. *Information analysis.* The steering committee must assure itself (and the public) that all important existing information has been collected and reviewed. Naturally, the steering committee must be provided with the resources and facilities they need to retrieve, store, and review that information.

8. *Translation to specific objectives.* With the help of experts, every factor from step 5 must be translated into a specific *quantitative* objective. For ex-

Table 1. An example of weighting each factor in environmental quality (E.Q.) units (step 12). Data are expressed as a mean E.Q. value for each factor.

Factor	Weight
Project costs	18
Traffic	10
Biotic diversity	5
Aesthetics	12
Nutrient loss	14
Water supply	4
Sewage disposal	8
Historical sites	8
Jobs created	5
Primary productivity lost	16
TOTAL	100

ample, construction engineers (or legislative committees dealing with budgetary appropriations) might limit the cost of the project to $1,250,000; transportation engineers might recommend that roads leading to the environmental awareness center accommodate 1,000 vehicles per hour; and professional ecologists might determine that either the carrying capacity of an important game or indicator species should not be reduced by more than ten individuals per 1,000 hectares or that the biotic diversity of a particular taxonomic group or guild is not to be reduced by more than ten percent of natural (preimpact) conditions. Each objective should be independently and quantitatively stated by experts in the particular study area. In some instances state or federal laws, such as air and water control standards, will already have stated such factors in quantitative terms.

9. *Designing additional research for statistical validity*. Let us assume that no data are available for a particular factor, such as aesthetics (see step 5). These data must therefore be collected, based on a valid research design (Hurlbert 1984), before this factor can be quantified (step 8). Experts familiar with public surveys might decide that a semantic differential test (Collins et al. 1979, Osgood et al. 1957) be given, asking the public (e.g., park visitors) to rank particular qualities on a scale from 0 to 10. The survey must first be field tested, worded, and stratified to obtain valid data. A drawing of the proposed center superimposed on one of the proposed natural park sites could be shown to park visitors for aesthetic response. Results from 0 (ugly) to 10 (beautiful) might indicate, for example, that the center should not decrease the aesthetic value ($\bar{x}$ = 7.2 ± 1.2 s.d.) of the park by more than 2.4 units.

10. *Data collection (present approach)*. Data would be collected at this step until experts can quantify each objective. This step is termed *present approach* because new data need only be collected if valid past data are lacking.

11. *Data analysis (quantitative)*. Data must be analyzed statistically based on the research design and data collection methods noted in steps 9 and 10. Outside statistical consultants may be called upon if they are not already part of the steering committee.

12. *Weighting*. Dollars, energy, and environmental quality (E.Q.) units are frequently used in impact assessment and problem solving (Odum 1977, Odum and Odum 1976). Here, let us assume that 100 E.Q. units are to be distributed (weighted) among the total number of factors (step 5) by each person in a random survey of park visitors. Each factor would be assigned an individual value by each participant until the 100 E.Q. units are exhausted. A mean weight value per factor is then determined for the total number of visitors surveyed. Table 1 provides an example of weighting differences for a limited list of factors. Survey experts, working in consultation with the steering committee, administer the survey.

Alternatively, the steering committee itself, using the Delphi Method (Dalkey and Helmer 1963), could weigh the factors if funding were insufficient to allow a full-scale survey. But the most representative weighting would come from the public because they are likely to be paying for the project via taxes or user fees, and the long-term success of the center will likely depend on their continued participation and support.

13. *Generating alternative solutions*. The steering committee must propose alternative solutions to the problem (i.e., alternative sites for the center) at this step. NEPA, for example, requires alternatives if federal funds are used for a project of this scale. Viable alternatives could be generated via land-use capability analysis (Naveh and Lieberman 1984) or map overlay techniques (McHarg 1969). Whatever the method, it must be used consistently in generating each alternative. (See Weinstein and Shugart [1983] for a review of ecological modeling pertaining to landscape dynamics.)

14. *Forecasting*. The value of each factor (step 5) must be projected, or forecast, for each alternative site. If a factor fails to meet the quantitative objective previously set for it, then that factor must be penalized for the difference; bonus units should be awarded proportionately to factors more than meeting the quantitative objective. For example, let us assume that "the cost should not exceed $1,250,000" (steps 5 and 8), and the public weighted this factor 18 E.Q. units (step 12). Let us further assume that site alternative A would actually cost $1,000,000; site B, $1,250,000; and site C, $1,500,000. The E.Q. units projected for cost would then be 21.6, 18.0, and 14.4 units for sites A, B, and C, respectively. Table 2 provides an example of this type of forecasting for the potential alternatives.

Table 2. An example of forecasting (step 14) for three potential sites (A, B, and C) for an environmental awareness center. Data are expressed as environmental quality (E.Q.) units.

Objective	Weight (E.Q. units)	Site A	Site B	Site C
Costs	18	15	18	12
Traffic	10	10	8	8
Biotic diversity	5	5	5	4
Aesthetics	12	8	12	10
Nutrient loss	14	5	12	7
Water supply	4	4	4	4
Sewage disposal	8	7	8	4
Historical sites	8	8	6	6
Jobs created	5	5	5	5
Productivity	16	10	12	8
TOTAL	100	77	90	68

15. *Evaluating alternative solutions*. Each potential site would generate a total number of E.Q. units based on the weighted and forecasted value for each factor; the highest value might be considered the "best" solution. If several groups of individuals were initially surveyed (step 12), then multiple weights

and forecasted values could be generated for each alternative. From these site means, statistical analyses like ANOVA would indicate which alternative is significantly the best, or if any of the alternatives is indeed significantly different.

16. *Selecting alternative solution(s).* Ideally, the best alternative would be selected in an unbiased and scientific manner at this step in the algorithm. The steering committee should make sure that all analyses are conducted as professionally and scientifically as possible.

17. *Implementation.* The steering committee should ensure that the best solution be implemented and that no last-minute changes take place in a smoke-filled room. Projects of this scope must not be deflected because of politics, bias, or vested interests.

18. *Inspection.* The steering committee should periodically inspect the project to ensure that the center is being constructed as specified. Federal and state laws also require certain permits, insurances, and inspections, which can help ensure that this step is completed as specified.

19. *Summary report.* A final report should be made available to the public to inform them how the solution was determined and how their respective interests were treated. Therefore, all concerned and/or those who participated in the decision-making process would understand how such decisions were made. The final report could also be used by other organizations facing a similar decision-making problem.

CONCLUSIONS

A strong demand exists for basic, long-term, large-scale ecological investigations (Callahan 1984). But basic science must be integrated with applied science as research and management needs continue to intensify (Barrett et al. 1982, Barrett 1984a). And we must develop and refine new approaches to understanding and managing both natural and socioeconomic systems. New integrative areas of research, such as landscape ecology, should increase our understanding of processes and regulatory mechanisms within and between these systems. The noosystem concept could encourage the effective integration of biological, physical, and socioeconomic components into these new areas of research.

Most ecologists recognize the need to incorporate more ecological theory and principles into applied areas like agroecology, forestry, fisheries biology, and integrated pest management. It is less clear whether they recognize the need to develop and refine an array of research algorithms (e.g., cost-benefit analysis and problem solving) when anthropogenic effects and needs unexpectedly perturb large landscapes. More attention needs to be devoted to the process by which problems are solved (Baldwin et al. 1975, Barrett 1984a, Barrett et al. 1982, Shull 1978). I hope that the problem-solving algorithm outlined here will encourage ecologists and resource managers to develop new approaches for discovering the natural regulatory mechanisms contained within large systems, establishing a holistic impact assessment approach, and educating the public on the importance of these systems for human benefit and survival.

ACKNOWLEDGMENTS

I thank the many colleagues and graduate students in the Institute of Environmental Sciences, Miami University, who encouraged me over the years to develop this problem-solving algorithm. I also thank Herman H. Shugart, University of Virginia for critical review of the manuscript; my wife, Terry, for the graphics; and Deborah M. Zimmerman for manuscript preparation.

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