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Environmental Management: From Assessment to Decision-Making

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Abstract

Changing processes of environmental decision-making have stimulated a large array of conceptual and methodological research in environmental science. This report deals with two large areas. Firstly, criteria for good environmental decision-making are established and associated with corresponding criteria for good scientific assessments to support it. It is found that the processes of decision-making and decision analysis should use the best available information about the biophysical characteristics, their changes and their socioeconomic implications, the social context and values involved in the environmental problem including cumulative and cross-scale effects. Both types of processes need to consider uncertainties by adopting analytical frameworks and decision-making processes capable of accommodating new information and course corrections. They also need to take into account equity, efficiency, and vulnerability concerns, pursue accountability and strive for effectiveness.

Secondly, a set of analytical frameworks is assessed according to selected features that are relevant in choosing among them for implementing environmental assessments. It is concluded that the diverse and sophisticated analytical frameworks, tools, and models to support environmental decision-making draw on various disciplines in social sciences and attain various degrees of formalization from mathematical models to discourse-based social processes. The ability to address specific aspects of the decision problem (efficiency and equity concerns, problem scale, uncertainties) varies accordingly.

The continuing challenge for environmental decision-making remains to select the relevant ingredients and to choose the analytical framework that provides the most relevant and useful information for the decision-making process. More systematic assessments of the relevant ingredients and of the capabilities of applicable tools are needed to further improve environmental assessments and thereby environmental management.

Environmental Management: From Assessment to Decision-making

Ferenc L. Toth

1. Introduction

Current efforts to sort out and structure basic definitions, concepts, methods, quality criteria and key characteristics relevant in the broad field of environmental management appear to be the culmination of an evolutionary process over the past 3-4 decades. This evolutionary process has been shaped by the changing characteristics of environmental problems on the social agenda as well as by the ways in which scientists, practitioners, and stakeholders reacted to those changes.

The direction, pace, and character of methodological development for environmental management and the assessments to support it have always been strongly conditioned by factors emerging from and affecting the contexts in which methods are being used. The last thirty years have seen major changes in environmental management issues. This has considerably modified the requirements and criteria for assessment methods to be applied. Some of the most significant changes have taken place in one particular group of approaches, namely those aimed at connecting scientific research to environmental policy.

The most relevant characteristic changes in environmental science and policy over the past three decades can be summarized on the basis of general observations drawing mainly on practical experience reported in the literature from North-America and Western Europe although not all statements apply for all countries in these regions for each period in time. The *social context* has shifted from confrontation around a set of quickly changing single issues triggered by local environmental incidents (pollutant spills in rivers or coastal areas, acute periods of urban smog and alike) to a slowly emerging consensus regarding at least the importance of local and, increasingly, global environmental issues. The *nature* of the environmental issues has shifted from local incidents of pollution, short episodes of easily reparable damages characterized by simple relationships both in terms of causes and cures to problems involving multiple nations, multiple generations, and complex linkages. The *concepts* adopted in addressing these issues have transformed from gradual changes, the importance of equilibrium states, and the inability of local changes to destroy the underlying global stability to the recognition that changes are abrupt and discontinuous, characterized by fast transitions between multiple states of equilibria.

As a result of some recent efforts to link environmental assessment and decision analysis to environmental policy, some disorientation seems to emerge concerning where decision analysis ends and decision-making begins. The risk of confusion seems to increase with the increasing popularity of integrated environmental assessments, especially the so-called participatory assessments that directly involve public decision-makers and private stakeholders. Section 2 attempts to provide some clarification by explicitly distinguishing the two domains and presenting some guiding principles for both. This is followed by a more detailed discussion of a set of decision analytical frameworks and their key characteristics concerning their applicability to environmental problems of different nature in Section 3. Finally, Section 4 summarizes the main conclusions.

2. Key ingredients to good decision-making

As experience in decision-making for environmental management and in the analytical work to support the related decision processes has been accumulated over the past decades, increasing attention was devoted to questions concerning the key criteria for success (The Social Learning Group, 2001; Clark et al., 2001). The bulk of environmental decision-making is deeply permeated with complexity, uncertainty, and the incompleteness of science. Accordingly, any assessment process intended to serve decision-making needs to take these facts of life fully into account. This section draws on recent critical appraisals and organizes the various ingredients into a synoptic framework. It is partly inspired by Chapter 8 of the report by the Conceptual Framework Working Group of the Millennium Ecosystems Assessment (MEA, 2003) and it also draws on Dietz (2002). We also make use of results of recent research on decision analysis, decision-making, and environmental governance. Conceptual work, analytical efforts, and case studies presented in the literature are also important sources. The objective is to specify a set of ingredients that have characterized successful decision-making in the past and are likely to lead to environmentally effective, socially fair, economically efficient, and politically feasible decisions in the future.

Table 1 lists the fundamental criteria and their implications for the two large domains: the decision-making process *per se* and the decision analysis/support activities. These criteria and the implied guidelines may appear to be far too general at the first glance. Without doubt, the relative importance, feasibility, and practicability of the individual points differ from case to case. Yet the guidelines draw on a large body of critical appraisal of environmental management (NRC, 1996; Ostrom et al., 2002; Dietz et al., 2003) so that they have general validity in human management of environmental systems. In particular, these principles and criteria are valid for decision-making processes (and decision analyses conducted to support them) for all public policymakers and private stakeholders. The relative importance of many criteria differs depending on which social actor or group has the primary right or mandate to make the decision. Public policymakers (local and national governments) are mandated to pursue the interests of the community as a whole and to give special attention to vulnerable or poor social groups but they are also required to use public funds efficiently. In the mirror case: private stakeholders tend to pursue their own interests and focus on economic efficiency but many of them pay increasing attention to the social and environmental implications of their decisions in the spirit of the emerging corporate responsibility and because of the increasing importance of their company's public image. Neither public nor private decision makers concerned with environmental problems in general and ecosystems services in particular can ignore the social context in which they want to implement their decisions. The actual fulfillment of these broad criteria varies immensely not only across societies and development levels but also across the types of decision-making entities.

A number of ingredients that are key to good decision-making with respect to environmental management, the protection and enhancement of ecosystem services and human well-being are broadly and strongly supported by the environmental management literature. These ingredients are listed in Table 1 and discussed below.

Table 1: Ingredients for good environmental management: Analysis and decision-making

Criteria	**Implications for decision-making (DM)**	**Implications for decision analysis (DA)**
Use the best available ecosystem/ bio-physical information	Devise DM process so as to allow using the best available information	Choose the DA tool to allow the incorporation of best available information
Use the best available impact assessment information	Establish DM process to permit input of the best available information about economic, social, and political consequences of environmental changes and of policy options	Choose a DA framework that allows the integration of best available information from diverse disciplines about the implications of changes and of options to manage them.
Use the best available information about social context	Design DM process consistent with prevailing social, economic, political, technological, and institutional situation	Choose DA framework according to prevailing social, economic, political, technological, and institutional situation
Use the best available information about values	Recognize values, beliefs, aspirations of affected stakeholders in the DM process	Choose the DA tools and decision criteria according to the existing values, beliefs, and aspirations stakeholders
Consider efficiency concerns and implications	Devise an efficient DM process to save time and costs (procedural efficiency); respect the prevailing economic principles (outcome efficiency)	Select the analytical tools and the decision criteria according to the relative importance of efficiency concerns in the decision-making context.
Consider equity concerns and implications	Devise a fair DM process to allow stakeholder participation (procedural equity) and understanding the outcome (transparency); respect the prevailing equity principles (consequential equity)	Select the analytical tools and the decision criteria according to the relative importance of fairness concerns in the decision-making context. Consider participatory assessment techniques.
Consider vulnerability concerns and implications	Beware of the interests of vulnerable groups/communities.	Assess the implications of different options for vulnerable groups/communities.
Consider uncertainties	Conduct a flexible DM process to accommodate new information about the ecosystem and possible changes in values or positions of stakeholders	Choose the analytical framework so that it allows an adequate representation of uncertainties; and define decision options that allow policy corrections as new information becomes available
Consider cumulative and cross-scale effects	Expand the decision process to initiate/comply with relevant policies at lower/higher levels	Choose the analytical tools to incorporate constraints from higher DM levels and to explore decision needs at lower DM level
Strive for effectiveness	Devise an effective decision process with clear and flexible procedures that foster finding compromises	Present complete results in understandable form
Pursue accountability	Establish clear responsibility assignments during and after the decision process	Set up quality control and good practice regimes for assessments

The proposition to use the best available information in the analytical work to support decision-making and in the decision process itself sounds rather obvious. Yet decisions concerning environmental quality and ecosystems services often suffer from information deficits ranging from insufficient effort to obtain relevant information to inadvertently ignoring or purposefully withholding information. Four main information domains are important to draw on for successful decisions: *biophysical* information about the ecosystem status and processes, *impact assessment information* about economic, social, and political consequences of both the environmental changes and of different policy options, socio-economic information about the *socio-political context* in which and for which the decision will be made, and, as an important subset of the latter, information about the *values*, norms and interests of the key stakeholders shaping decisions and affected by them. For most ecosystems and environmental risks, there is a large body of information available in natural sciences that should be identified and used. Similarly, social science can offer not only information about which policies would be acceptable and feasible, but also information about how ecological changes (whether or not policy driven) affect such important human outcomes as economic growth, distribution of jobs, availability and price of food, organizational viability, cultural change, and the potential for social conflict. At the same time, however, it is important to recognize how much natural and social sciences do *not* know about ecological processes and their effects on the ecosystems goods and services that humans value. Therefore, when we argue below for using the best knowledge it inherently implies to make the best use of ignorance as well, i.e., the knowledge of what is not known (see Ravetz, 1986). This underlines the importance of analytical methods (for example, decision analysis or value-of-information calculations) that can inform the decision-making process about the implications of the different types of looming uncertainties, of the resolution of uncertainties in the future as knowledge improves, and of the potential course corrections that might be required in the light of new knowledge.

The metastrategy presented in NRC (1996) involves a process that entrains the best decision-relevant information from the various perspectives of those involved or affected and that considers this information from the variety of relevant perspectives. This NRC report also emphasizes the need to get the science right, but also to get the right science. The former entails that the "underlying analysis meets high scientific standards in terms of measurement, analytic methods, data bases used, plausibility of assumptions, and respectfulness of both the magnitude and the character of uncertainty" (NRC 1996, pp 7-8), whereas the latter implies that the analysis needs to address "the significant risk-related concerns of public officials and the spectrum of interested and affected parties, such as risks to health, economic well-being, and ecological and social values" (NRC, 1996, p 8). For complex environmental management problems plagued with profound uncertainties, it is advocated to accomplish this via a process that engages the interested and affected parties at an early point of defining the questions to be subjected to analysis.

Use the best available ecosystem/biophysical information: the decision-making process needs to open communication channels to the diverse sources of relevant information about the biophysical status and processes of the ecosystem concerned. In addition to state-of-the-art modern science, traditional knowledge should also be used where it is relevant and available. The mirror implication on the analytical side is the need to choose analytical frameworks that are capable of incorporating and handling the diverse set of information from different sources required for the assessment of a useful range of decision options.

Use the best available impact assessment information: closely related to the criterion above, it is essential to collect and evaluate information about the socioeconomic implications of environmental changes as well as about the economic and social impacts of the feasible policies and measures to manage them. This requires integration of knowledge of widely diverging uncertainties from different scientific disciplines and sociopolitical perspectives and its consolidation in a form acceptable to all stakeholders. Complex decision problems can be usefully supported by analytical frameworks that are specifically developed to incorporate diverse sets of data, tools, and perspectives, like integrated environmental assessments (Rotmans and Vellinga, 1998).

Use the best available information about the social context: the decision-making process must be realistic in the sense that it observes and accommodates prevailing social customs and practices, economic realism (power, interests), political situations (authority, control), technological conditions (availability, feasibility), and institutional status (implementation, enforceability). The same features influence the choice of the analytical framework because its underlying principles must be congruent with the social situation. Moreover, these features also determine the range of options that can be meaningfully assessed to help decision-making because only strategies and measures viable in the given social context will be considered.

Use the best available information about values: a crucial field of the social context for environmental decisions is information about the norms, beliefs, values, and aspirations of the affected communities. Even the best intended and, from a different perspective, perfectly rational decisions or measures will inevitably fail if they run counter to norms and rules the affected stakeholders follow. These aspects need to be recognized in decision-making. Accordingly, prevailing norms and values influence the choice of the decision analytical tool and the decision criteria adopted in the assessment.

There are two main implications and a corollary resulting from the criteria "to use the best available information about values" specified above. The first implication is to bear in mind the relevant *efficiency* criteria, while the second is the need to treat *equity* concerns adequately. The corollary of the equity aspect is the obligation to pay special attention to *vulnerability* issues.

Consider efficiency concerns and implications: The basic principle of devising efficient decision-making is to conduct fast and thrifty decision processes (procedural efficiency). This implies designing the decision process so as to allow for fast and clear exchange of information and views, to allow flexibility for shifting positions and progressing towards compromise solutions. The assessment activities can enhance and support the efficiency of decision-making by presenting the multitude of feasible decision options with all relevant implications, uncertainty features (qualitative characterization and quantitative ranges), preconditions for and possible pitfalls of implementation and enforcement. However, there is often a trade-off between the principles of procedural equity and efficiency. There are conflicting claims about stakeholder participation and the efficiency of the decision process. Some maintain that participation is cumbersome and slows down the process while others claim that stakeholder involvement is controllable and may even turn out to be faster if the consensus-based outcome is implemented once the decision is made as opposed to the long delays resulting from several rounds of rebuffs and revisions instigated by excluded stakeholder groups. Moreover, the emerging policy or regulation needs to be compatible with prevailing economic values and principles (outcome efficiency). This is especially important in cases when (re)distribution of public funds is involved. In order to help fulfill these objectives, the assessment framework and the decision criteria should be chosen so that they can properly handle the relative importance of economic and financial concerns in the given decision-making context. Typical efficiency criteria include balancing costs and benefits or identifying least-cost solutions under a given set of constraints. An important but often neglected factor in cost and efficiency calculations are the transaction costs required for implementation, enforcement, etc.

Consider equity concerns and implications: The most direct way of using "the best available information about values" is to devise a fair decision-making process and to involve stakeholders directly in it. Different disciplines and different schools in ethics define what is fair in many different ways (Rayner and Malone, 1998; Toth, 1999). In the present context fair is simply what those involved or affected by the decision-making find to be fair. This entails giving a fair chance to all affected groups to participate, to present their values and concerns, and to protect their interests (procedural equity). Participation has become a buzzword in recent years and evidence is accumulating that it increases the overall quality of decisions concerning environmental assets and natural resources (World Bank, 1996). In addition to the possibility of mobilizing local knowledge not otherwise accessible and of increasing the acceptance of the decision, broad participatory approaches also facilitate dealing with the diversity of values, interests, conflicting interpretations of biophysical and social science analyses, and perspectives on how to cope with uncertainty. Even if participation of all stakeholders is impractical or impossible, the decision process needs to be open so that all affected parties can understand how the outcomes arise, what is the rationale behind them, and how it affects different social or stakeholder groups (transparency). Irrespective of whether direct participation is possible and/or meaningful, the decision outcome needs to obey prevailing fairness principles in the society (consequential equity). The corresponding axiom in the analysis domain is the requirement to choose the assessment framework and the decision criteria according to the relative importance of fairness concerns in the decision-making context. Exploring outcomes under different criteria provides valuable insights into the trade-offs among them while multi-criteria frameworks can help progress towards compromise solutions. In recent years, a variety of participatory assessment techniques has been proposed and increasingly used (Toth and Hizsnyik, 1998) in which stakeholders jointly investigate the problem and the range of available options in preparation for the decision process. Participatory techniques are particularly worth considering in complex and controversial decision situations.

Consider vulnerability concerns and implications: A crucial aspect of equity issues is related to vulnerable groups and communities. Vulnerability here refers to people who are sensitive to changes in ecosystems services or environmental quality and lack the ability to cope with those changes: recognize preliminary signals in time, consider response options, adapt to emerging changes or counteract them. The interests of the vulnerable communities are much better respected when defended by a credible, legitimate advocate, coming ideally from the concerned community(ies). Yet vulnerable groups are often unable to engage even into open and receptive decision processes because they lack basic knowledge, the necessary information or communication tools. Special representatives or legitimate assigned advocates are therefore required to speak for their interests in order to prevent top-down decisions being imposed on them. In the assessment work, extended analyses framed from the perspectives of vulnerable groups are required to estimate the implications of the different options for them.

Additional attributes of the information-related criteria for successful decision-making include the need to consider the type and magnitude of *uncertainties* in all four information domains discussed above and *cumulative and cross-scale* effects.

Consider uncertainties: Decision-making about environmental management and the use of ecosystems services is plagued by inherent uncertainties. Even if the functioning of an ecosystem is relatively well understood under the prevailing conditions, the ecosystem behavior might shift as a result of changes in some external driving forces or conditions (Walker and Steffen, 1996). Moreover, the values and valuation of environmental quality, ecosystems and their services by the relevant communities might change or stakeholders may revise their positions. The implication of all these uncertainties for decision-making is that both the process and its outcome must be flexible so that they can respond to newly available information about the biophysical system (ecological or scientific uncertainties), about the social system (value- and behavior-related uncertainties), and about the effectiveness of the decision itself (regulatory uncertainties) (see NRC, 1996). The sources, nature, and magnitude of uncertainties involved in a given decision problem also have implications for choosing the analytical framework (Morgan and Henrion, 1990). In order to provide useful insights, the assessment tool needs to be suitable for accommodating decision-making under uncertainty and hedging, and multiple decision criteria reflecting differing values of the different stakeholder groups. Ideally, a single assessment framework should be chosen that is sufficiently flexible to accommodate and help consolidate a diversity of relevant perspectives on environmental change. If this is not possible, multiple frameworks are needed but this raises the important problem of how to consolidate their results. The range of decision options explored by the analytical tool should also take adaptation possibilities into account, including the feasibility and costs of mid-course corrections in the light of new information and give special consideration to irreversibilities, uncertain thresholds, etc.

Consider cumulative and cross-scale effects: the overwhelming majority of new decisions about environmental management have to be incorporated in the hierarchy of existing policies and regulations. Accordingly, the decision-making process needs to be open to comply with relevant policies already in place or to initiate appropriate changes in them. Similarly, the decision-making process has to be extended to initiate relevant decisions at lower levels that might be required for effective implementation. On the analytical side, the selected tools must be capable of incorporating the hierarchical conditions of the decision problem at hand. They must be able to accommodate constraints provided by higher-level regulations and to explore decision needs and options at lower levels required to achieve the goals of the decision problem explored.

Strive for effectiveness: Effective decisions result in policies and measures that can be and will be realistically implemented to achieve the intended outcomes. The effectiveness of the decisions is thus the function of the extent to which the decision-making process is able to fulfill all the criteria above, ranging from the acquisition and use of the best available information to accommodating the appropriate mix of concerns (efficiency, equity, etc.). Decisions based on appealing ideals but void of pragmatic aspects are bound to fail and are therefore ineffective. The assessment process can foster the effectiveness of the decision by performing "reality checks" of the policy options by adopting analytical tools from disciplines like political science or game theory.

Pursue accountability: Responsibility for environmental decisions and their implications is an elusive issue if one takes into account the multitude and magnitude of uncertainties about the biophysical process, social behavior, and the poor controllability of the underlying processes in both domains. Yet a reasonable level of accountability for at least the manageable aspects of the decisions would encourage decision-makers to use the best available information, involve relevant stakeholders, and keep the decision process transparent. In relatively simple regulatory or resource allocation cases, the responsibility rests with the decision maker who has the ultimate authority to put policies and measures in place. In more complex situations involving several organizations, each should be accountable for the formulation and implementation of the decision component in its own domain or mandate. Similar principles of accountability would motivate analysts to use the most suitable tools and the best available data and to expose their results to extensive reviews.

The relative importance of the criteria in Table 1 differs depending on the temporal and spatial scale of the environmental, ecosystem or resource management problem, on the number and relative power of the stakeholders involved, on the institutional capacity to implement and enforce the emerging decisions, and many others. Yet at least a modest amount of all these ingredients can be recognized in the assessment and decision processes that led to successful decisions. Similarly, it is easy to identify *a posteriori* which ingredients were missing from failed or outright disastrous analytical and decision processes.

The preceding discussion focuses on various ingredients of successful decision-making and analysis. It is important to note the critical importance of judgment and scientific ignorance in these processes. NRC (1996) presents the concept of an analytic-deliberative process and argues that in order to understand policy choices involving risks to environmental quality and human health, it is necessary to employ a process in which scientists, decision makers, and the interested and affected parties to the decision deliberate about the nature of the questions that require analysis, the forms of analysis that would be relevant and useful for the decision, the assumptions that should be incorporated in the analysis when the correct assumptions are unknown or disputed, the appropriate interpretation of the results of the analysis, etc. In other words, a process of public participation is required for decision analysis (not just decision-making) to ensure that decisions are well informed. These issues are further addressed in the context of ecosystems in NRC (1999a) (see also Dietz and Stern, 1998). The main conclusions of NRC (1996) are also integrated into other studies on environmental decision analysis at the NRC (1999b, 1999c), in the USA and other countries (CSA 1997; RCEP 1998) or at international organizations (OECD, 2002).

In summary: this section argues on the basis of recent literature on environmental decision-making that the process of choosing a strategic intervention or a broader policy in response to potential or emerging environmental problems needs to be informed by the best available information that is responsive to the concerns of those who may be interested in or affected by the ultimate decision. Accordingly, the analytical work to support choosing responses should also incorporate the perspectives, values, and interests of those affected by the final outcome. These ingredients are important to keep in mind when we focus on the decision-analytical frameworks in the next section.

3. Decision analytical frameworks and tools

For the purposes of this section, decision analysis frameworks (DAFs) are defined as analytical techniques aimed at synthesizing available information from many (broader or narrower) segments of an environmental problem in order to help policymakers assess consequences of various decision options in their own jurisdictions. DAFs organize all relevant information in a suitable framework, apply a decision criterion (both based on some paradigms or theories), and identify options that are better than others under the assumptions characterizing the analytical framework and the application at hand.

DAFs play a critical role in environmental management and policymaking because many environmental policy debates originate from differing or outright contradicting results obtained from different DAFs. Often the apparently contradicting results are published in peer-reviewed scientific literature. The contradicting results reflect paradigmatic differences among the DAFs or competing scientific theories underlying them. Therefore the value of the results of policy-oriented analyses would be much higher if they came together with a pedigree of their source: what are the conceptual foundations of the adopted analytical tools. Thorough analysts always document their application-specific assumptions along their results but the theoretical underpinnings and the possibly arising limitations of the adopted DAF often remain hidden to policymakers. Analysts should try to do a better job in serving the decision-making community by highlighting the advantages and limitations of different DAF applications when presenting their results.

It is a different question how much policymakers and stakeholders know about DAFs and to what extent they believe the numbers they get from them even if they commission the studies. Moreover, even in their most complex implementations, DAFs depict a drastically simplified, ideal world in which they magnify key factors and processes related to the environmental problem they address and ignore issues considered or assumed less important. Among other reasons, that is why hardly ever decisions are made on the basis of exact numerical results from any analytical framework. Yet these results are important when they are considered in decision-making together with many other interests and arguments.

A starting point for analyzing options and making decisions in any problem area is to identify basic characteristics of the situation. The profound characteristics of many environmental problems include insufficient knowledge (large uncertainties or outright ignorance), complex dynamic relationships (non-linearities, potentially irreversible changes), diverse temporal scales (often long time lags and planning horizons), and multiple spatial scales (regional processes with global implications and global changes with major regional variations in causes and effects). This calls for a thorough investigation of both the applicability of off-the-shelf versions of traditional decision analytical frameworks (DAFs) as well as of the relevance and usability of their results, because most of them were developed for and performed reasonably well in problem areas characterized by lesser degree of complexity, shorter time horizons, smaller spatial expanses, etc.

Who are the decision makers these DAFs are intended to serve? To ensure consistency with the elaboration in Section 2 above, we take a conveniently general definition: "[A] decision or policymaker is anyone authorized or able to alter the flow of pertinent events" (Brewer and deLeon, 1983, p14).

A number of supranational organizations can be identified that shape both global- and national-scale environmental decisions at international negotiations. Some of them are long-standing and were established for non-environmental purposes (European Union, OPEC, G77), others are ad hoc and were created to be operational in specific environmental issues like AOSIS in the case of international climate negotiations.

National governments are generally recognized to have the legitimacy to agree on global decisions and the authority to make and implement decisions under their jurisdictions accordingly. The positions they take in international fora and the ways they implement global decisions at the national scale are crucially influenced by the positions regions and sectors belonging to their jurisdictions take on the matter. Finally, myriads of decisions are made daily at the micro level by individuals, families, and small communities.

The diverse characteristics of the decision-making situations associated with ecosystems and biodiversity management imply the need for a diverse set of decision analytical frameworks (DAFs) and tools so that the ones most relevant to the problem at hand can be selected and applied. It is important to note that none of the frameworks can incorporate the full complexity of decision-making. Hence their results comprise only part of the information shaping the outcome.

A broad range of frameworks can be used in principle and has been used in practice to provide information for policymakers concerned with environmental policy and ecosystems-related decisions at various levels. Table 2 provides an exemplary rather than an all-encompassing list. Many DAFs overlap in practice and clear classification of practical applications is sometimes difficult.

Table 2. Decision Analytical Frameworks: compatibility with decision-making principles, applicability at geopolitical levels, in environmental policy domains, and the ability and form to treat uncertainties.

DAFs	Decision principles			Level of applica-tion	Domain of applica-tion	U-Rig U-frm
	Optimi-zation/ Efficienc y	Precau-tionary principle	Equit y			
Decision analysis	*	+	+	X	B	* St
Cost-benefit analysis	*	-	+	X	D	+SA *Sc
Cost-effectiveness analysis	*	+	+	X	D	+SA *Sc
Inverse Control Approach	+	*	+	X	D	+SA *Sc
Game theory	+	-	+	X	B	+SA *Sc
Portfolio theory	*	+	-	X	B	* St
Public finance theory	*	-	*	N-M	B	- SA
Behavioral decision theory	-	+	+	X	B	- Sc
Ethical and cultural prescriptive rules	-	+	+	X	D	-Sc
Policy exercises	+	+	+	X	B	+Sc
Focus groups	-	+	+	R-M	I	- Sc
Simulation-gaming	-	+	+	X	B	+Sc

Notes:

Compatibility with/usability of decision principles in DAFs:

- \- weak but not impossible
- \+ possible but not central
- * essential feature of DAF

Level of application:

G = Global I=Inter/Supra-national N=National R = Regional/Sectoral (sub-national)
L=Local (community) M = Micro (family, firm, farm) X = All

Domain of application:

D=Direct intervention I=Indirect influence B=Both

Uncertainty treatment:

Rigor: * high + good - moderate/low
Form: St=Model structure SA=Sensitivity analysis Sc=Scenarios

Different decision-making principles can be used individually or in combinations as DAFs are adapted to specific ecosystem problems. Table 2 indicates the compatibility of different principles with and their usability in relevant DAFs. It is apparent from the table that some DAFs can accommodate some decision principles better than others but downright incompatibility is rare. There are always hidden value judgments involved in the selection and application of DAFs.

Some of these DAFs are more useful at the global and national scales, while others can be more usefully applied at regional, sectoral or micro scales. Table 2 also contains entries regarding the decision-making level at which the given DAF can be applied. Another series of entries indicates whether the DAF at hand is applicable for decisions concerned with environmental management and policy-making directly or for broader policies that influence the direct and/or indirect drivers of environmental change via other mechanisms. The next column provides indications regarding the ability of a framework to address uncertainties.

Decision analysis (DA) is the product of integrating utility theory, probability, and mathematical optimization (see Keeney and Raiffa, 1993; Clemen, 1996; French, 1990; Kleindorfer et al., 1993; Morgan and Henrion, 1990). The process starts with problem identification and preparing a possibly comprehensive list of decision options. Structural analysis would organize options into a decision tree carefully distinguishing decision nodes (splitting points at which the outcome is chosen by the decision maker) and chance nodes (splitting points at which the outcome results from stochastic external events). Next, uncertainty analysis would assign subjective probabilities to chance nodes while utility analysis would stipulate cardinal utilities for outcomes. Finally, optimization analysis produces the best outcome according to a selected criterion, most typically maximizing expected utility, or any other that reflects the risk attitude of the decision maker best.

Decision analysis is a powerful DAF that can provide useful results at different levels of decision-making and can be formulated according to different decision-making principles. One of its powerful and particularly convenient features is that it can be set-up to include multiple criteria. This is often helpful in consolidating the confronting objectives of different stakeholder groups and in analyzing the trade-offs among them.

Cost-benefit analysis (CBA) involves valuing all costs and benefits of a proposed project or policy over time (see Ray, 1984; Morgenstern, 1997). Any gain in utility counts as benefit and any loss in utility counts as costs (measured as opportunity cost) irrespective of to whom they accrue. The primary decision criterion to accept or turn down the project is that the sum of discounted benefits should exceed the sum of discounted costs. Many projects tend to fulfill this criterion in the reality leading to the problem of capital rationing. In this case the ratio of benefits over the costs can be used to rank the projects and those with the highest ratios should be selected. In real life they seldom are because CBAs are good at providing a rough picture but suffer from many imperfections. The criterion of costs exceeding benefits formally corresponds to the compensation principle implying that those who benefit from the project should be able to compensate the losers, at least hypothetically.

Cost-effectiveness analysis (CEA) takes a predetermined objective (often an outcome negotiated by key stakeholder groups in a society) and seeks ways to accomplish it as inexpensively as possible. The thorny issue of compensations and actual transfers boil down to less complex but still contentious issues of burden sharing. CBA will always be controversial due to the intricacies of valuing benefits of many public policies, especially intangible benefits of environmental policies properly. CEA takes the desired level of a public good as externally given (has a vertical marginal benefit curve) and minimizes costs across a range of possible actions. Similarly to other target-based approaches, CEA often turns into an implicit CBA, especially if even the least-cost solution turns out to be too high and beyond the society's ability to pay for its implementation. In this case the target is iteratively revised until an acceptable solution is found.

The *Inverse Control Approach (ICA),* also known as the Tolerable Windows Approach (Toth et al, 1997), is particularly useful to reconcile the difficulties between the long-term dynamics of some ecosystem processes and the short-term nature of decision-making. It is conceptually related to both CBA and CEA (Toth, 2003). It formulates the issue as a control problem by taking ecosystem status and change as state variables for which constraints are imposed externally by decision-makers. Constraints can also be imposed on selected control variables, typically on implementation costs. The analysis then identifies boundaries for the evolution of control variables within which decision makers can choose their preferred course of action with a view to other considerations not included in the analysis directly.

Game theory investigates interactions between agents and predicts outcomes by simultaneously accounting for their objectives, costs and benefits (see Bacharach, 1976; Shubik, 1982). The emphasis is on the strategic behavior of players, each of whom is assumed to consider two points: first, impacts of his action on other players, and second, the fact that other players do the same in making their own decision. Game theory has provided useful insights as a DAF in many resource management problems, and it can also generate information for finding feasible protection measures.

Portfolio theory is concerned with creating under a budget constraint an optimal composition of assets characterized by different returns and different levels of risks. Decision options (portfolio elements) are represented by a probability distribution of expected returns while risks are estimated on the basis of the variability of expected returns, and only these two factors determine the decision maker's utility function. The decision rule is to choose the efficient portfolio compared to which no other portfolio offers higher expected return at the same or lower level of risk or lower risk with the same (or higher) expected return. Portfolio theory originates in (private) financial investments but there is nothing to preclude its application in public policy decision-making. It is an outstanding candidate to help determine an optimal portfolio of genes/species/ecosystems to maximize ecosystem/biodiversity benefits under budget constraints and uncertainty.

Public finance theory provides the microeconomic foundations of managing the public sector and addresses subjects like public good theory, theory of taxation, welfare analysis, and externalities (Tresch, 2002). It is mainly concerned with the choice of second best. Its applications seek a compromise between efficiency and equity. Benefits theory of taxation, impact and tax burden analyses are particularly useful in making decisions about ecosystems and biodiversity management.

Behavioral decision theory (BDT) combines economics and psychology to describe human decision-making (see Hogarth, 1990; Einhorn and Hogarth, 1988). It is utilitarian to the extent that it tries to understand human behavior as a purposeful attempt to improve well-being but it recognizes that people's information processing capacity and decision-making skills are limited. BDT has been applied as a DAF to a broad variety of social issues and situations. It rests on the basic assumption that people usually (re)act rationally in order to solve a problem. Collective human behavior represents the efforts people undertake in order to find solutions to problems they jointly face. BDT provides important insights into the discrepancies between stylized assumptions of economics and real-world decision-making. These insights might be especially relevant in the case of a complex and controversial problem of biodiversity management.

Ethical and cultural prescriptive rules as a DAF can be traced back to the cultural theory of risk and related concepts in sociology and social anthropology (Douglas and Wildavsky, 1982). Cultural theory is concerned with forms of social organization that are largely ignored by economists and political scientists and emphasizes the importance of including in DAFs social organizations that are usually excluded by conventional social science dichotomies. This leads us to the second large group of DAFs: the ones that are used in traditional societies to contemplate decision options and to facilitate the choice among them.

Probably one important feature of traditional societies, especially at the micro/local level is that the decision analysis/support function is not specialized, designated, or even separated from the decision-making function as it is often the case in modern societies.

Recently, there has been increasing emphasis on the importance of involving stakeholders in the analytical processes that are intended to support policymaking. Various techniques have been developed and used.

The *Policy Exercise (PE) approach* involves a flexibly structured process designed as an interface between experts/analysts and policymakers. Its objective is to synthesize and assess knowledge accumulated in several relevant fields of science for policy purposes in the light of complex practical management problems. Key components of the process include scenario writing ("future histories", emphasizing non-conventional, surprise-rich but plausible futures) and scenario analyses via the interactive formulation and testing of alternative policies that respond to the challenges in the scenarios. These scenario-based activities take place in an organizational setting reflecting the institutional features of the addressed issues. Throughout the exercise, a wide variety of hard (mathematical and computer models) and soft methods are used (Brewer, 1986; Toth, 1986, 1988a, 1988b). The product of a PE is not necessarily new scientific knowledge or a series of explicit policy recommendations, but rather a new, better-structured view of the problem in the minds of the participants. Successful applications serve policymakers by preparing them for participation in official decision-making processes and summarize the most important policy insights in the form of a Policy Briefing Document. The exercises also produce statements concerning priorities for research to fill gaps of knowledge, institutional changes that are needed to better cope with the problems, technological initiatives that are necessary, and monitoring and early warning systems that could ease some of the problems in the future.

Applications of the *Focus Group* technique to environmental problems are based on a monitored social process to allow citizens to express their judgments on global, national or local environmental problems and policies in a form that provides useful information for policymakers. This is a very "soft" analytical framework and its main value is to provide information about citizens' views rather than in doing a rigorous ranking. The social process draws on small-group techniques used in applied social science research (see Krueger, 1988) and in political decision-making (see Stewart et al., 1994). Focus Groups can also be conceived as an extended small-group version of Contingent Valuation with advantages and drawbacks: while participants can go much further in expressing their views about a particular environmental management problem (than simply providing willingness to pay or to accept values), the outcome may be dominated by the small-group dynamics (dominant personalities, judgment inconsistencies).

Simulation-Gaming (S&G) exercises define decision situations, roles, rules and procedures in order to study particular social situations in which individual decisions and their interactions are crucial to the outcome. As opposed to game theory where consistent and rational behavior is taken for granted for all actors at all times, simulation-gaming is more concerned with human behavior as it unfolds in an artificial microcosm. In contrast to PEs where institutional settings and procedures defined for the exercise closely imitate reality, decision situations in S&G sessions are significantly simplified emphasizing just a few selected features of reality. Two aspects are particularly relevant for ecosystem management. The first entails the potential offered by simulation-gaming to communicate and teach complex issues to players (teaching-training games). The second is related to the so far largely underutilized potential to gain insights about processes of negotiating complex issues among parties with widely diverging values and interests, especially at the international and national levels.

In summary: a large and diverse set of DAFs is available to analysts in their efforts to support environmental policy formulation and decision-making. The choice of the proper DAF should be made according to the characteristics of the environmental decision problem, its social and political context, and the decision criteria of the key stakeholder groups involved in the process and affected by the outcome. For example, the applicability of cost-benefit analysis to guide global climate policy has been disputed for over a decade because climate change has many features (especially the long time horizons, the possibility of irreversible changes, the problems of valuing non-market impacts, the delay between emissions/mitigation costs and damages/mitigation benefits) that are difficult to handle in a traditional cost-benefit framework. Instead, cost-effectiveness and inverse control approaches have been extensively used in recent years. Another example concerns local-level decisions. Cost-benefit analysis can provide good guidance for managing a privately owned forest under free-market conditions. In contrast, decisions concerning a community forest in a developing country would probably benefit from using culture-based frameworks or suitably adopted participatory approaches. The selection of the appropriate analytical framework to tackle a given problem should follow from matching features of the problem (scale, complexity, social context) with the capabilities of candidate methods.

4. Summary

Environmental issues on the social agendas and processes of environmental decision-making have changed considerably in recent decades. These changes have stimulated various types of conceptual and methodological research in environmental science. Two large areas are addressed in this report. The first one draws on reflexive-analytical efforts to establish the criteria for good environmental decision-making and associates them with corresponding criteria for good scientific assessments to support it. The second area is methodology where a sample of analytical frameworks is briefly characterized according to selected features that are relevant in choosing among them for implementing environmental assessments.

The process of choosing a strategic intervention or a broader policy in response to potential or emerging environmental problems needs to be informed by appropriate information that reflects the concerns of those who may be interested in or affected by the ultimate decision. The processes of decision-making and decision analysis to support it should use the best available information about the biophysical characteristics, their changes and the socioeconomic implications, the social context and values involved in the environmental problem (changes in valued processes or services) including cumulative and cross-scale effects. Both types of processes need to consider uncertainties and make use of ignorance by adopting analytical frameworks and decision-making processes capable of accommodating new information and course corrections (adaptive management). They also need to take into account equity, efficiency, and vulnerability concerns, pursue accountability and strive for effectiveness.

The diversity and sophistication of analytical frameworks, tools, and models to support environmental decision-making have also grown significantly. They draw on various disciplines in social sciences ranging from economics, sociology, psychology, anthropology, and others. The degrees of formalization in terms of mathematical models of these frameworks range from highly formalized and complex models typically implemented as computer tools to artificial argumentative discourse-based social processes. The ability to address specific aspects of the decision problem (efficiency and equity concerns, problem scale, uncertainties) varies accordingly.

The continuing challenge for environmental decision-making remains the selection of relevant ingredients presented in Section 2 and their ranking according to the characteristics of the problem to be addressed. The outcome of this step can then guide the choice among the analytical frameworks presented in Section 3 and selecting the one that might provide the most relevant and useful information for the decision-making process. In many cases, these choices are made in an arbitrary manner, often dominated by the skills of the analysts and by the biases of the decision-makers. While there is need for diversity and room for flexibility in analyzing and managing most environmental problems, there is also a need for more systematic assessments of the relevant ingredients and of the capabilities of applicable tools. The brief reviews in this paper are intended to help such assessments.

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