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MANAGING CUMULATIVE IMPACTS: A KEY TO SUSTAINABILITY?

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MANAGING CUMULATIVE IMPACTS: A KEY TO SUSTAINABILITY?

Ecology forces us to recognize three major features of all life: interdependence, diversity and vulnerability. Its message is not that we should avoid change, but that no ecosystem is an island.

Introduction

Cumulative impacts on ecosystems are a function of increasing numbers of humans and their associated activities per unit area; as impacts continue to increase, the ability to sustain a desired condition for humans and other species becomes questionable. The implementing regulations of the National Environmental Policy Act (NEPA) define cumulative impacts as "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions. . ." [40 C.F.R. Sect.1508.7 (1978)]. Dickert and Tuttle (1985) provide a somewhat more detailed definition:

. . . cumulative impacts are those that result from the interactions of many incremental activities, each of which may have an insignificant effect when viewed alone, but which become cumulatively significant when seen in the aggregate. Cumulative effects may interact in an additive or a synergistic way, may occur onsite or offsite, may have short-term or long-term effects, and may appear soon after disturbance or be delayed.

Douglas, Fuchs, and Lester (1995) provide an excellent overview of works relevant to cumulative impacts, and Irwin and Rodes (1992) present a review of requirements for cumulative impacts in U.S. statutes and definitions of cumulative impacts.

Extensive literature exists on cumulative impacts--what they are, how their effects can be assessed or evaluated, and how they can be managed (e.g., Preston and Bedford 1988; Williamson and Hamilton 1989; Irwin and Rodes 1992; Hildebrand and Cannon 1993; Douglas, Fuchs, and Lester 1995). Despite the long-time recognition of this phenomenon and a substantial literature that addresses it, we have not been particularly effective at assessing or managing cumulative impacts. Better interaction between the natural and social scientists and policymakers is necessary and should improve our ability to manage cumulative impacts. In addition, the assessment and management of cumulative impacts has to occur at all levels--local, regional, and national, and it has to be an interactive and ongoing process.

This paper addresses how science can be more effectively used in creating policy to manage cumulative effects on ecosystems. The paper focuses on the scientific techniques that we have to identify and to assess cumulative impacts on ecosystems. The term "sustainable development" was brought into common use by the World Commission on Environment and Development (The Brundtland Commission) in 1987. The Brundtland Commission report highlighted the need to simultaneously address developmental and environmental imperatives simultaneously by calling for development that "meets the needs of the present generation without compromising the needs of future generations." We cannot claim to be working toward sustainable

development until we can quantitatively assess cumulative impacts on the environment: the two concepts are inextricably linked in that the elusiveness of cumulative effects likely has the greatest potential of keeping us from achieving sustainability. In this paper, assessment and management frameworks relevant to cumulative impacts are discussed along with recent literature on how to improve such assessments. When possible, examples are given for marine ecosystems.

Assessment Frameworks

Researchers in Canada and the United States (Canadian Environmental Assessment Research Council and U.S. National Research Council 1986, Peterson et al. 1987) have published excellent definitions and discussions of cumulative impacts and associated issues. The U.S. Fish and Wildlife Service was one of the first federal agencies to work on developing an assessment protocol (Williamson, Armour, and Johnson 1986). Very early the U.S. Environmental Protection Agency (EPA) supported research into cumulative effects in wetland ecosystems. Preston and Bedford (1988) synthesized concepts from an excellent collection of papers on wetlands; this was followed by the work of Liebowitz et al. (1988). Although not without problems, the Federal Energy Regulatory Commission's (FERC's) cumulative impact assessments and subsequent management of hydropower permits probably constitute the most extensive example of cumulative impact work within a U.S. federal agency.

FERC's efforts include both a policy and numerous examples of its implementation (FERC 1985a, FERC 1985b, Cada and Hunsaker 1990, Irving and Bain 1993). Since 1978, the implementing regulation for NEPA required assessment of potential cumulative effects, and many of the states' "mini-NEPAs" also have such requirements.

Frameworks provide a useful construct for the thought processes and work needed to accomplish any assessment. Two general frameworks are especially relevant to cumulative impact assessments. Ecological risk assessment, especially when applied at the regional scale (Hunsaker et al. 1990, Hunsaker 1993), is one of these. The objective of risk-based ecological assessment is to provide a quantitative basis for comparing and balancing risks associated with environmental hazards. Risk assessment is distinguished from other assessments in that it provides a systematic means of improving the estimation and understanding of those risks and it explicitly recognizes and quantifies uncertainty about the risks. The EPA's framework for ecological risk assessment (Risk Assessment Forum 1992) is a good synthesis of current scientific thinking and is conceptually similar to the National Research Council's paradigm for human health risk assessments. Components of the risk assessment framework include problem formulation; analysis (i.e., characterization of exposure and characterization of ecological effects); data acquisition, verification, and monitoring; and risk characterization (Figure 1).

Effective assessment and management of cumulative effects requires a holistic approach that recognizes the linkages between the activities that drive or create stress on ecosystems, the costs and benefits (market and nonmarket) of ecological effects,

and the policy options. The World Bank (Serageldin and Steer 1994) has stated that we will fail in our efforts to make development sustainable unless better progress is made to integrate the viewpoints of economists, ecologists, and sociologists. A truly holistic risk assessment would try to quantify, in some way, all of the applicable components shown in Figure 2. In reality, the assessment scientist is often able to quantify only some of these with any confidence-- whether because of lack of information and knowledge or a lack of time and money. However, keeping the holistic picture in mind is important. Interaction between the risk assessment scientist and the risk manager must occur at some level; however, risk analysis and risk management themselves remain separate activities (Figure 1). The risk assessment scientist provides the critical link between the policymaker and society and the scientists in the field and laboratory that gather and analyze ecological data (Figure 3). Often it is the assessment scientist who must translate fuzzy and complex questions and ideas from the policymaker or society into discreet assessment questions that can, hopefully, be answered through the use of data collected by the field and laboratory biologists. Suter (1993) discusses the role of societal values and ecological endpoints/indicators in the risk assessment process.

Regional ecological risk assessment is especially suited to quantifying cumulative effects because it addresses a larger geographic scale and focuses on a structured problem formulation phase and the quantification of uncertainty. Cumulative impacts are best addressed at the regional scale because it is at this spatial scale and associated temporal scales that the majority of cumulative effects will manifest

themselves (Hunsaker 1993). Because the availability of data and models, as well as time and/or money will constrain the completeness of the assessment, following the structured problem formulation phase of risk assessment (Risk Assessment Forum 1992) should help ensure a successful assessment of cumulative effects. During problem formulation the goals, breadth, and focus of the assessment are established, and the conceptual model is developed, including the stressors, endpoints, and spatial/temporal boundaries. Finally, because risk assessments include uncertainty or confidence estimates throughout the process, during the problem formulation phase the assessor may better focus on those stressors and endpoints that seem most critical and tractable for assessment. Furthermore, the inclusion of uncertainty in cumulative impact assessments should assist the risk manager in making policy or management decisions, which usually require trade-offs, to curtail cumulative effects.

Irwin and Rodes (1992) present another unique framework developed to help identify the mismatch between the boundaries for management and the boundaries that define a cumulative impact (Figure 4). Crafted by scientists and policymakers actively involved in cumulative impact assessment, the framework provides program managers with a means of comparing the boundaries of management decisions with the boundaries of cumulative effects and their causes. On the basis of this comparison, managers should be able to determine whether a mismatch occurs and, if so, find ways to use more appropriate boundaries. A set of questions, discussions, and examples are provided to walk one through each step of the framework. The framework of Irwin and Rodes (1992) is complementary to risk assessment frameworks (Hunsaker et al.

1990, Risk Assessment Forum 1992). The first assists managers in understanding why cumulative impacts are occurring; the latter, in quantifying those impacts. The separate frameworks highlight the important fact that assessment and management of cumulative impacts are separate but linked activities (Figures 1 and 2). This linkage should be part of the role of the assessment scientist.

Good assessment scientists need to have multidisciplinary backgrounds and be able to synthesize and communicate information from the physical, biological, and social sciences (Figure 3). While a few good academic programs produce such graduates, significant impediments exist for the training and career development of such applied scientists. During the National Research Council's symposium Improving Interaction Between Sciences and Policy in the Gulf of Maine Region, discussions highlighted such impediments and included the following recommendations:

- Modify academic reward systems to encourage applied research and to improve science-policy interactions,
- Create incentives and/or provide adequate funding for interdisciplinary assessments, and
- Identify and foster academic degree programs that produce graduates skilled in integrating information and communicating it to all parts of society.

Techniques for Assessing Cumulative Impacts

Shopley and Fuggle (1984) and Hunsaker and Williamson (1992) provide reviews of techniques for assessing cumulative impacts. Assessment techniques can be divided into those used for problem definition and those used for analysis and interpretation, two of the phases illustrated in EPA's ecological risk assessment framework (Figure 1). Ad hoc techniques, checklists, and matrices are often used for the problem definition phase. Techniques used in the analysis and interpretation phase include network or system diagrams, cartographic techniques, mathematical modeling, evaluation techniques, and adaptive methods or combinations. Weaknesses in assessment techniques consist of inability to quantify effects, especially at the ecosystem scale, lack of interactive or coupled models, and lack of models that can deal with multiple media and stresses.

Concepts developing in the discipline of landscape ecology hold promise for helping with cumulative impact assessments, and several publications illustrate the importance of a landscape ecology approach (Bedford and Preston 1988, Hunsaker et al. 1990, Gosselink et al. 1990) to evaluating cumulative effects. A landscape can be defined in terms of the following:

- structure--the spatial relationships between distinct elements,
- function--interactions between spatial elements, and

- change--temporal alterations in the structure and function of the landscape mosaic.

Landscape ecology is the study of the distribution patterns of communities and ecosystems, the ecological processes that affect those patterns, and changes in pattern and process over time (Forman and Godron 1986). The study of scale, both spatial and temporal, is a major part of landscape ecology, and a better understanding of scale issues is critical for cumulative effects assessments (Hunsaker 1993).

While the majority of landscape ecology research has addressed terrestrial systems, landscape ecology concepts have been applied to marine ecosystems. Many of the impacts on coastal marine systems are caused by activities on land. Examples include (1) water pollution in coastal areas from land use change and (2) habitat destruction in the land-water interface zone from increased recreation activities on the land. Landscape ecology seeks to relate landscape structure and pattern to ecosystem processes, and it often calculates pattern metrics on land cover maps developed from remotely sensed imagery. Using sonar data, the researcher can use the same computer algorithms to quantify the spatial pattern of ocean floor. Such information can be used to identify habitat for marine organisms and to measure change over time for large regions. The referenced studies illustrate how landscape ecology research and quantitative tools are relevant for marine ecosystems. Robbins and Bell (1994) discussed the application of landscape ecology principles to seagrass, and Browder et al. (1985) studied the relationship between marshland-water interface and marsh

disintegration. Paine and Levin (1981) studied patch dynamics and disturbance in the rocky intertidal zone, and Steele (1989) evaluated pelagic zone habitat related to physical and chemical processes. Wetlands have served as case studies for landscape ecology, risk assessment, and cumulative effects research (Bedford and Preston 1988, Gosselink et al. 1990, Liebowitz et al. 1992). Hunsaker et al. (1993) reviewed the use of geographic information systems and environmental models for the marine environment. Rieser and Vestal (1995 in press) reviewed both literature and case studies and organized a workshop on cumulative impacts. In their report on methodologies and mechanisms for management of cumulative coastal environmental impacts, Rieser and Vestal stress not only the contribution that landscape ecology has today but also its importance in the future.

Improving Cumulative Impact Assessment and Management

Many ideas have been discussed in the literature about how we can improve cumulative impact assessment, but only when assessment and management activities work together can we hope to be effective in understanding and controlling cumulative effects. Following are brief synopses of three recent papers that capture the essence of what we need to work on for improvement. Contant and Wiggins (1993) identified the following three areas to improve assessments:

- improving monitoring and prediction of actions and impacts over space and time;
- increasing the knowledge of the responses of environmental systems to development perturbations, including synergistic and indirect effects; and
- developing management systems that provide the appropriate responses to actions that produce significant cumulative effects.

Williamson (1993) stresses the importance of remembering that an assessment is a process: "... employ a problem-solving process that can be applied intensively to a wide range of situations and that utilizes adaptively the most appropriate methods and techniques." He states that to be effective, a cumulative impact assessment must use both a problem-solving process and scientific cause and effect, while cumulative impact management must use both goal setting and collaboration. In highlighting the need for a common language among scientists and policymakers, Douglas, Fuchs, and Lester (1995) state that our institutional capacities are inadequate to manage cumulative impacts because of fragmented, incremental decisionmaking. In other words, we need to design a new way of business. With regard to the need to integrate science and policy, Douglas, Fuchs, and Lester (1995) identify the following issues:

- management goals and research priorities;
- identification of methods, indicators, and causal models for evaluation of cumulative impacts;

- design of monitoring programs; and
- design and maintenance of databases and information management systems.

As shown in Figure 3, the assessor and policymaker should know something about what society values. Often the scientist or policymaker assumes that they know about aspects of the environment the public values. However, this assumption is not appropriate. The EPA is funding a study to determine if people understand and care about the ecological indicators proposed by the scientists for monitoring and whether these indicators can be related to, or mapped onto, people's value domain(s). Figure 5 illustrates a schematic approach proposed for this research.

Conclusions

Although NEPA legislation was effective in bringing both attention and efforts to bear on cumulative impacts, it has not provided an especially effective way of truly managing them except perhaps when a programmatic environmental impact statement (EIS) is being done (Cada and Hunsaker 1990, Hunsaker 1993). Aside from the fact that cumulative impacts are very hard to assess within usual time, dollar, and data constraints, an EIS usually does not have a long-term plan or vision to guide or give context to the single proposed project. To address cumulative impacts effectively, we

need to improve our assessment capabilities and to revise our management approach to environmental resources. To forge a better science-policy interface, we need innovative thinking and activities. A collaborative goal is required for this to happen, and knowledge of societal values is important. The World Bank identified four broad categories of unresolved questions for sustainable development: valuation, decision making in the presence of thresholds and uncertainty, policy and institutional design, and social sustainability (Serageldin and Steer 1994). The ecological risk assessment framework (Risk Assessment Forum 1992) and the cumulative impact framework (Irwin and Rodes 1992) strive to provide such a construct. Integrated coastal zone planning at local and regional scales, fishery and habitat management goals, and statements about desired ecosystem condition (like sustainability)-- all of these could provide such a long-term context for marine systems that is consistent with societal values [see Reiser and Vestel (1995 in press) for recent direction about marine systems].

Reasonable blueprints surely exist for addressing cumulative impacts in a more effective manner--the assessment and management frameworks discussed in this paper. However, cumulative impact assessment needs to be viewed as an ongoing process and not a one-time report. Numerous examples or case studies of cumulative impact assessments can be studied for insights. Tools and materials exist for assessments, but they are not complete. Cumulative impact assessments will continue to be difficult until we have the following:

- Monitoring designed for regional assessment;

- More experience with ecological indicators;
- Cause-effect relationships and more information from model comparisons at the ecosystem scale;
- Tools for describing and modeling spatial heterogeneity;
- Theory and data concerning the effect of spatial heterogeneity on ecological processes;
- Better understanding of the error associated with data aggregation, remotely sensed data, and geographic information system processing.

To address cumulative impacts effectively requires a sustained effort that includes both evaluation of historic information and future prediction and planning.

Neither science nor policy areas have an especially successful record of such sustained efforts (e.g. long-term ecological monitoring and data archiving as well as comprehensive planning and implementation at all levels of government rather than crisis management). It is time to stop talking about cumulative impact assessment and management and to start practicing it with the knowledge and tools that we have.

Cumulative impacts are a key to understanding sustainability. Sustainable development can serve as the common goal that brings science and policy together. Sustainable development must meet present economic needs in an equitable fashion while safeguarding the earth's natural heritage for future generations. How else can we do this if not through the use of quantitative tools and a framework that explicitly recognizes cumulative impacts and the importance of spatial and temporal scale? To

perform such work, we need to *seriously* foster the development of interdisciplinary scientists and of multidisciplinary teams that include at least economists, ecologists, and sociologists.

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References

Bedford, B.L., and E.M. Preston. 1988. Developing the scientific basis for assessing cumulative effects of wetland loss and degradation on landscape functions: Status, perspectives, and prospects. *Environmental Management* 12(5):751-771.

Browder, J.A., H.A. Bartley, and K.S. Davis. 1985. A probabilistic model of the relationship between marshland-water interface and marsh disintegration. *Ecological Modeling* 29:245-260.

Cada, G.F., and C.T. Hunsaker. 1990. Cumulative impacts of hydropower development: Reaching a watershed in impact assessment. *The Environmental Professional* 12:2-8.

Canadian Environmental Assessment Research Council and U.S. National Research Council. 1986. *Cumulative Environmental Effects: A Binational Perspective*. Hull, Quebec: Canadian Environmental Assessment Research Council.

Contant, C.K., and L.L. Wiggins. 1993. Toward defining and assessing cumulative impacts: Practical and theoretical considerations. Pp. 336-356 in *Environmental Analysis: The NEPA Experience*, S.G. Hildebrand and J.B. Cannon, eds. Boca Raton:

Lewis Publishers.

Dickert, T.G., and A.E. Tuttle. 1985. Cumulative impact assessment in environmental planning: A coastal wetland watershed example. *Environmental Impact Assessment Review* 5:37-64.

Douglas, P., E. Fuchs, and C. Lester. 1995. Managing the cumulative impacts of development: An opportunity for integration? Pp. ? in *Improving Interaction Between Sciences and Policy in California*. Washington, D.C.: National Research Council, Ocean Studies Board. ??

FERC (Federal Energy Regulatory Commission). 1985a. Procedures for assessing hydroelectric projects clustered in river basins: Request for comments. *Fed. Regist.* 50:3385-3403.

FERC (Federal Energy Regulatory Commission). 1985b. Final environmental impact analysis of small-scale hydroelectric development in selected watersheds in the Upper San Joaquin River Basin, California. FERC/EIA-001. Washington, D.C., Federal Energy Regulatory Commission.

Forman, R.T.T., and M. Godron. 1986. *Landscape Ecology*. New York: Wiley.

Forman, R.T.T., and M. Godron. 1986. *Landscape Ecology*. New York: Wiley.

Gosselink, J.G., G.P. Shaffer, L.C. Lee, O.M. Burdick, D.L. Childers, N.C. Leibowitz, S.C. Hamilton, R. Boumans, D. Cushman, S. Fields, M. Kock, and J.M. Vfiesser. 1990. Landscape conservation in a forested wetland watershed. *BioScience* 40(8):588-600.

Hildebrand, S. G. , and J. B. Cannon (eds). 1993. *Environmental Analysis: The NEPA Experience*. Boca Raton: Lewis Publishers.

Hunsaker, C.T. 1993. Ecosystem assessment methods for cumulative effects at the regional scale. Pp. 480-493 in *Environmental Analysis: The NEPA Experience*, S.G. Hildebrand and J.B. Cannon, eds. Boca Raton: Lewis Publishers.

Hunsaker, C.T., A. Schiller, M.A. Kane, and V.H. Dale. 1995. Relating indicators of landscape condition to societal values for ecosystems. P. 97 in *Working in a World Dominated by Humans, Program and Abstracts, Tenth Annual U.S. Landscape Ecology Symposium, 22-26 April 1995*. Minneapolis: International Association of Landscape Ecology and University of Minnesota.

Hunsaker, C.T., R.L. Graham, G.W. Suter II, R.V. O'Neill, L.W. Barnthouse, and R.H. Gardner. 1990. Assessing ecological risk on a regional scale. *Environmental Management* 14(3):325-332.

Hunsaker, C., and S. Williamson. 1992. Techniques for assessing cumulative impacts. Pp. 49-51 in *Making Decisions on Cumulative Environmental Impacts: A Conceptual Framework*, F.H. Irwin and B. Rodes, eds. Washington, D.C.: World Wildlife Fund.

Hunsaker, C.T., R.A. Nisbet, D.C.L. Lam, J.A. Browder, W.L. Baker, M.G. Turner, and D.B. Botkin. 1993. Spatial models of ecological systems and processes. The role of GIS. Pp. 248-264 in *Geographic information Systems and Environmental Modeling*, M. Goodchild, B. Parks, and L. Steyaert, eds. New York: Oxford Press.

Irving, J.S., and M.B. Bain. 1993. Assessing cumulative impact on fish and wildlife in the Salmon River Basin, Idaho. Pp. 357-372 in *Environmental Analysis: The NEPA Experience*, S.G. Hildebrand and J.B. Cannon, eds. Boca Raton: Lewis Publishers.

Irwin, F.H., and B. Rodes. 1992. *Making Decisions on Cumulative Environmental Impacts: A Conceptual Framework*. Washington, D.C.: World Wildlife Fund.

Liebowitz, S.G., E.M. Preston, L.Y. Arnaut, N.E. Detenbeck, C.A. Hagley, M.E. Kentula, R.K. Olson, W.D. Sanville, and R.R. Sumner. 1992. Wetlands research plan FY92-96: An integrated risk-based approach. EPA/600/R-92/060. Corvallis, OR: U.S. Environmental Protection Agency.

Paine, R.T., and S.A. Levin. 1981. Intertidal landscapes: Disturbance and the

dynamics of Pattern. *Ecological Monographs* 51:145-178.

Peterson, E.B., Y.-H. Chan, N.M. Peterson, G.A. Constable, R.B. Caton, C.S. Davis, R.R. Wallace, and G.A. Yarranton. 1987. *Cumulative effects assessment in Canada: An agenda for action and research*. Ottawa, Ontario: Canadian Environmental Assessment Research Council.

Preston, E.M., and B.L. Bedford. 1988. Evaluating cumulative effects on wetland functions: A conceptual overview and generic framework. *Environmental Management* 12(5):565-583.

Reiser, A., and B. Vestal. 1995. *Methodologies and mechanisms for management of cumulative coastal environmental impacts*. Washington, D.C.: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Coastal Ocean Office. In press.

Risk Assessment Forum. 1992. *Framework for ecological risk assessment*. EPA/630/R-92/001, Washington, D.C.: U.S. Environmental Protection Agency.

Robbins, B.D., and S.S. Bell. 1994. Seagrass landscapes. A terrestrial approach to the marine subtidal environment. *TREE* 9(8):301-304.

Serageldin, I., and A. Steer (eds.). 1994. Making development sustainable: From concepts to action. *Environmentally Sustainable Development Occasional Paper*, Series No. 2. Washington, D.C.: The World Bank.

Shopley, J.B., and R.F. Fuggle. 1984. A comprehensive review of current environmental assessment methods and techniques. *Journal of Environmental Management* 18:25-47.

Steele, J.H. 1989. The ocean 'landscape'. *Landscape Ecology* 3(3/4):185-192.

Suter, G.W., II. 1993. *Ecological Risk Assessment*. Boca Raton: Lewis Publishers.

Williamson, S.C., C.L. Armour, and R.L. Johnson. 1986. Preparing a FWS cumulative impacts program: January 1985 workshop proceedings. U.S. Fish and Wildlife Serv. Biol. Rep. 85(11.2). Washington, D.C.: Department of the Interior.

Williamson, S.C., and K. Hamilton. 1989. Annotated bibliography of ecological cumulative impacts assessment. U.S. Fish and Wildlife Serv. Biol. Rep. 89(11). Washington, D.C.: Department of the Interior.

Williamson, S.C. 1993. Cumulative impacts assessment and management planning: Lessons learned to date. Pp. 391-407 in *Environmental Analysis: The NEPA Experience*, S.G. Hildebrand and J.B. Cannon, eds. Boca Raton: Lewis Publishers.

FIGURES

Figure 1. Framework for ecological risk assessment (Risk Assessment Forum 1992).

Figure 2. Integrated assessment illustrates need to consider science, economic, and policy interrelationships.

Figure 3. The assessment scientist (assessor) plays a critical role in linking what the policymaker and society are interested in knowing with the data being collected by field and laboratory scientists. Scientists with multidisciplinary training are best suited for this work.

Figure 4. Framework for matching boundaries of decisions and of cumulative impacts (Irwin and Rodes 1992).

Figure 5. Research activities being undertaken to link societal values and environmental indicators from the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program.

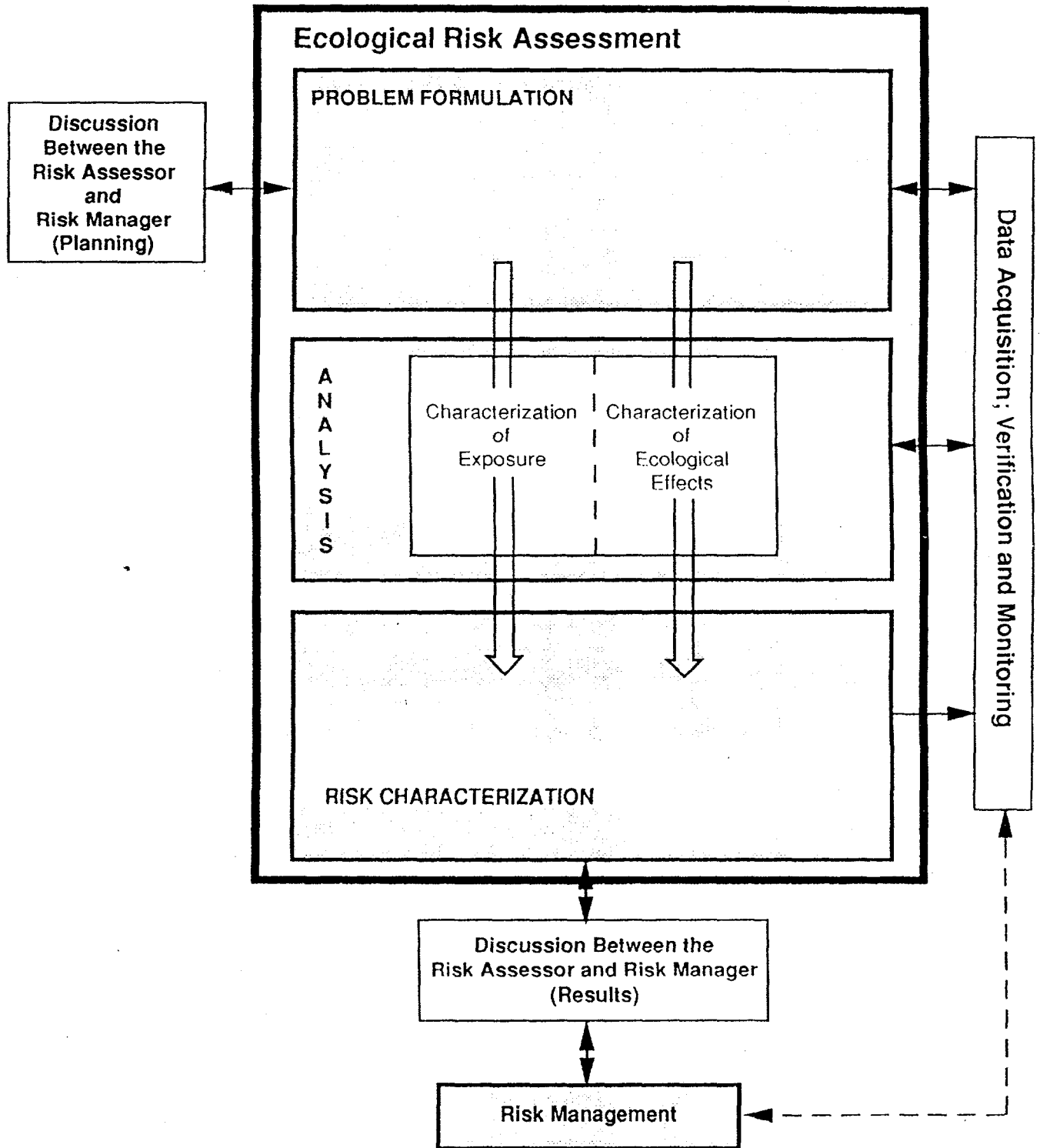


Figure 1. Framework for Ecological Risk Assessment (Risk Assessment Forum 1992)

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Assessment Framework

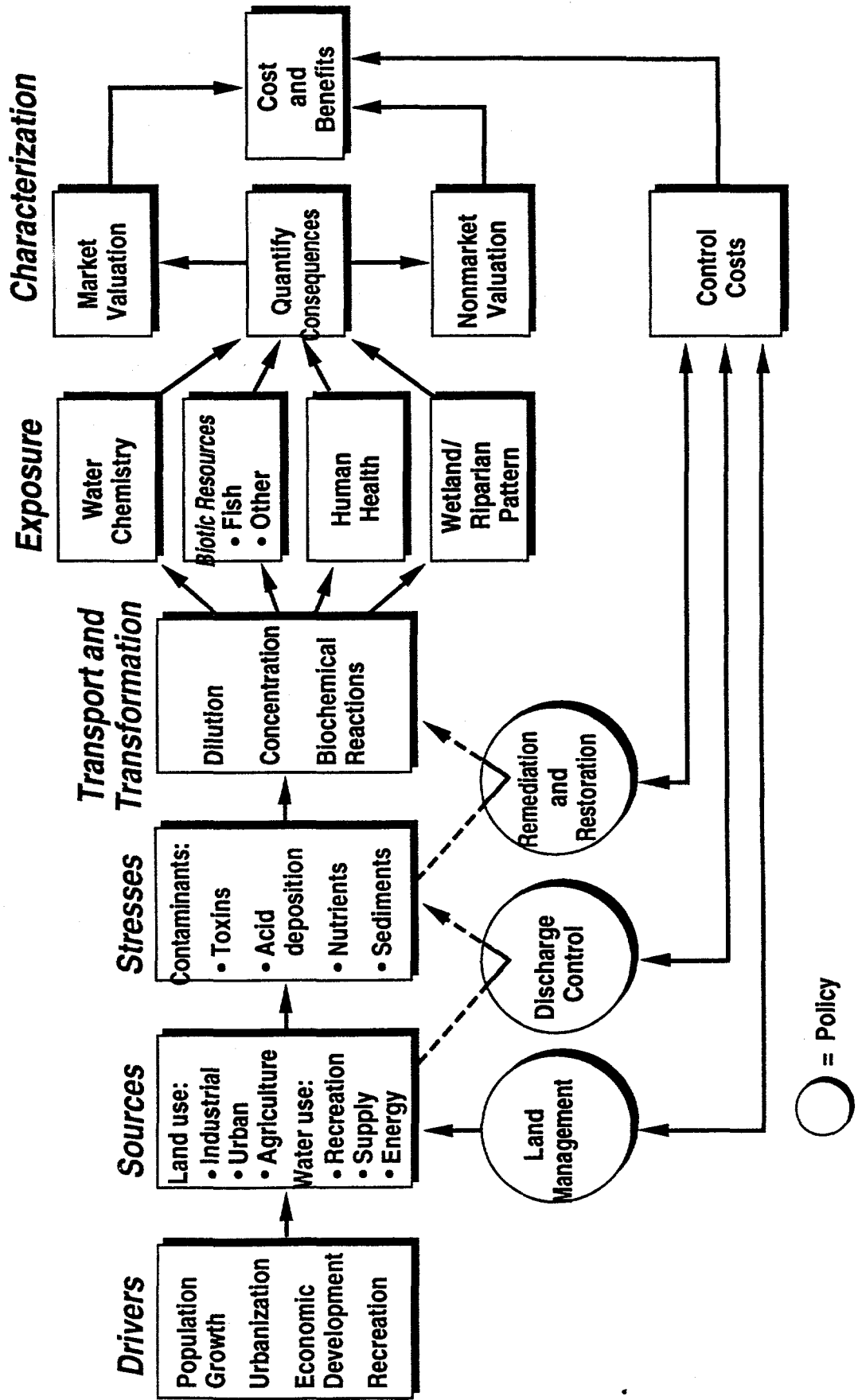


Fig. 2

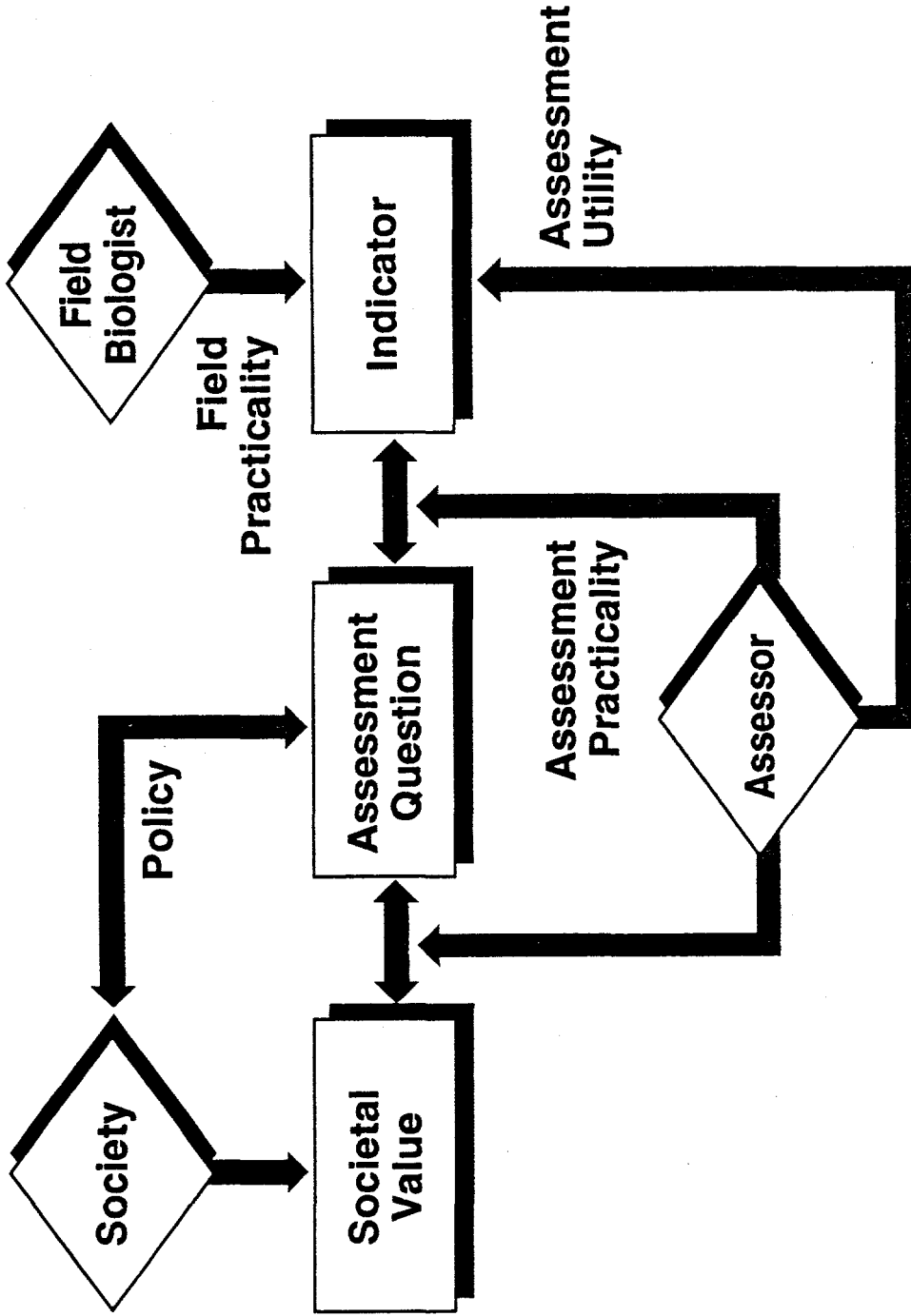
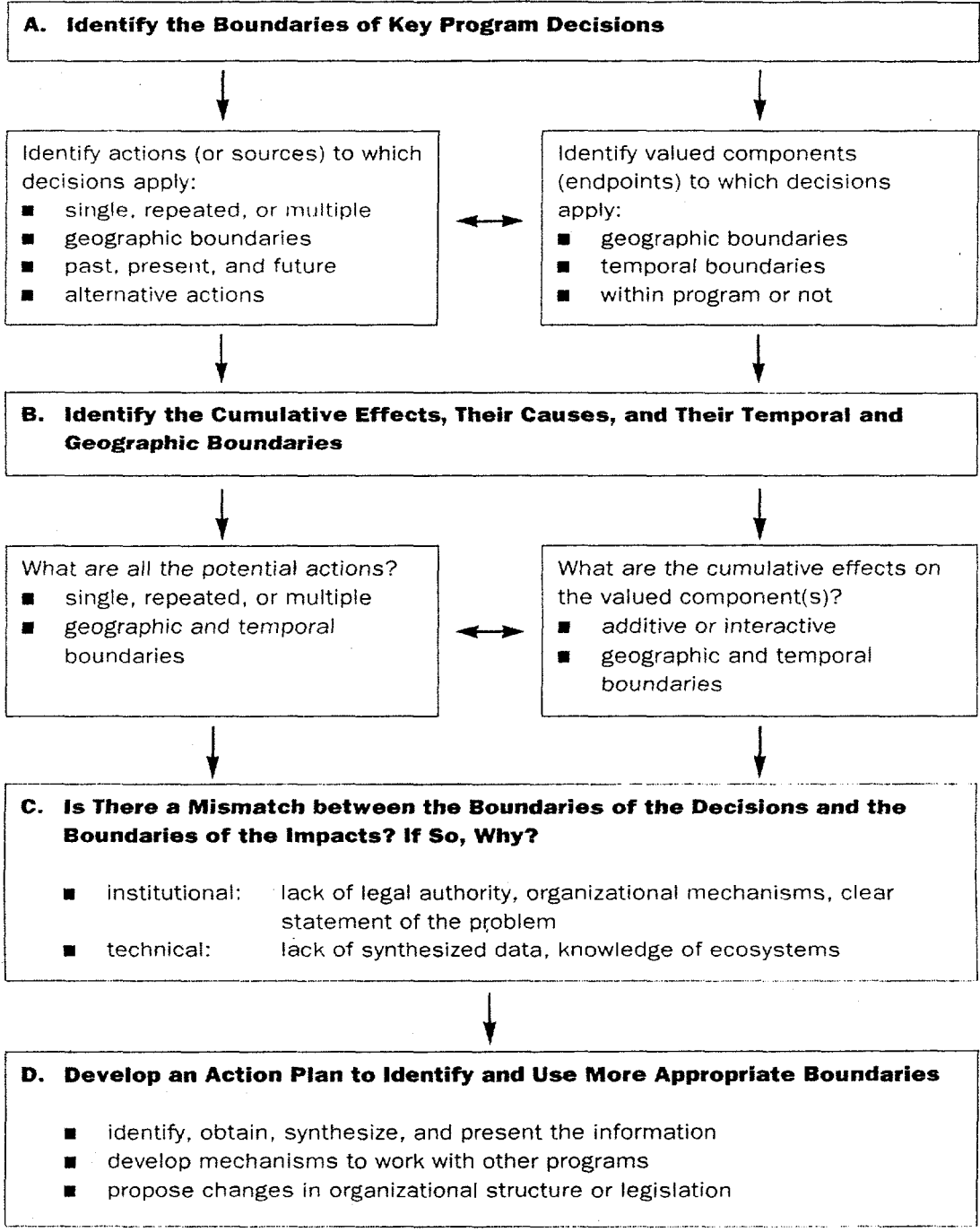


Figure 4.

Figure 3

FRAMEWORK FOR MATCHING BOUNDARIES OF DECISIONS AND OF CUMULATIVE IMPACTS
(Irwin and Rodes 1992)



Approach for Relating Societal Values to Ecological Indicators

