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Abstract: Discusses the value of an ecosystem 'report card' in linking societal values with scientific information. Scientists as advisors to community decision makers, telling them which ecological goals are achievable; Criteria for an ecosystem integrity support card; Proposed report card framework; Development of performance criteria to set, monitor, or modify mamagement actions; Value of multi-agency cooperation. INSETS: Example goals and objectives for an ecosystem integrity report; Generic considerations for selecting ecosystem endpoints.

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A FRAMEWORK FOR AN ECOSYSTEM INTEGRITY REPORT CARD

Examples from South Florida show how an ecosystem report card links societal values and scientific information

Ecosystem management is astructured process for societyto define what ecological condition is desired at each part of a region and to develop and implement management policies designed to achieve that mosaic of desired sustainable ecological conditions (US MAB 1994, IEMTF 1995a, 1995b, Christensen et al. 1996, Harwell et al. 1996, Harwell 1998). Ideally, the establishment of ecological goals involves a close linkage between scientists and decision makers, in which science informs decision makers and the public by characterizing the ecological conditions that are achievable under particular management regimes, and decision makers make choices reflecting societal values, including issues of economics, politics, and culture. Because ecosystem management is adaptive--that is, management is adjusted if necessary to achieve goals--the general public, the scientific community, resource managers, and decision makers need to be routinely apprised of progress toward achieving the desired ecological goals, that is, they need a "report card" on ecosystem condition or integrity.

The concept of report cards or performance measurements to describe progress toward environmental goals has evolved over the past few decades as environmental legislation and the appropriation of public funds for environmental restoration, preservation, and management have increased. Over this time, reports have expanded from measurement of the effects of single initiatives (e.g., land acquisition goals for parks and protected areas) and progress toward pollution reduction in single media (e.g., reduction of air or water emissions) to encompass the broader and longer-term regional ecosystem management and restoration approaches that have been developing in highly valued ecosystems throughout the country (e.g., the Greater Everglades, San Francisco Bay, Chesapeake Bay, the Great Lakes, and the Pacific Northwest).

These holistic, often multi-agency efforts to maintain accountability for regional ecosystem integrity and the progress of restoration activities stem in part from the proactive desire of resource managers to maintain public interest, support, and, consequently, funding for long-term environmental restoration and management efforts. They also stem in part from specific legislative or regulatory requirements to engage the public in the ecosystem management process (e.g., EPA/EC 1995, 1996, Chesapeake Bay Program 1996, NSTC 1996a, 1996b) or from direct requests from Congress, state legislatures, and governors to report the results of public investment (e.g., Florida Executive Office of the Governor 1983-1996a, 1996b, US Congress 1993, Tuchmann et al. 1996). For example, the ability to reduce phosphorous and nitrogen loads in Chesapeake Bay depends, in large part, on the successful voluntary implementation of best management practices on farms in the watershed (Chesapeake Bay Program 1996). Reports that track the implementation and progress of these voluntary programs have motivated farmers to participate in this long-term effort. In another example, the City of Jacksonville, Florida, developed an index to report annually to citizens about the equitability and efficiency with which tax-supported services, such as pollution control and environmental cleanup, are delivered to residents (Jacksonville Community Council Inc. and the City of Jacksonville 1994, 1996).

The scope of many regional report cards is constrained by the specific regulatory authority of the government agency or agencies conducting the assessment. For example, the US Department of Agriculture Forest Service (USFS) and the US Department of Interior Bureau of Land Management (BLM) produce separate reports on progress toward attaining the specific goals required by the Northwest Forest Plan (BLM 1995, USFS 1995). The presentation formats and level of detail among regional report cards also vary. Some regional report cards are available over the Internet; these offer the advantage of a nested, hypertext approach that, as one moves deeper through the hierarchy of Web pages, provides a summary report targeted to the general public; charts, graphs, and narratives that support the summary; and quantitative data and measurements that are used to compile the charts, graphs, and summary. For example, the State of the Great Lakes report (EPA/EC 1995, 1996) assesses the overall condition of the Great Lakes ecosystem in six general categories: aquatic community health, human health, habitat, contaminants, nutrients, and economy. The report focuses on a small number of indicators intended to summarize the state of the ecosystem and to measure progress made in addressing the many sources of stressors. The health conditions of the six general categories are rated by a panel of technical experts who review indicator data and classify health into four categories: poor, mixed/deteriorating, mixed/improving, and good/restored. The Chesapeake Bay Web site is also organized hierarchically and provides extensive hypertext links to related reports, Web sites, and databases (Chesapeake Bay Program 1995; the latest report can be found at www.chesapeakebay.net/bayprogram).

Another type of report card is exemplified by The State of Boston Harbor reports (MWRA 1990, 1992), which present an assessment of four primary concerns expressed by the public: safety of fishing and swimming, safety of shellfish for consumption, protection of living resources from pollution, and the aesthetic condition of the harbor. From a base of scientific information, factors affecting the quality of these four areas are given letter grades that represent the condition (excellent, good, satisfactory, or poor) and are compared with the previous year's grades. The grades in each area are combined into a report card that aggregates the various findings to answer a single question, for example, "Is it safe to eat fish and shellfish from the Harbor?" In early reports, the letter grades were based on expert judgment of staff, but a quantitative method has been applied in recent annual reports. The State of Boston Harbor report card draws from a large, diverse base of scientific studies from government, academic, and environmental groups. In addition, the grading system is adjusted annually to reflect input from the public.

These performance reports on regional ecosystem management and restoration initiatives have a number of characteristics: they are driven by goals for a certain level of environmental quality; they draw on currently available scientific studies; they assess the status of ecological conditions and how well society is doing in reducing stressors; they are often constructed hierarchically; and they are usually produced to be accessible to a diverse audience, from the general public to scientists and managers (Myers and Sharp 1997).

However, a systematic framework is lacking for an ecosystem integrity report card that is derived from a sound conceptual understanding of ecological principles and ecological risk assessment; that characterizes ecosystem integrity across spatial and temporal scales, organizational hierarchy, and ecosystem types; and that is adaptable for any set of environmental goals. Moreover, no generic report card framework has been created that can be used to develop specific performance evaluation report cards for specific ecological systems, to identify ecosystem benchmarks or restoration milestones, or to make explicit the relationships among societal goals, decision-making endpoints, and environmental monitoring (Figure 1). Through its case study on ecosystem management principles and their applicability to the environment of South Florida (Harwell et al. 1996, Harwell 1997, 1998), the US Man and the Biosphere Program's (US MAB) Human-Dominated Systems Directorate (HDS) has developed a generalizable framework for such an "ecosystem integrity report card." In this article, we present this framework and show how it addresses these needs and provides a foundation for the development and implementation of report cards that characterize the integrity of actual ecological systems and that may ultimately aid in comparing integrity across regions. The framework we propose has the additional benefit that it can be adapted to an abbreviated form that reports on the ecological condition of less comprehensive environmental assessments, that is, following the same hierarchical structure but with less detail at each level.

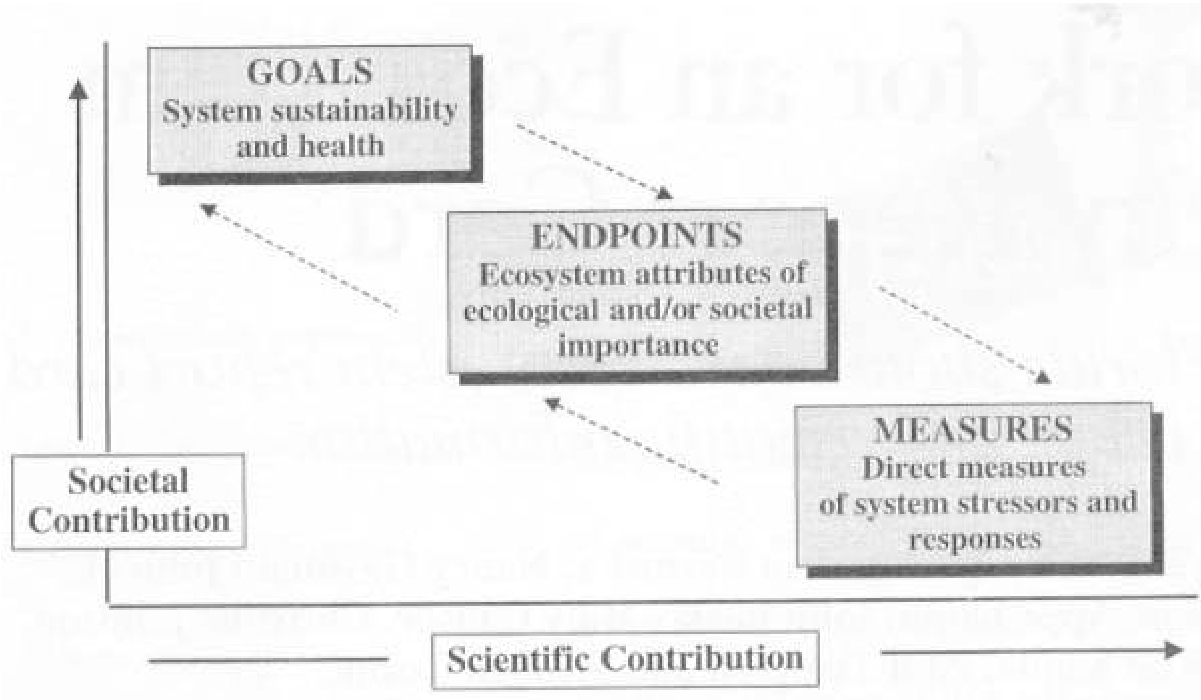


Figure 1. Relationship between societal goals and scientific endpoints and measures in ecological assessments. Societal values have a dominant role in establishing goals, and scientific issues have a dominant role in selecting measures. Ecosystem endpoints are formed at the juncture of societal and scientific considerations.

Criteria for an ecosystem integrity report card

To structure a framework for an ecosystem integrity report card, it is important that it meet the criteria for a successful report card: * It should be understandable to multiple audiences. The report card must be understandable to audiences ranging from the highly technical to the totally nontechnical; it must also address scientists and environmental managers, the public policy community, stakeholders, representatives of interest groups, and the general public. A report card would be inadequate if it were to address only a single audience, were to fail to make explicit the scientific bases for the ecosystem integrity assessment, or were to fail to translate the scientific information into policy- and goal-relevant terms that both decision makers and the public can understand.

• It should address differences in ecosystem responses across time. That is, it should show how an ecosystem is doing annually as well as on decadal or longer time scales. The ultimate goal of ecosystem management is the sustainability of ecological systems, which inherently requires long-term perspectives.

• It should show the status of the ecosystem. The report card should use selected "ecosystem endpoints" (i.e., ecosystem-specific attributes that describe the ecosystem at the level of detail necessary to characterize ecosystem integrity) to show both the current and past status of the ecosystem. It should also show past and current trends in condition over time and, perhaps, provide an indication of prospects for the future condition. Trends should be reported in the context of natural variability, allowing scientists to determine if there is a real signal of a trend or just normal environmental noise. The report card should also provide a ready indication of the progress made toward each goal, including a relative measure of how much remains to be achieved. Therefore, the report card needs to include various reference, benchmark, and desired conditions so that the state of the ecosystem can be judged relative to the goals.

• It should characterize the selected ecosystem endpoints. The ecosystem endpoints are established through ecosystem management or restoration programs and are designed to identify those changes in the ecosystem's condition that are significant, either ecologically or to society (Kelly and Harwell 1990, Gentile and Harwell 1998). Consequently, every ecosystem endpoint that reflects the integrity of the ecosystem must be incorporated in an explicit manner in the report card framework. Moreover, from the large number of possible ecosystem endpoints a parsimonious subset must be selected so that the report card is focused on those essential characteristics of the ecosystem.

• It should transparently provide the scientific basis for the assigned grades. The report card should include the details of monitoring data, models, and experiments supporting the assessment so that other people can reproduce the grade or assign their own grade based on alternative criteria. An approach to accomplish this transparency is to couple the report card to ecosystem conceptual models (Gentile et al. 1993) that describe causal relationships and linkages among societal drivers (i.e., what humans do to affect the environment directly or inadvertently), stressors (i.e., the physical, chemical, or biological changes to the system), and ecological effects (i.e., the ecological changes caused by the stressors). Those relationships and linkages constitute the basis on which the ecosystem functions and responds to stress, both natural and anthropogenic. Transparency of the conceptual models and the relationships between data and grades will enhance credibility, acceptance, and usefulness of the report card.

Proposed report card framework

Based on the US MAB project on ecosystem management (Harwell et al. 1996, Harwell 1997, 1998), we have developed a hierarchical structure for an ecosystem integrity report card (Figure 2) that meets all of the above criteria and draws on the experiences of existing report cards. This framework is driven from the top down by the societal goals for ecosystem integrity and from the bottom up by the detailed scientific measurements of ecosystem conditions.

The highest tier in the framework is the environmental "goals," that is, the broad articulation of societal values and desired ecosystem conditions of each part of a regional environment. The second tier, termed "objectives," disaggregates the goals into more specific items, but these items are still characterized in layperson's terms. Goals and objectives must be decided on by society, based on the best available science to identify what is feasible and consistent with the characteristics of the ecological system itself. For any particular region, there might be a handful of goals, each of which might have 5-10 associated objectives (each of which may be further articulated as sets of sub-objectives).

The middle tier in the proposed report card framework, the "essential ecosystem characteristics" (EECs), provides the critical interface between the societally determined ecosystem goals and objectives and the scientifically determined characteristics of the ecosystems of concern. That is, each goal or objective must be translated into a specific ecological meaning. For example, society might desire a restored and sustainable wetland system, but precisely what that means in terms of wetland EECs must be stated explicitly.

The EECs and associated subcategories in turn are linked to the next lower tier in the proposed framework, ecosystem endpoints. Ecosystem endpoints as defined in this report card framework are the same as those of the ecological risk assessment framework (Kelly and Harwell 1990, EPA 1992, Harwell and Gentile 1992, Gentile et al. 1993).

Below the ecosystem endpoints is the lowest tier of the report card framework, the "ecosystem measures." This tier, which should be defined only by scientists, constitutes the specific environmental attributes that need to be measured or monitored to indicate the status or trends of the ecosystem endpoints and associated EECs. In essence, this tier defines the field measurements that will provide the foundations for the entire report card. Each EEC must have a set of specific ecosystem endpoints associated with it, and each ecosystem endpoint must have at least one, and sometimes many, associated ecosystem measures.

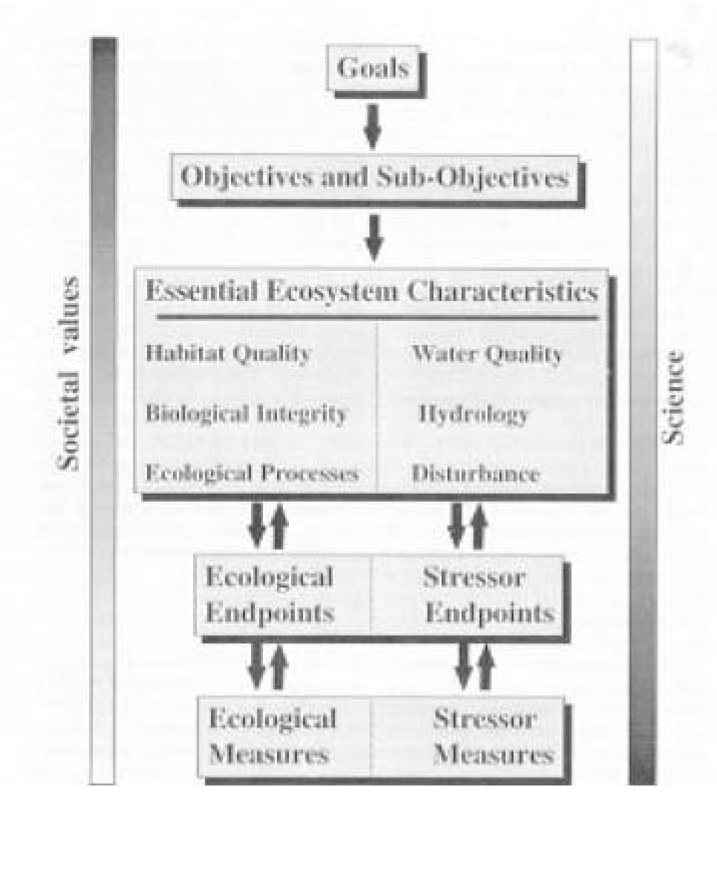


Figure 2. Proposed ecosystem integrity report card framework. The bars along the sides represent the gradient of societal and scientific roles at various levels of the process. The arrows from goals to objectives signify the goals-driven process. The two-way arrows between the other tiers signify the top-down processes of selecting the endpoints to represent the EECs and selecting the measures needed to characterize the endpoints, and the bottom-up processes of aggregating the information from the measures into a characterization of the endpoints and aggregating the endpoints into a characterization of the EECs.

Tiers 1 and 2--Goals and objectives (and sub-objectives). The goals and objectives (and sub-objectives) serve to articulate a comprehensive vision of what society deems significant and meaningful about the environment. This concept--that the report card is driven by societal goals and objectives--follows directly from the principles of ecosystem management, in which decisions are made by society about the desired sustainability condition of each part of the landscape. Those decisions are both informed and constrained by science, but they are made by society through various mechanisms to convert the societal preferences and values into explicit environmental decisions (NRC 1996). Objectives combine societal values with scientific knowledge to provide more specific guidance for resource management. The audience for the goals and objectives tiers of the report card is primarily decision makers, stakeholders, and the public, that is, the same group that establishes the goals and objectives in the first place.

Some management and restoration programs begin with a process to develop goals and objectives (e.g., the South Florida ecosystem restoration program, Harwell 1997; the San Francisco Bay restoration program, CALFED 1998). In other cases, generation of a report card will require engaging in a process to construct goals and objectives. This undertaking is not simple because human perceptions and values about ecosystem integrity can vary widely.

One mechanism to understand individual values about the environment is traditional economics, which assumes that values are held by individuals and that societal values are merely the summation of individuals' values, expressed through economic decisions in the marketplace. Thus, an extensive literature in economics defines individuals' willingness to pay for environmental amenities, including direct use (e.g., of fish, timber, and water), indirect use (e.g., hedonic costs of an aesthetic view from a piece of property), and existence values (e.g., the knowledge that a healthy ecosystem exists, even if the individual never sees it). (See Freeman [1993, 1997] and Goulder and Kennedy [1997] for overview of these methodologies and associated assumptions.)

However, a growing literature focuses on the inadequacies of this perspective (cf., Costanza and Folke 1997). For example, critics suggest that the assumption that individuals will make informed decisions about complex ecological systems is invalid for most individuals; that the assumption that certain resources can be substituted for one another, which is necessary to derive willingness-to-pay estimates, is invalid when applied to irreplaceable ecological resources; that willingness to pay is tied to the ability to pay, with costs that are exorbitant to one individual being trivial to another; that issues of sustainability, inter-generational time horizons, and cumulative effects of multiple stressors are not addressed adequately by individual-level decisions; that there is no neutral way to measure individual-level values; and that environmental decisions require long time frames and major commitments of society, rather than individual choices made repeatedly. The alternate perspective on environmental valuation therefore considers that higher-level values emerge within the hierarchy of society, just as all complex systems are characterized by emergent properties (von Bertalanffy 1968, O'Neill et al. 1986). Such emergent societal values exist because decisions by society are more than just the sum of the parts of individual values.

An example of how societal values can be used effectively in the establishment of goals and objectives is provided by the Florida Governor's Commission for a Sustainable South Florida, which the late Governor Lawton Chiles established in 1994. This diverse institution contains 47 members selected to represent a balanced picture of society as a whole; it consists of representatives from state, local, and tribal government; business groups; environmental groups; and other stakeholders. The Governor's Commission has met frequently, deliberated extensively in public meetings with considerable support and advice from the scientific community, and constructed environmental and societal goals and objectives for South Florida.

The commission's conceptual plan is a spatially explicit representation of what ecological or societal condition is desired at each location on the regional landscape. Thus, the Governor's Commission reports constitute general regional environmental goals (Governor's Commission 1995) that are further interpreted as site-specific ecological and societal goals and objectives (Governor's Commission 1996). The commission developed three goals and 16 objectives (see box page 548). Although these goals and objectives were designed specifically for the South Florida regional environment, they may be readily adapted to other regions.

Tier 3--EECs. The EECs constitute a description of the essential characteristics of an ecosystem. EECs differentiate one type of ecological system from another; for example, the EECs for wetlands differ from the EECs for forests. But EECs can also distinguish the ecological integrity of one wetland from another and one forest from another. Because the EEC tier is the critical interface between science and society, its audience includes decision makers, stakeholders, and the public, as well as the scientists.

EECs capture relevant scientific information into a limited number of discrete, but not necessarily independent, characteristics that describe the major ecological features in any type of ecosystem. That is, EECs are a set of generic attributes that apply to all ecological systems (Table 1), thereby providing a guide for selecting specific attributes for a particular ecosystem. EECs should be considered as a set describing the integrity state (i.e., healthy versus non-healthy) of the system. Each EEC has several subcomponents (also generic but adaptable to specific ecosystems) that describe the state of the ecosystem in more detail and with more specificity.

By translating society's desired goals and objectives into the EECs, scientists provide clarity and specificity to what society wants and, in the process, explain and educate nonscientists about what the scientific characteristics for a given ecosystem mean. Associated with this process is a determination of what constitutes "healthy," that is, deciding on the grade (or other target) to be assigned to the ecosystem condition given the goal and objectives. A critical mechanism for this process is the development of a conceptual model (John H. Gentile, Mark A. Harwell, Wendell P. Cropper Jr., Diego Lirman, and Christine C. Harwell, unpublished manuscript) that graphically illustrates the linkages between societal goals and EECs, that makes explicit the specific ecological and stressor attributes to be assessed (i.e., ecosystem endpoints), and that shows connectivities and feedbacks. Such a graphical illustration will help nonscientists to understand the complexities and indirect pathways that are typical of ecological systems.

Seven generic EEC categories are sufficient to capture the range of ecosystem attributes that are important. These categories include habitat quality, integrity of the biotic community, integrity of ecological processes, water quality, hydrology, disturbance regime, and sediment-soil quality. Each EEC in turn has subcategories (Table 1). The list of EEC subcategories is derived from consideration of major ecological features of two ecosystem management case studies that are actively underway: South Florida ecosystem restoration and San Francisco Bay regional ecosystem management. Sets of EECs and ecosystem endpoints for each ecosystem type in South Florida were developed at US MAB workshops (Harwell and Long 1995, Harwell et al. 1996).

Similarly, a coalition of government and private groups has developed an initial set of EECs for the ecosystem management of San Francisco Bay from which ecological endpoints will be developed (Levy et al. 1996, Young et al. 1998). Although the EEC subcategories in Table 1 appear reasonably comprehensive and adaptable to any ecological system, additional EEC subcategories may need to be added for different types of ecosystems.

Tiers 4 and 5--Ecosystem endpoints and measures. The concept of ecosystem endpoints was developed to distinguish stressor-induced changes that are ecologically significant from those that are not important (Harwell et al. 1990). The idea that ecosystem endpoints constitute those ecological attributes that are sufficiently important to humans to be used as decision-making points was incorporated as a component of the ecological risk assessment framework (EPA 1992, Gentile et al. 1993) and subsequently expanded on by Harwell et al. (1994) and Gentile and Harwell (1998). Furthermore, because the ecosystem conceptual model construct (John H. Gentile, Mark A. Harwell, Wendell P. Cropper Jr., Diego Lirman, and Christine C. Harwell, unpublished manuscript) is derived from the ecological risk assessment framework, those ecosystem endpoints that are at the lowest tier of an ecosystem conceptual model are precisely the ecosystem endpoints to be incorporated into the report card. Because the ecosystem endpoints tier allows for a scientific specification and refinement of the EECs, the audience for the ecosystem endpoints tier is primarily scientists and only secondarily decision makers and stakeholders.

Ecosystem endpoints can be selected by following a checklist of issues to consider for each specific ecosystem (see box this page). The selection process requires looking explicitly across the organizational hierarchy (i.e., at the population, community, ecosystem, and landscape levels) to identify those ecosystem-specific ecological attributes that, if changed, would alter the integrity of the ecological system. Conversely, if there were a change in ecosystem integrity, it should be manifested in changes in one or more ecosystem endpoints. An ecosystem endpoint's importance may reflect its ecological role (e.g., ecological processes, keystone species, and trophic structure integrity) or its value to society, whatever its ecological importance (e.g., endangered species are important attributes because humans have particular concerns about them). Other societally important ecosystem endpoints include the viability of economically important species (e.g., commercial or recreational fishes), aesthetic species (e.g., wading birds), and landscape-level aesthetics (e.g., vistas of natural systems).

Consequently, selection of ecosystem endpoints is driven by both scientific issues and societal values. Furthermore, ecosystem endpoints should relate directly back to one or more of the EECs. For example, if the EEC is the integrity of the biotic community, then the ecosystem endpoints associated with that EEC would include community species diversity; the population condition and dynamics of endangered, economic, or keystone species; the presence of exotic or noxious species; and so on.

Ecosystem measures, the lowest tier of the report card framework, consist of those specific attributes that need to be measured or monitored over time to characterize the state of ecosystem endpoints. Each endpoint must have one or more measures, and a particular measure might reflect on more than one ecosystem endpoint. For example, if the ecosystem endpoint is the integrity of a particular economically important fish species, its ecosystem measures might be catch per unit effort, age and size distribution of the population, rates and success of recruitment, or even frequency of physical abnormalities or measures of body burdens of toxic chemicals. Because ecosystem measures are those specific attributes to be monitored and are determined by scientists, the audience for this tier is primarily scientists.

Harwell et al. (1990) provided criteria for selecting ecosystem endpoints and associated measures (also termed ecological indicators and measurement endpoints). Table 2 and the box on page 551 list these criteria. As is the case for the endpoints themselves, the criteria for selecting measures are generic and should be adapted to each ecological system as a checklist of issues that need to be considered. For example, a US MAB workshop (Harwell and Long 1995) developed sets of ecosystem endpoints and measures for all of the ecological system types in South Florida following the above considerations. Table 3 illustrates the selected ecosystem endpoints for seagrass ecosystems of South Florida.

Ecosystem endpoints and measures are also necessary to characterize the stressors on the ecosystems (Figure 2). In fact, stressors can often be characterized more easily and rapidly than their effects because there may be a significant time lag between the stressor and the effect (e.g., greenhouse gas increases and climate change; exposure of birds to DDT and population effects through eggshell thinning). In addition, tracking stressor characteristics may provide insights into what management options might reduce the stressor and, eventually, achieve the ecological goal. As in the ecological risk assessment framework (Gentile et al. 1993), stressors and ecological effects need to be monitored and evaluated in parallel to understand anthropogenic risks to the environment; consequently, both stressor and effects endpoints and measures need to be incorporated into the report card. Each stressor endpoint will have one or more stressor measures to characterize stressor intensity, frequency, duration, and distribution.

By following this stress-effects duality at the endpoint and measures level, the report card framework reflects the reality of routine monitoring and assessment that is a component of environmental protection. The historical emphasis on regulation of end-of-pipe emissions (stressors) as the principal means of environmental improvement continues, although there is clearly a trend toward more ecosystem effects-based management because it provides the next best opportunity for environmental protection and sustainability (EPASAB 1998). However, even if there were a complete focus on effects-based environmental management, what humans usually can directly control are the stressors, not the responses of ecosystems; consequently, there would still need to be specific endpoints for evaluating how well the stressors are being controlled to achieve effects goals.

These considerations introduce a new component to the report card framework, namely, the ability to set, monitor, evaluate, and modify management actions based on "performance criteria." That is, through development and assessment of the ecosystem conceptual models, specific stressor levels that relate to the specific ecosystem endpoints can be determined. Those stressor levels are then translated into performance criteria for developing and implementing the environmental management system. The endpoints and measures define what ecological or stressor attribute is being considered, whereas the performance criteria tell what specific number or level of the endpoint or measure is desired. For example, if a healthy Everglades is desired, then scientific analyses should determine what water management system would result in the hydrological regime that would lead to a healthy Everglades, as characterized by the ecosystem endpoints. Stressor endpoints (e.g., hydroperiod, water flow patterns, and water quality) that are predicted to be commensurate with the specific ecosystem endpoints are then translated into the direct performance criteria for the restoration process (e.g., restoration of a particular wetland habitat within the Everglades requires the performance criterion of a mean annual hydroperiod of 300 days of inundation, with interannual variability of approximately 30 days). And just as the ecological effects endpoints have associated ecological effects measures, the stressor endpoints have associated stressor measures that are monitored to characterize the status and trends of the stressor.

Finally, stressor endpoints and measures can be separated into two categories: process endpoints and measures, and outcome endpoints and measures. Process endpoints relate to management activities, and outcomes endpoints relate to the consequences of management with respect to changing stressors or causing ecological effects. An example of the process stressor endpoint is the effectiveness of regulations to reduce pollution, and an associated process stressor measure is the number of pollution citations issued in an area over a certain period of time. An example of an outcome stressor endpoint is the amount of exposure of an important species to a pollutant, and an associated outcome stressor measure is tissue concentrations of mercury in edible fish.

Linkages of goals through measures--the example of South Florida. Some specific examples from South Florida show how the tiers would be connected, although it is important to note that a complete report card in accordance with the framework has not yet been developed. However, enough of the elements of the various tiers have been developed for South Florida to be discussed here for illustrative purposes.

For example, consider the first goal, to "restore the Everglades and associated ecosystems of South Florida to provide adequate supplies of clean, safe water for the natural, human, and economic systems" (see box page 548). This goal is obviously broad; therefore, it was subdivided into seven objectives to delineate this goal according to terms developed by the deliberative process of stakeholders and decision makers who sit on the Governor's Commission. Thus, these goals and objectives were developed in accordance with the framework's concept of the upper two tiers' reflecting societal values as appropriately informed by science.

One of the listed objectives for the first goal is to "provide the spatial extent of natural areas required to support the mosaic habitat characteristic of the pre-drained Everglades ecosystem." The next step in the framework is to translate that objective into the EECs (Table 1) that relate to it. This particular objective would relate directly to the EECs "Habitat Quality" and "Integrity of the Biotic Community" and indirectly to other EECs. The habitat quality EEC here is linked to several EEC subcategories, including "landscape mosaic," "spatial extent," "landscape diversity," and "landscape fragmentation." The integrity of the biotic community EEC includes subcategories of "biodiversity" and "community structure." (Other linkages may also apply indirectly, but for this example we focus only on the direct ones.)

Each of these EEC subcategories is next linked to the specific ecosystem endpoints selected for each ecosystem type. For example, for the seagrass ecological system (Table 3), the landscape mosaic EEC is associated with the specific seagrass ecological endpoint of the spatial distribution of seagrass communities across the landscape, as well as the stressor endpoints of storm frequency and sea-level rise.

Next, each ecological and stressor endpoint is associated with specific measures. Some candidate measures for the example of the landscape EEC for seagrass ecosystems would include the areal extent of different seagrass communities (e.g., measured as the percentage cover of different subclasses of seagrass systems), changes in the distribution patterns over time (e.g., measured as the rates of change in their areal extents), amount of seagrass habitat destroyed by dredging or altered salinity regimes (e.g., measured as hectares converted per year), and so on.

Finally, performance criteria would be set for each endpoint and each measure. In this example, the performance criteria might be a change of no more than 5% in the relative distributions of seagrass communities per decade, or no more than 100 hectares converted per year. Other examples of performance criteria include less than 10 ppb phosphorus released into surface waters, or attaining a manatee population in South Florida of 1000 healthy individuals.

The number of specific measures can become quite large because each goal may have several objectives and sub-objectives, each objective and sub-objective may relate to several ecosystem and stressor endpoints, and each endpoint may be related to several measures. The hierarchy of the framework not only guides the selection of more and more specific elements as one goes down the hierarchy but also focuses the aggregation process of going up the hierarchy so that there is a more tractable number of decision-making points. This hierarchical structure alleviates a serious concern that scientists often express about decision making (see Gentile 1996), which is that because decision makers need to make decisions and evaluate progress on a limited number of considerations, they may ignore much of the important scientific information necessary to characterize complex human-environment systems and, consequently, may not address the myriad issues that scientists recognize are critical to understanding the larger picture of environmental integrity and sustainability.

Developing a report card

A two-phase process is required to implement the proposed report card framework: The first phase is a top-down process in which societal goals and objectives (and sub-objectives) are established and the remaining tiers of the hierarchy are developed as derivatives from the top tiers. The second phase is a bottom-up process in which, once the complete set of elements of the report card is defined (i.e., the specific EECs, endpoints, and measures selected as discussed above), the ecological measurements are made and analyzed, and grades are assigned at each of the remaining tiers as an aggregation from those measures, as discussed below.

The top-down process. The development of the specific elements of the report card for a particular ecosystem must be driven by the goals and objectives for the environment, that is, at the top tiers, which are designed to reflect societal values. Thus, establishing goals and objectives requires a complete, deliberative process. An in-depth discussion of the nature of such a deliberative process has been provided by the National Research Council (1996), which called for a rich dialogue among stakeholders, decision makers, and scientists to address major environmental and other risk issues. Establishing ecosystem sustainability goals and objectives would seem to qualify as just such major issues.

Extensive societal participation is essential if the environmental goals are to be accepted as representing the fundamental values of society. Therefore, when developing goals and objectives, consideration must be given to such issues as existence values, intergenerational equity, distributional equity, aesthetics and quality of life, economic relationships, and diverse cultural and political perspectives. Ecosystem and societal sustainability goals require considering the need for a long time horizon; tradeoffs with other societal goals; historical perspectives, such as recognition of the mistakes of the past; and appropriate input of scientific knowledge as a critical component of informed societal decisions.

There are no simple or well-established mechanisms to identify and reach consensus on environmental goals and objectives. However, the Florida Governor's Commission for a Sustainable South Florida (Governor's Commission 1995, 1996, 1998) provides an example of an effective institutional mechanism that was developed specifically to represent the values and perspectives of a diversity of stakeholders in the process of defining regional and subregional goals for the environment. Another example of establishing goals at the national level is the EPA Environmental Goals Project (EPA 1996), which specified draft goals for the nation's environment and specific milestones for achievement by 2005.

Once the goals and objectives are established, the selection of the particular elements of the report card at the EEC, endpoint, and measures tiers is done primarily by scientists and environmental managers, with decreasing participation by stakeholders and the public at lower levels of the hierarchy (Figure 2). We have described the EECs as the scientific translation of the goals and objectives into specific characteristics of the ecological systems that can be related to the desired conditions. Because this tier is the key interface between science and society, the descriptions of the EECs must be understandable to an informed set of decision makers and stakeholders, and it is the responsibility of scientists to ensure this understandability. At the ecosystem endpoints tier, stakeholders and the public need to be questioned about environmental preferences to identify those ecosystem endpoints that are of most societal relevance. However, other ecosystem endpoints, stressor endpoints, and all ecological and stressor measures should be determined only by scientists using the criteria for endpoint and measure selection discussed above.

Establishing grading scales. At the goals and objectives levels, progress may be reported by a general narrative that articulates success (or lack of success) in achieving the goal. This narrative may be qualitative and should not necessarily try to apply a quantitative score to the goal or objective. The purpose of such a general description is to inform elected officials, decision makers, and the general public, in the broadest terms, of progress toward achieving the goals and objectives.

The narrative is used to describe general trends in the cumulative efforts to reach each goal. For example, if several key projects to acquire sensitive lands in an effort to restore and protect habitat have been initiated or completed, and if actions to address water-quality issues have been implemented in critical portions of the ecosystem, a general narrative would describe these actions. The description would be used to help target audiences gauge the level of progress made toward achieving the overall goal. This information would be useful in gaining public support for ecosystem restoration and sustaining the financial resources needed for long-term ecosystem management.

The description at the two highest tiers is substantiated by the more quantifiable grades given for the EECs, endpoints, and measures. At the EEC level, the types of grades that could be assigned are qualitative or perhaps quantitative representations of how the EEC relates to its reference conditions. The grades are intended to be relative indicators of the status or trends of the tier; consequently, a set of particular conditions needs to be developed that provides the basis for a relative scale or grading scheme.

The grading scheme also needs to include several types of conditions (Figure 3): reference conditions, desired conditions, and benchmark conditions. Reference conditions are the bounding conditions for the EECs, that is, some descriptor of the EECs at each end of the spectrum from high degree of disturbance to high degree of pristine ecological condition. Desired conditions are descriptions of the EECs should the desired goal ultimately be achieved, that is, the target system. In many cases, however, the extant ecological condition is far removed from the desired condition, and progress toward restoration would be indicated more clearly by establishing benchmark conditions--a set of intermediate conditions along the way to the complete restoration goals. It is important to note that nothing in this framework is meant to signify static conditions; rather, each benchmark or reference condition and the characterization of the actual ecosystem explicitly incorporates natural variability as well as processes such as succession or other directional changes over time and space.

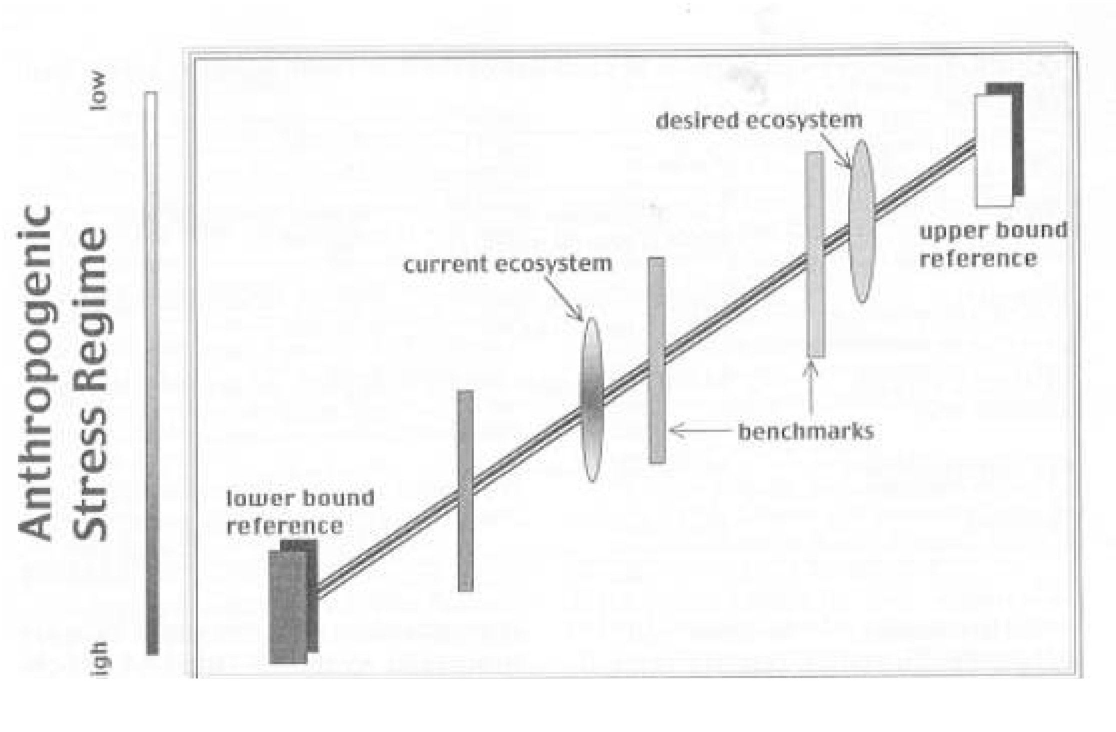
Once the desired ecological conditions are established, scientists should develop performance criteria for the stressor endpoints; these criteria will define what stressor levels are commensurate with the ecological outcome. In many cases, as with water-quality parameters such as salinity, the range of established values appropriate for the integrity of a specific habitat is known. For other parameters, baseline data will need to be generated or evaluated to establish these performance criteria. Once set, the performance criteria should not change significantly with time.

The bottom-up process. Once the complete set of elements of the report card for a particular ecosystem is established and delineated, then the data at the level of the measures should be collected. These data will periodically be "aggregated" into each successive tier of the report card to derive grades on performance. For example, the condition of a particular ecosystem endpoint at some point in time would be derived through combining and analyzing data collected at the measures level. Thus, unlike the establishment of the report card elements, which is a societally driven, top-down process, the actual assignment and interpretation of grades is a scientifically driven bottom-up process.

The report card framework is based on a hierarchy in which a large number of measurement values generated in the lower levels are then condensed into a progressively smaller number of parameters during the transition to higher levels. Values at each tier could be aggregated using algorithms that weight a factor's relative value in a given habitat. Alternatively, established equations could be used for translating measurements into an endpoint value. Performance criteria consisting of a quantitative, scientifically determined, ecologically relevant, habitat-specific range of target values should be developed for each measure, endpoint, and EEC, as discussed above.

The particular nature and form of the aggregating algorithms require research and development, but in general the aggregation algorithms should be designed to translate the measurements into attributes that can be compared against the performance criteria so that grades can be assigned. For example, to evaluate the status of a crocodile population (the ecosystem endpoint), a large number of measurements related to nest density, hatch success, male-to-female ratio of offspring, and total population number could be translated into a single value that describes this endpoint. Similarly, to calculate an EEC an algorithm must be developed to translate and aggregate the associated endpoints. Each endpoint value is normalized to a performance criterion, and these normalized values are weighed according to current scientific thought on each endpoint's relative contribution to and influence on the integrity of a given habitat. All possible ecosystem endpoints relevant to a given EEC should be included in the equation.

Thus, the aggregation of measures to endpoints and the aggregation of endpoints to EECs are based on expert scientific judgment in the development of appropriate performance criteria and translating algorithms. Once established, these equations remain the same, providing the quantitative basis for assigning grades. The aggregated endpoints and EECs are compared to the established benchmarks or desired conditions to determine a grade. The grade may be presented in a variety of formats depending in part on the audience, including letter grade (e.g., the familiar A through F scale), the use of multiple icons graphically illustrating the position of each EEC along the continuum, or more simplified graphics such as happy faces or success meters (see Table 4). However it is presented, the grade representation of the EEC portion of the report should include a graphic that shows current conditions, normal variability, recent trends, reference conditions, various benchmark conditions, and ultimate desired condition.



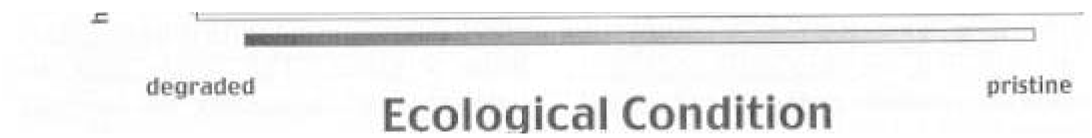


Figure 3. The relationship among the benchmark, reference, and desired conditions. The upper and lower bounds of condition for an ecological system are indicated. Bars show benchmark conditions along the continuum between the bounds. The various conditions are not static but represent the normal variability and ecological changes that occur.

Conclusions

Ecosystem managers and decision makers continually confront the question of how to determine the effectiveness of management decisions. This problem is exacerbated by the diversity of audiences for this information, each of which has a stake in the outcome but different perspectives on what is important. For example, the public and political leaders are interested in achieving broad goals relative to valued resources (e.g., endangered species, recreational fisheries), whereas resources managers must monitor the ecological characteristics of a region. Scientists and regulators seek to understand the causal links among sources, stressors, and ecosystem effects so that they will be able to recommend effective source control policies that will lead to ecosystem recovery and sustainability. What is needed is a mechanism to report on the magnitude and quality of change in ecosystems in response to management decisions and policies that is relevant to each of these audiences.

This need defines the primary challenge of an ecosystem integrity report card--how to accurately capture a scientific picture of the integrity of the ecosystem that illustrates a credible and transparent progression from quantitative scientific measurements to qualitative evaluations of success or failure in achieving societal goals for the environment. Under the auspices of the US MAB HDS, with support from the US Army Corps of Engineers and the National Oceanic and Atmospheric Administration Coastal Ocean Program Office, a generalizable framework for an ecosystem integrity report card has been developed, with examples from ecosystem management of the South Florida regional ecosystem.

The timeliness, relevance, and importance of a report card framework are articulated in the Federal Government Performance Results Act of 1993 (US Congress 1993). The Results Act explicitly calls for performance measures and a report card system to characterize the efficacy of decision making, including decisions about ecological health, evaluated in the context of goals, objectives, and sub-objectives. However, many decision makers, including a recent EPA administrator as well as resource managers for South Florida, have expressed their inability to understand and defend the efficacy of environmental decisions, to make the case that investments in the environment have paid off, and to allocate resources in a manner that results in the greatest improvement in environmental quality. The EPA Science Advisory Board has argued (EPASAB 1990a, 1990b, 1999) that the time has come to make the transition to an ecological effects-based management system, but such a management approach fundamentally requires an appropriate process for evaluating performance. We believe that the ecosystem integrity report card framework described here provides just such a method for evaluating the efficacy of management decisions. The next step is to exercise this framework in a case study setting, such as the South Florida restoration process, as it unfolds over the next few decades.

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Table 1. Generic essential ecosystem characteristics (EECs) and associated subcategories.(a)

Legend
A - Essential ecosystem characteristic
B - Associated subcategories

A	B
Habitat quality	Landscape mosaic; spatial extent; landscape and community diversity; landscape connectivity and fragmentation; habitat structural diversity
Integrity of the biotic community	Biodiversity; community composition; trophic structure; economically or aesthetically important species; exotic, invasive, or noxious species; threatened or endangered species
Ecological processes	Primary and secondary productivity; biogeochemical cycling; decomposition; energy flow; succession; spatial dynamics (dispersal, migration)
Water quality	Biological characteristics; physical characteristics; chemical characteristics
Hydrological system	Hydroperiod; surface and groundwater flow; water storage; water supply; channel complexity and other structural characteristics; sediment-materials transport
Disturbance regime (changes from frequency and natural variability)	Fire frequency and intensity drought frequency and intensity; storm frequency and intensity; event frequency and intensity; disease or pest outbreaks; anthropogenic

	disturbances; other outside factors (e.g., sea-level rise, climate change, loss of migratory species' habitat)
Sediment/soil quality	Biological characteristics; physical characteristics; chemical characteristics; sedimentation, soil erosion,and accumulation of soil and sediment

(a) Derived by the US MAB based in part on previous lists of ecosystem endpoints and EECs (Harwell et al. 1996; Levy et al. 1996; Young et al. 1998; John C. Ogden, South Florida Water Management District, Joan Browder, National Oceanic and Atmospheric Administration, and John H. Gentile, unpublished manuscript; Joan Browder and John C. Ogden, unpublished manuscript). These EECs and EEC subcategories are designed to be generic and may be applied to any ecological system.

Table 2. Generic considerations for selecting ecosystem measures based on their purposes. (a)

Legend
A - Purposes for ecosystem measures
B - Key characteristic
C - When to use

A	B	C
Intrinsic importance	Measure is the endpoint itself	Population levels of economic species
Early warning indicator	Rapid identification of potential effects	Use when endpoint is slow to respond or has delayed effect; minimal time lag in response to stressor, rapid response rate; low signal-to-noise ratio of the measure, low discrimination; screening tool; false positives acceptable
Sensitive indicator	Reliability in predicting	Use when endpoint is response relatively insensitive; high stressor specificity; high signal-to-noise; minimize false positives
Process or functional	Endpoint is a process	Monitoring chemical or indicator physical processes; complements structural measures

(a)Modified from Harwell et al. (1990).

Table 3. Example ecosystem endpoints for seagrass ecosystems.(a)

Endpoint type	Example
Species-level endpoints	Thalassia and Halidule productivity; epiphyte productivity; status of endangered, threatened, or economic species (e.g., turtles, snail kite, pinkshrimp, manatees); redfish; diving birds; wadingbirds; raptors; spiny lobsters; dolphins
Community/ecosystem-level endpoints	Salinity; seagrass die-off; water quality; water input (variability for quantity, timing, and frequency); carbonate dynamics; hydrodynamics and circulation dynamics; nutrient and particle flux; fish productivity and diversity; invertebrate productivity and diversity; detrital dynamics; plankton blooms
Landscape-level endpoints	Spatial mosaic (physical distribution across landscape); storm frequency; sea level rise

(a) Modified from Harwell and Long (1995). Specific ecosystem endpoints are listed for the seagrass ecosystem, derived from the generic lists of the boxes on pages 549 and 551 and Table 2.

Table 4. Audiences and purpose of each tier of the ecosystem integrity report card framework.

Legend
A - Tier
B - Audience
C - Use

A	B	C
Goals	Elected officials; decision makers; general public	Support; funding; social; economic
Objectives	Elected officials; decision makers; general public	Support; funding; social; economic

Essential ecosystem characteristics	Managers; decision makers	Applied management; education and research
Ecosystem endpoints	Managers; scientists	Research
Measures	Scientists	Hypothesis testing

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Inset Article

EXAMPLE GOALS AND OBJECTIVES FOR AN ECOSYSTEM INTEGRITY REPORT CARD

These goals and objectives were developed by the Governor's Commission for a Sustainable South Florida.(a)

Goal I: Restore key ecosystems--that is, restore the Everglades and associated ecosystems of South Florida to provide adequate supplies of clean, safe water for the natural, human, and economic systems:

• Objective 1: Restore more natural hydropatterns, including associated sheetflow.

• Objective 2: Provide more natural quality and quantity, timing, and distribution of freshwater flow.

• Objective 3: Provide the spatial extent of natural areas required to support the mosaic habitat characteristicof the pre-drained Everglades ecosystem.

• Objective 4: Regain lost water storage capacity.

• Objective 5: Restore and enhance regional groundwater storage.

• Objective 6: Restore and, where appropriate, improve functional quality of natural systems (including bothwetlands and uplands).

• Objective 7: Restore more natural organic and marl soil formation processes and arrest soil subsidence.

Goal II: Protect wildlife and natural areas--that is, provide sufficient open space to protect wildlife and provide natural and recreational areas for public use:

• Objective 1: Reduce the spatial extent of invasive non-native species enough that they do not affect thenatural system.

• Objective 2: Halt or reverse conditions causing the spread of native species that are threatening (andperhaps dominating) areas as a result of nutrient enrichment or other disturbances.

• Objective 3: Provide for sustainable populations of native plant and animal species, with special attentionto species that are threatened, endangered, or otherwise of special concern.

• Objective 4: Improve and protect habitat quality, heterogeneity, and biodiversity.

• Objective 5: Improve connectivity and reduce fragmentation of habitats.

Goal III: Achieve a clean, healthy environment and prevent and reverse pollution in South Florida's air, land, and water:

• Objective 1: Improve water quality, including reduction of toxins, and ensure appropriate water qualityconsistent with designated uses, including restoration and protection of the natural systems.

• Objective 2: Control saltwater intrusion into freshwater aquifers.

• Objective 3: Increase the use and effectiveness of pollution prevention measures.

• Objective 4: Improve regional air and water quality for wildlife, humans, and the surrounding environment.

(a) The goals are derived from the preface of Governor's Commission (1995). The objectives are derived from Governor's Commission (1995, 1996), modified slightly from the original text to provide a more concise representation here.

Inset Article

GENERIC CONSIDERATIONS FOR SELECTING ECOSYSTEM ENDPOINTS

Species-level endpoints

• Societal importance (economic, aesthetic, recreational, nuisance, endangered species)

• Ecological importance (interactions between species [e.g., predation, competition, or parasitism]; trophicrelationships; habitat role [e.g., physically dominant species such as mangrove tree species]; functionalrelationships; critical species [e.g., keystone species that affect overall trophic structure or controlimportant ecological processes])

Community-level endpoints

• Trophic structure

• Species diversity of communities

• Biotic diversity of communities

Ecosystem-level endpoints

• Ecologically important processes (e.g., decomposition, primary productivity)

• Economically important processes (e.g., air purification)

• Water quality

• Habitat quality

Landscape-level endpoints

• Mosaic of ecosystem types (e.g., relative coverage of plant communities)

• Corridors for migration (e.g., habitat for endangered species)

• Spatial and temporal patterns of habitat (e.g., timing and location of wetlands for bird nesting)

• Feedbacks to regional- and global-scale physical systems (e.g., albedo, evapotranspiration, sources ofbiogenic gases)

Human health concerns

• Vectors for human exposure to diseases or toxins (e.g., distribution of disease-bearing insects, drinkingwater quality)

• Species for deriving medicinal chemicals

Modified from Harwell et al. (1990). These considerations are designed to be generic and may therefore be used to select endpoints in any ecological system.

General factors to consider in selecting measures

• Signal-to-noise ratio (sensitivity to stressor versus natural variability)

• Rapid response (early exposure [e.g., low trophic level]; rapid dynamics[e.g., short life span])

• Reliability and specificity of response to stressor

• Ease and economy of monitoring

• Historical database availability

• Relevance to endpoint

Modified from Harwell et al. (1990).

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