Science and Environmental Decision Making in South Florida

Mark A. Harwell

Ecological Applications, Vol. 8, No. 3. (Aug., 1998), pp. 580-590.

Stable URL:
http://links.jstor.org/sici?sici=1051-0761%28199808%298%3A3%3C580%3ASAEDMI%3E2.0.CO%3B2-X

Ecological Applications is currently published by Ecological Society of America.

Your use of the JSTOR archive indicates your acceptance of JSTOR's Terms and Conditions of Use, available at http://www.jstor.org/about/terms.html. JSTOR's Terms and Conditions of Use provides, in part, that unless you have obtained prior permission, you may not download an entire issue of a journal or multiple copies of articles, and you may use content in the JSTOR archive only for your personal, non-commercial use.

Please contact the publisher regarding any further use of this work. Publisher contact information may be obtained at http://www.jstor.org/journals/esa.html.

Each copy of any part of a JSTOR transmission must contain the same copyright notice that appears on the screen or printed page of such transmission.

The JSTOR Archive is a trusted digital repository providing for long-term preservation and access to leading academic journals and scholarly literature from around the world. The Archive is supported by libraries, scholarly societies, publishers, and foundations. It is an initiative of JSTOR, a not-for-profit organization with a mission to help the scholarly community take advantage of advances in technology. For more information regarding JSTOR, please contact support@jstor.org.

http://www.jstor.org
Fri Nov 30 23:33:33 2007

Ecological Applications, 8(3), 1998, pp. 580–590

SCIENCE AND ENVIRONMENTAL DECISION MAKING IN SOUTH FLORIDA

MARK A. HARWELL

Center for Marine and Environmental Analyses, Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, Florida 33149 USA

Abstract. The ecosystems of South Florida are unique and highly valued by society. Explosive population growth this century has made the Everglades one of our nation's most endangered ecosystems. The dominant anthropogenic stressor is hydrological modifications instituted to provide flood protection for land selected for agriculture and urban development. Thus, major redesign of the hydrologic system is essential if the Everglades and associated coastal ecosystems of South Florida are to be restored and sustained. Following conceptual frameworks developed for ecological risk assessment, ecological sustainability, and ecosystem management, the U.S. Man and the Biosphere Human-Dominated Systems Directorate has conducted a project on ecosystem management in South Florida. An extremely complex hierarchy of federal, state, and local governmental activities presently underway is directed toward a sustainable South Florida. The scientific community is playing a significant role in this process, but the success or failure of ecosystem management for South Florida is still uncertain. If ecosystem management can result in a sustainable South Florida, this will be a prototype for environmental decision making through the next century.

Key words: adaptive management; comparative risks; ecological restoration; ecological risk assessment; ecological sustainability; ecosystem management; environmental decision making; environmental values; South Florida; U.S. Man and the Biosphere Program.

BACKGROUND AND CONCEPTUAL FRAMEWORKS

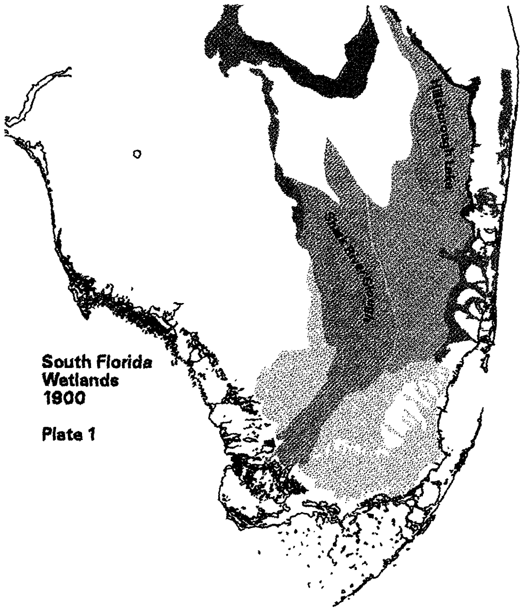
Human impacts on the South Florida environment

The ecosystems of South Florida are unique and highly valued by society. The natural regional landscape and seascape, from the Kissimmee River watershed, through Lake Okeechobee and the Everglades, to the estuaries of Florida Bay, Biscayne Bay, and the Ten Thousand Islands, and out to the largest coral reef system of the U.S., is connected by the movement of water (Plate 1) (Myers and Ewel 1990, Webb 1990, Davis and Ogden 1994*a*, *b*, *c*, Light and Dineen 1994). Because the carbonate bedrock and sediments tightly bind phosphates, nutrients are very low in the surface waters; yet these oligotrophic ecosystems are highly productive. This apparent paradox is because of the efficient recycling of nutrients and the great diversity of the trophic structures supported by primary production and detrital-based food webs.

Very small differences in elevation cause distinct ecosystem types; for example, the long-hydroperiod communities of the Everglades slough system differ from the hardwood hammock islands by only tens of centimeters in elevation (Davis and Ogden 1994*a*, Gunderson 1994; J. Browder and J. C. Ogden, *unpublished manuscript* and J. Obeysekera, J. Browder, L. Hornung, and M. A. Harwell, *unpublished manuscript*). The connectivity of the surface water and the minor topographic relief largely determine the landscape mosaic, forcing the interaction of hydroperiod, fire frequency, soil type and depth, and even susceptibility to infrequent freeze events (Robertson 1962, Davis and Ogden 1994*a*, Duever et al. 1994, Gunderson 1994; J. Browder and J. C. Ogden, *unpublished manuscript*). Other episodic events are formative for the landscape, especially hurricanes and tropical storms, and prolonged periods of drought or flooding (Craighead 1964, Davis and Ogden 1994*a*, Duever et al. 1994, Armentano et al. 1995).

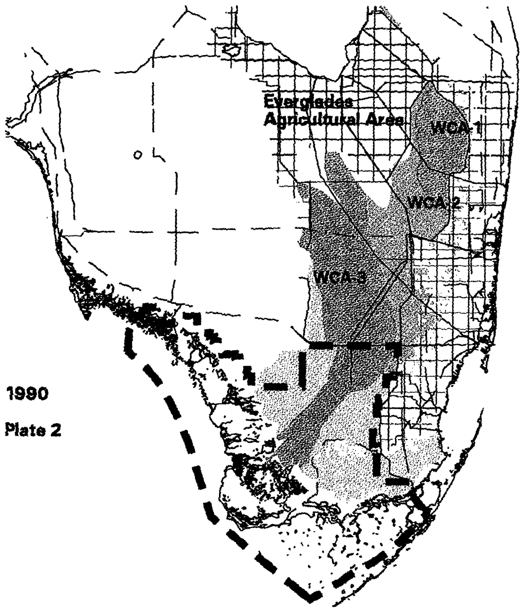
At the beginning of this century, South Florida's regional environment was essentially untouched wilderness considered unsuitable for human habitation (Davis 1943, Gannon 1996). The key characteristic of the historical Everglades and coastal ecosystems of South Florida was a large spatial scale of landscape connected by broad sheetflows of very low nutrient water (Douglas 1988). This vast expanse was a complex mosaic of diverse ecological communities that sustained populations of important species requiring large territory (J. Browder and J. C. Ogden, *unpublished manuscript*).

Manuscript received 6 February 1997; revised 7 July 1997; accepted 6 August 1997; final version received 24 October 1997. For reprints of this Invited Feature, see footnote 1, page 569.



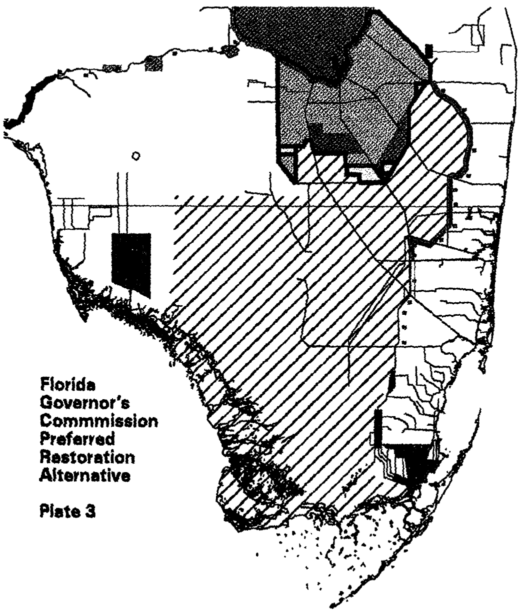
South Florida Wetlands 1900

Plate 1



1990

Plate 2



Florida Governor's Commmission Preferred Restoration Alternative

Plate 3

Restoration Plate 3

- ▨ **Stormwater Treatment Areas**
- ■ **Water Storage**
- ▨ **Soil Subsidence Control**
- ■ **Restoration**
- ■ **Water Preservation Areas**
- □ **Seepage Control**
- ▨ **Re-establishment of Natural Flows**
- ▣ **Aquifer Storage and Recovery**

Wetland/Development Plates 1, 2

- □ **Developed Area**
- ▨ **Southern Marl-Forming Marsh**
- ▨ **Sawgrass Dominated Mosaic**
- □ **Sawgrass Plains**
- ■ **Swamp Forests**
- ■ **Cypress Strand**
- ■ **Peripheral Wet Prairie**
- ▨ **Slough/Wet Prairie, Tree Island, Sawgrass Mosaic**
- ▬ ▬ **Everglades N.P.**
- ——— **Canals**
- — — **Roads**

PLATES 1–3. Plate 1: The natural ecological systems of South Florida. The map was produced by J. Gentile and C. Rivero (Center for Marine and Environmental Analyses, University of Miami) and is derived from the ecological classification system of J. Browder and J. C. Ogden (*unpublished manuscript*). Plate 2: The human-altered ecological systems of South Florida. The map was produced by J. Gentile and C. Rivero (Center for Marine and Environmental Analyses, University of Miami) and is derived from the ecological classification system of J. Browder and J. C. Ogden (*unpublished manuscript*). Plate 3: The USMAB schematic representation of the conceptual plan of the Florida Governor's Commission for a Sustainable South Florida, illustrating the hydrologic and ecological system modifications. The map was created by C. Rivero (Center for Marine and Environmental Analyses, University of Miami) based on Governor's Commission (1996).

TABLE 1. Environmental stressors affecting South Florida (modified from Harwell and Long 1992).

Natural	Anthropogenic
hurricanes	hydrological modifications
droughts	habitat modification
freezes	nutrient enrichment
fires	harvesting
sea level rise	recreation
	toxic chemicals
	global change

The interannual variability in precipitation was a critical driver to the long-term dynamics and sustainability of the historical wading bird populations and their fish and invertebrate food resources (Duever et al. 1994, Frederick and Spalding 1994, Ogden 1994; J. Browder and J. C. Ogden, *unpublished manuscript*).

However, South Florida is now a human-dominated ecosystem. There are now 4.5×10^6 people in the area, with a net rate of increase of almost 1×10^6 per decade (W. D. Solecki et al., *unpublished manuscript*). The necessity for converting land to urban and agricultural uses, and associated flood protection to reduce risks to the human populations, has led to major alterations in the landscape, especially driven by hydrological modifications (Blake 1980, Davis et al. 1994, Light and Dineen 1994; W. D. Solecki et al., *unpublished manuscript*). In fact, the Central and Southern Florida Flood Control Project (C & SF), built by the U.S. Army Corps of Engineers (USACOE), is one of the largest water management systems in the world (USACOE 1960, Light and Dineen 1994). Developed to support society, its inadvertent consequence has been the substantial degradation of the ecology of the historical Everglades. A comparison of the historical ecosystem with the present (Plate 2) demonstrates the loss of more than half of the original spatial extent of the system, including the essential elimination of whole classes of ecosystems. Table 1 lists all stressors, both natural and anthropogenic, that affect South Florida. By far the dominant cause of ecological degradation is hydrologic modification (Davis et al. 1994, Harwell et al. 1996).

The connectivity of natural episodic events and major changes in societal policies can be seen throughout the history of South Florida over the last century (W. D. Solecki et al., *unpublished manuscript*). A sequence of naturally triggered events directly led to responses by society to modify and attempt to control the regional environment, especially the hydrologic regime. The seminal event was the deep freeze of 1895 in north and central Florida, which led Julia Tuttle to send Henry Flagler an unblemished orange blossom from South Florida (Chapman 1991, Gannon 1996). The following year, Flagler's railroad system was extended to South Florida, and Miami was established, planting the seed for the boom in population growth. In 1926 and 1928, a series of hurricanes caused Lake Okeechobee to overflow its southern bank, a natural process that replenished the waters of the Everglades (Hanna and Hanna 1948, Light and Dineen 1994, Gannon 1996). But the large loss of human life led to construction of the Hoover Dike and levees, substantially isolating the Lake from the rest of the hydrologic system (Light and Dineen 1994).

The droughts of the 1930s led to construction of canals for water supply security. However, the most important triggering event occurred when two hurricanes in the same month in 1947 and another in 1948 left most of South Florida underwater for more than half a year (Light and Dineen 1994, Gannon 1996). That event led to the authorization by Congress of the C & SF system, which was constructed throughout the 1950s and into the 1960s (Light and Dineen 1994). In the 1970s, a period of droughts led to development of new water delivery schedules, assuring supply to human systems and further reducing natural variability of the ecological system (Light and Dineen 1994); and freezes forced the citrus industry to move south into the region (W. D. Solecki et al., *unpublished manuscript*). The 1980s saw major ecological problems, including the crash of many bird populations (Frederick and Spalding 1994), nutrient enrichment-induced community shifts in sawgrass communities just south of the Everglades Agricultural Area (EAA) (Snyder and Davidson 1994), and loss of more than a third of the seagrass community in Florida Bay, apparently associated with altered salinity and perhaps nutrient regimes (Robblee et al. 1991, Boesch et al. 1993, McIvor et al. 1994).

The other major triggering event, though not naturally induced, was the crisis in U.S.–Cuba relations in the late 1950s and early 1960s, which led to a ban on imports of sugar produced in Cuba and the consequent order-of-magnitude expansion of the sugar industry in the EAA (Bottcher and Izuno 1994; W. D. Solecki et al., *unpublished manuscript*).

Without major redesign of the water management system, the continued existence of the Everglades and associated coastal ecosystems of South Florida is greatly in jeopardy. This article discusses how the environmental management regime has brought us to this point of non-sustainability, and proposes that an ecosystem management approach is essential to its restoration and survival. The experience underway in South Florida is a prototype of the new generation of environmental management that must be implemented in many areas of the nation if the quality of our environment is to be protected and sustained into the next century.

Background on environmental management

The environmental regulations and decision making in the U.S. are characterized by the following (Harwell 1989): (1) Regulation focuses on control of sources of pollution entering the environment; the end-of-the-pipe approach in part developed because it provided a relatively straightforward benchmark for action, focusing on the best available or practicable technology, rather than on what results would be achieved ecologically. The assumption was that doing the best possible technically would eventually result in the greatest improvement of the environment. (2) Regulations and even specific criteria are legislatively mandated by Congress, differentiated by media (water, air, land), with little attempt for integration. (3) The rule is adversarial decision making, with the judicial system playing at least as important a role as the executive and legislative branches, and with procedural processes often taking precedence over substantive considerations. Consequently, environmental decision making by the U.S. Environmental Protection Agency (USEPA) and state regulatory agencies is dominated by the timing of litigation and court decrees. The agenda detailing which decisions have to be made when is forced in response to congressional and interest group pressures, rather than what might be in the best interests of reducing ecological risks.

To a great degree, this strategy has worked. The environment of the U.S. and western Europe has greatly improved over the past generation. Particularly noteworthy are improvements in water quality of surface waters, replacement of long-lived, biomagnifying pesticides by short-lived non-concentrating toxics, and greatly reduced air pollution over most cities and entire regions. It is becoming less and less clear, however, how successful the continuation of following only this strategy will be in further improving the environment. Nowhere is this more evident than in South Florida. The development of new conceptual frameworks of ecological risk assessment and ecosystem management for sustainability offers the potential to become the next paradigm for environmental decision making.

Conceptual frameworks

In 1983 USEPA Administrator William Ruckleshaus directed the agency to make decisions on a risk assessment basis. Risk assessment is a process that identifies, organizes, analyzes, and interprets information about a problem in a way that facilitates the decision-making process regarding environmental risks (Gentile et al. 1993). The primary risk assessment approach of the time was outlined in the National Research Council's "Red Book" (NRC 1983), which proposed the methodology to use for assessing risks of human cancers from chemicals, combining *hazard* (inherent ability to cause harm) and *exposure* (quantity experienced by humans) into a probabilistic assessment of health risk.

In 1986 the USEPA conducted a cross-agency examination of the relative risks from environmental problems affecting humans or ecological systems. The ecological component of this comparative risk assessment (known as the Unfinished Business project) developed a matrix approach to capturing expert judgment on relative ecological risks (USEPA 1987*a*, *b*). In 1989, Administrator Reilly asked the USEPA's Science Advisory Board (SAB) to review and expand upon the Unfinished Business report. The resulting Reducing Risk Project was a milestone in the federal government's understanding of relative risks to the environment (USEPA 1990*a*, *b*, Harwell et al. 1992). Currently, the SAB has underway another risk assessment activity, known as the Integrated Risk Project (IRP), which is expected to make significant advances in our ability to assess relative environmental risks in the U.S. IRP will likely confirm one of the major conclusions of the Reducing Risk project: that the greatest anthropogenic risks to the environment are associated not with chemical pollution or point-sources of effluents, but with habitat alterations of the landscape (USEPA 1990*b*, Harwell et al. 1992). (Examples of habitat alteration in South Florida are conversion [e.g., converting wetlands to shopping centers and pinelands to housing developments], fragmentation [e.g., dissecting the landscape by highways and canals], and other physical changes [e.g., hydrologic modifications] that reduce the ability of species and whole communities to survive and be sustained.) There is a remarkable disconnection between the ecological risks that are ranked highest by scientists and the perception of risks by the general public (Harwell et al. 1992). This parallels the disconnection between the current environmental management process, which remains dominated by concern for single-chemical stressors, and the actual full range of risks to the environment deriving from human activities.

One offshoot of the USEPA comparative risk projects was recognition of the need for a framework for ecological risk assessments, modifying the NRC Red Book's methodology in order to accommodate the nature of ecological risks. Particularly important are the multiplicity of ecological stressors (not just chemical, but also physical and biological), the multiplicity of endpoints (not just human cancers, but ecological effects at population to landscape levels), and the pervasiveness of uncertainty (not just in extrapolating from laboratory data, but in dealing with greatly different ecological systems and often large natural variability) (Gentile et al. 1993). Of course, environmental decisions must be made in the presence of uncertainties, because there will always be environmental uncertainties, yet society cannot wait to make decisions until these are fully resolved (Harwell and Harwell 1989).

There are three central aspects to understanding the roles and interactions of a stress in ecological risk assessments: (1) the characterization of the stress regime experienced by various component of the ecosystems; (2) the characterization of how ecosystems respond to

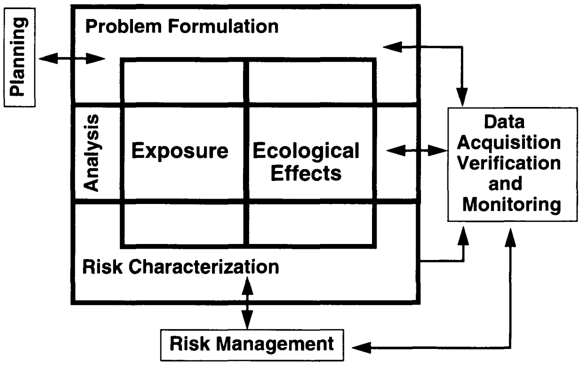


FIG. 1. The ecological risk assessment framework. From Harwell and Gentile (1992), USEPA (1992), and Gentile et al. (1993).

stresses; and (3) the characterization of how ecosystems recover from or adapt to stress (Kelly and Harwell 1990). This recognition of the complexity of risks to the environment led to development by the USEPA of a new ecological risk assessment paradigm (Fig. 1; Fava et al. 1992, Harwell and Gentile 1992, USEPA 1992, Gentile et al. 1993). The elements of this paradigm are stress characterization and ecological responses characterization, systematically evaluated through the steps of *problem formulation, analysis,* and *risk characterization. Problem formulation* is used to identify ecosystem components of interest, select ecological endpoints, and develop a *conceptual model* that explicitly describes stress–response relationships, linking human activities (drivers) with environmental stressors (physical, chemical, or biological changes) that cause ecological responses manifested as changes in ecological endpoints. Evaluating ecological health requires a diversity of ecological endpoints crossing organizational scales (species, population, community, ecosystem, and landscape/seascape) (Harwell et al. 1990, Gentile et al. 1993). The *analysis phase* is for development and testing of models, experiments, and data analyses to evaluate these relationships. *Risk characterization* is the integration of these two components into an overall assessment of risk provided to the decision maker to weigh along with other issues in the risk management process.

The USEPA relative risk analyses point to the necessity for a new approach to environmental decision making that requires ecosystem management of regional landscapes. Ecosystem management is a concept that originated in the conservation science of Aldo Leopold (1949) and in the emergence of ecology as a science (Shelford 1933, Tansley 1935, Wright and Thompson 1935), emphasizing the need to protect ecosystems while accommodating fluctuations in ecological processes. Agee and Johnson (1988) presented a theoretical framework of ecosystem management, consisting of a dynamic view of the environment, incorporating pattern and process, and requiring defined ecological boundaries, clearly stated management goals, interagency cooperation, monitoring of environmental results, and adaptive management. Ecosystem management provides a framework for harmonizing the mutually dependent sustainability needs of society and the environment and for applying scientific principles to the management of natural systems while considering the costs and benefits of long-term ecosystem restoration to society (Slocombe 1993, GAO 1994, Grumbine 1994, Christensen et al. 1996). The set of generic principles for ecosystem management developed by the USMAB project, expanding on the work of the White House Task Force on Ecosystem Management (IEMTF 1995*a*, *b*), is discussed below (USMAB 1994). These principles are listed in Table 2.

TABLE 2. Generic principles for ecosystem management (from USMAB [1994] and A. M. Bartuska et al. [*unpublished manuscript*]).

Use an ecological approach that would recover and maintain the biological diversity, ecological functions, and defining characteristics of natural ecosystems.
Recognize that humans are part of ecosystems and that they shape and are shaped by the natural system.
Adopt a management approach that recognizes ecosystems and institutions as being characteristically heterogeneous in time and space.
Integrate sustained economic and community activity into the management of ecosystems.
Provide for ecosystem governance at appropriate ecological and institutional scales.
Use adaptive management as the mechanism for achieving both desired outcomes and critical new understandings regarding ecosystem conditions.
Integrate the best science available into the decision-making process, while continuing scientific research to reduce uncertainties.
Develop a shared vision of desired ecosystem conditions.
Implement ecosystem management principles through coordinated government and non-government plans and activities.

The ecosystem management approach is a major divergence from the management strategy used in South Florida for the last 40 yr, when the focus has been to satisfy human-centered needs for development, water, and agriculture with little or no recognition of the system as a whole.

ECOSYSTEM MANAGEMENT PRINCIPLES APPLIED TO SOUTH FLORIDA

Overview of USMAB ecosystem management case study

The Man and the Biosphere Program (MAB) was established in 1970 as an international institution to foster understanding of human interactions with the environment. The USMAB Program is sponsored by more than a dozen federal agencies and conducts interdisciplinary research through five research directorates. The strength and uniqueness of the USMAB scientific research program derive from its membership: each directorate consists of an equal mixture of natural and social scientists, equally drawn from academic and governmental institutions. Participants contribute their expertise and experience but do not officially represent their affiliated institutions or agencies. Consequently, USMAB is an independent forum that combines the best elements of interdisciplinarity, academic freedom, scientific objectivity, and real-world experience.

In 1991, the USMAB Human-Dominated Systems Directorate (HDS) established a core project on ecosystem management for ecological sustainability, seeking to define what that means ecologically and societally and to evaluate patterns of human uses of the environment, establish ecological sustainability goals, examine societal factors affecting sustainability, assess potential policies and institutions to attain ecological sustainability, and apply this methodology through a case study on South Florida (Harwell et al. 1996, Harwell 1997). The project has involved >150 scientists examining ecological endpoints and sustainability goals for the region; assessing water resources and storage needs; establishing generic principles for ecosystem management; and developing scenarios to assess the potential for ecological and societal sustainability.

The foundation of ecosystem management is defining ecological sustainability goals, i.e., explicitly deciding what parts of a regional ecosystem are to be protected and maintained at high levels of ecological condition, and what parts are to be sacrificed ecologically in order to support the human population and/or to support the attainment of ecological goals for the core or protected areas. At one extreme the Everglades could be managed as a totally artificial environment; e.g., maintaining enclosures of selected species to be viewed by tourists. At the other end of the spectrum would be an Everglades returned completely to its predisturbed condition, with natural flows of water throughout the original watershed. Neither of these alternatives is realistic or acceptable to society. However, between these extremes are many different potential ecosystems distributed along a continuum of naturalness vs. artificiality, each in theory sustainable by the appropriate management system. What types of sustainable ecological systems are possible is a scientific issue, determined by the nature of the ecosystem itself, but what particular ecological system is selected is a societal decision, made either explicitly or de facto. Ideally, appropriate societal policies and institutions could be developed both to direct the changes in ecosystems necessary to achieve sustainability goals and to maintain the appropriate societal controls required for long-term ecological sustainability.

Identification of restoration objectives for South Florida

Based on this framework, the USMAB HDS project identified: (1) the regional boundaries and ecosystems of concern for South Florida; (2) ecological endpoints for characterizing the health of those ecosystems; (3) tentative ecological sustainability goals, that is, specific ecological conditions whose attainment and sustainability are desired; (4) the anthropogenic and natural stresses impinging on the systems; and (5) the legal, policy, economic, and institutional framework of South Florida (Harwell and Long 1992, Long and Harwell 1992). Note that in defining the regional boundary of concern, even though the watershed extends from the headwaters of the Kissimmee River, our primary concern is with the region from Lake Okeechobee south, recognizing that a massive restoration of the Kissimmee River system is already underway (see Cummins and Dahm 1995 and associated articles in that special issue of *Restoration Ecology*). We also recognize that the groundwatershed, airshed, and "sociopoliticalshed" all differ, but the dominant influence of surface water on structuring the ecological and societal systems led us to select the surface watershed to define the system boundaries.

Other activities initiated in the USMAB HDS core project were to:

1) develop a centralized geographical information systems (GIS) database for the South Florida region, including natural and societal information on current and historical distributions of vegetation, soils, climate, demographics, economic characteristics, and many other types of data (documented in Solecki et al. 1995);

2) develop an extensive bibliography (Borden and Landers 1996) concerning the South Florida regional environmental and societal systems;

3) initiate mechanism-oriented research on human/environment interactions, including:

  a) analysis of economic processes relevant to South Florida;

  b) analysis of the current and historical legal and institutional framework for South Florida (Ankerson and Hamann 1996);

  c) current and historical examination of the natural and human-altered hydrological system of South Florida (J. Obeysekera, J. Browder, L. Hornung, and M. A. Harwell, *unpublished manuscript*);

  d) analysis of international trade, economic, soils degradation, and other factors affecting the sustainability of the sugar industry in the Everglades Agricultural Area (EAA);

  e) examination of alternative agricultural possibilities for the EAA (C. Harwell et al., *unpublished manuscript*); and

  f) study of the broader constitutional issue of "takings" of privately owned property by governmental actions as related to regional environmental management (Tisher 1994).

The USMAB project convened an intensive, interdisciplinary workshop (known as a *charette*) on Isle au Haut, Maine, USA, in June 1994 to provide an intense interaction setting for ~50 social and natural scientists, supplemented by South Florida environmental decision makers, to facilitate the integration of the various components of the methodology. Working groups were established to:

1) complete development of the frameworks for ecological sustainability and for ecological–societal interactions (M. Harwell, J. Gentile, V. Myers, and A. Bartuska, *unpublished manuscript*; W. D. Solecki et al., *unpublished manuscript*);

2) develop the ecological sustainability goals for the region (M. Harwell et al., *unpublished manuscript*);

3) reach consensus on the characteristic qualities of the historical Everglades as a benchmark for assessing sustainability goals (J. Browder and J. C. Ogden, *unpublished manuscript*; J. C. Ogden et al., *unpublished manuscript*);

4) refine and finalize a set of generic ecosystem management principles (Table 2) (USMAB 1994; M. Harwell, J. Gentile, V. Myers, and A. Bartuska, *unpublished manuscript*);

5) develop an improved understanding of the hydrologic system, historically and under the present alterations (J. Obeysekera, J. Browder, L. Hornung, and M. A. Harwell, *unpublished manuscript*);

6) develop a suite of plausible regional scenarios of alternate management regimes for the hydrologic system (J. Obeysekera, J. C. Ogden, R. Fennema, and J. Wang, *unpublished manuscript*);

7) evaluate the consequences of the scenarios to the ecological systems (J. C. Ogden et al., *unpublished manuscript*);

8) evaluate the consequences of the scenarios to societal systems (C. Harwell et al., *unpublished manuscript*); and

9) explore issues of governance and institutional development consistent with ecosystem management for South Florida (M. Harwell et al., *unpublished manuscript*).

The USMAB project used the scenario–consequence analysis approach to explore the ecological and societal implications of hypothetical regional management regimes. One scenario suggested the possibility of mutually dependent sustainability of the EAA agricultural system and the ecological system (Harwell et al. 1996; M. Harwell et al., *unpublished manuscript*). Under this scenario, a sizable portion of the EAA would be converted to water storage. Agricultural practices would be instituted to grow sugar, rice, and other crops capable of production under high water table conditions, thereby preventing the rapid loss of soil occurring in the EAA (Stephens and Johnson 1951, Bottcher and Izuno 1994, Snyder 1994, Snyder and Davidson 1994). The water management system would be opened up to re-establish large spatial expanses of more natural hydroperiods. The natural and human systems would be separated by a buffer zone that would add valuable ecological habitat, reduce groundwater seepage, and prevent westward migration of urban development.

The USMAB scenario was the first recognition that a regional-scale solution was possible for meeting ecological, agricultural, and urban water needs. The scenario was presented to various institutions participating in the decision-making process, discussed below.

Decision-making/restoration process

When USMAB began its South Florida project in 1991, the magnitude of ecological degradation was just being recognized, and the scientific community addressing the environmental problems of the region had limited resources allocated among very few scientists. The political environment was highly contentious, with the federal government suing the state government for not implementing water quality regulations. The lawsuit focused on nutrient-enrichment effects of the upper wetlands ecosystem, but did not address the larger hydrologic modifications problem. That was in part because there were laws and regulations controlling releases of nutrients but not controlling hydroperiod, and in part because of a lack of understanding of the relative importance of nutrient enrichment compared with the more ecologically consequential hydrologic modifications. At best the litigation process led to a lack of cooperation among scientists and institutions, and at worst it resulted in hostility, exclusion, and the absence of competitive awarding of research grants. However, soon after Governor Lawton Chiles was inaugurated in 1991, he admitted fault on the part of the State of Florida and began a process to reach a settlement agreement. That settlement agreement was codified into the Everglades Forever Act (Florida Statutes 1995). A major component was the requirement for stormwater treatment areas (STAs) to be developed on the southern part of the EAA to act as wetlands for removal of phosphorus from surface waters before release into the Water Conservation Areas (WCAs) and other parts of the upper Everglades system. A portion of the costs of the STAs is to be borne by the sugar industry.

The Everglades Forever Act, however, did not resolve the fundamental problem of hydroperiod, leaving this issue for later negotiations. Consequently, the USMAB project concluded that under the Everglades Forever Act, the Everglades would in fact not be "forever" at all (Harwell et al. 1996; M. Harwell et al., *unpublished manuscript*). Further, USMAB concluded that the lack of sufficient water entering the remnants of the natural Everglades does not simply result from competition of water among the urban, agricultural, and ecological interests. While all three uses require about equal amounts of water on an average annual basis, more than an order-of-magnitude more water is just sent "out to tide" through the canals that drain the system for flood protection. Thus, it is clear that the issue is not water availability into the region—more than enough precipitation occurs in most years (J. Obeysekera, J. Browder, L. Hornung, and M. A. Harwell, *unpublished manuscript*). Rather, the critical issue is the storage and release of low-nutrient water at the right times, in the right amounts, and at the right locations into the natural system.

Providing for appropriate water storage and delivery is the driving force for the process of ecosystem restoration that began in the early 1990s. At the direction of Congress, the Corps of Engineers instituted a study to develop a comprehensive plan for restructuring and managing the Central and South Florida Project, resulting in publication of a reconnaissance report (USACOE 1994) and in the current "Restudy". Under the Water Resources Development Act of 1996 (U.S. Congress 1996), COE has until 1999 to submit the comprehensive plan to Congress, much as the 1947 comprehensive plan developed after the hurricanes led to the initial C and SF authorization (Light and Dineen 1994). But the decision-making process developed during the 1990s is much more complex than the USACOE Restudy. The Clinton White House established an interagency task force on ecosystem restoration of South Florida, and a complex, hierarchical institutional structure has evolved which includes a task force of leaders of all the federal agencies with interests in South Florida, plus state agencies and Native American Tribes. Under the task force are working groups of regional managers of federal, state, and local institutions, and various science and policy subgroups. One mission of the science subgroup has been to coordinate scientific research planning in order to avoid redundancies across agencies and facilitate close cooperation of scientists, sharing of data, and identification of priority research needs (Science Subgroup 1993). The highly contentious and territorial scientific community of 1990 has been largely replaced by one of the most collaborative federal/state/local research activities in the nation.

Another key institution is the Governor's Commission for a Sustainable South Florida, appointed by Governor Chiles in 1994 to provide recommendations of a suite of actions the state should do to ensure sustainability of the human and ecological systems of South Florida. The Commission consists of ~40 representatives from political units, industry and environmental groups, and other stakeholders of the region. As such, the Commission constitutes an effective mechanism to meet the deliberative input into environmental decision making recommended by the NRC Panel on Risk Characterization (1996). The Commission has submitted an extensive list of recommendations to the Governor (Governor's Commission 1995). USMAB presented the concepts of ecosystem management to the various federal and state decision-making institutions working on South Florida restoration, and outlined the potential scenario for sustainability. Ecosystem management has now emerged as the central organizing concept for the restoration process. The USMAB project continues, now supported by research funding from the USACOE Waterways Experiment Station and the NOAA Coastal Ocean Program, with its final focus on helping develop a strategic mechanism by which science can more effectively be brought to bear on the environmental decision-making process (Gentile 1996; M. Harwell et al., *unpublished manuscript*). This includes development of conceptual models of the human–environment systems of the region, selection of the parsimonious set of ecological and societal endpoints for characterization of the condition of the systems vis á vis the established goals, and creation of a "report card" process by which progress towards sustainability goals can be assessed by scientists and communicated to decision makers.

Following publication of its set of general recommendations (Governor's Commission 1995), the Governor's Commission undertook the task of developing consensus goals for the South Florida region as well as for each specific subregion. The purpose of this activity was to provide guidance to the USACOE Restudy process, in particular to represent the values and goals of society for sustainability of South Florida. The Commission worked closely with governmental and academic scientists, so that the environmental goals and subregional conceptual themes are consistent with ecological and hydrologic constraints. The resulting goals and the preferred specific modifications to the water management system suggested by the Commission to reach those goals have been captured in a schematic map of South Florida (Plate 3) (Governor's Commission 1996). Specific recommendations include: opening a larger contiguous area for surface water sheetflow; creation of water storage areas in various locations, including along the southern part of the EAA, to hold and release large quantities of water; simulating more natural hydroperiods; creation of water preservation areas and other buffer functions along the boundary between the natural system and the human system; and other actions to increase water deliveries to the southern part of the system, especially Florida Bay. Thus, the Governor's Commission conceptual plan closely follows the primary scenario for ecological sustainability developed by USMAB, but provides more specific guidance and, most importantly, reflects the societal choices that have to be made to implement ecosystem management (Governor's Commission 1996).

PROSPECTS FOR THE FUTURE

There is a growing recognition that the scientific and decision-making process underway in South Florida is unique. The sheer complexity of all of the elements is remarkable, and many individuals playing key roles in the process essentially are occupied full-time with meetings and coordination activities. It is unclear, however, if the ecosystem restoration process will be successful or not. There exist major forces working against consensus building and decision making, illustrated by the 1996 statewide initiative for imposing a one-cent fee on each pound of raw sugar produced in the EAA to help pay the costs of restoration. The sugar industry spent tens of millions of dollars in an anti-sugar fee ad campaign, and both pro- and anti-fee ads were notable for their wide divergence from the facts. The majority of the public was convinced by the sugar ads, and the initiative failed. However, a "polluter-pays" initiative on the same ballot passed, and lawsuits are being prepared to force more funds from the sugar industry than the Everglades Forever Act requires.

Another major stumbling block to restoration is the tension between land use regulations, especially if driven by the federal government, and private property ownership. South Florida is only one example of a national conflict over these issues, the resolution of which remains in doubt at present. A final reason for pessimism is the tendency of people to seek simple answers to complex problems. Achieving ecological sustainability for South Florida will take a multi-decadal commitment and very complex modifications to the physical and management systems of the region.

But there is also reason for optimism. The values society associates with the natural ecosystems of South Florida are extremely high, and there is a fundamental intergenerational aspect to these values, in which people not only want a healthy Everglades and coral reef system now, they also want it for their grandchildren. The attention of the scientific community has become so focused that answers to many questions are beginning to appear, including a better appreciation of what we don't know, where the sensitivities are, and what is needed to provide those answers. Development of conceptual models linking societal drivers with environmental stressors, and linking those stressors to changes in ecological endpoints that characterize environmental goals, is just now beginning, but should provide a clear road map to what has to be done and how to do it. And essential scientific tools are available now for the first time, including geographical information systems, remote sensing, fast computers capable of handling massive databases, and new methodologies for developing complex, nested models of the landscape and the seascape. Thus, we soon will have reliable tools that can be used to answer the "what if" questions of decision makers. This will allow direct comparison of the ecological consequences of management decisions. The newly developed frameworks of ecological risk assessment, ecological sustainability, and ecosystem management now provide the structured construct upon which this decision-making/scientific interface can occur effectively. But institutionalization of the process, so that positive decisions made today will be maintained through the decadal time period required for ecosystem restoration, has yet to be assured (M. Harwell et al. *unpublished manuscript*).

Finally, there is a fundamental realization that if the ecological restoration and sustainability process underway at present does not succeed, the essence of the historical Everglades and coastal ecosystems of South Florida will be irreversibly lost. If the process fails now, it may never succeed. And because of the direct and fundamental dependence of the economic base of South Florida on the health of its environment, if successful implementation of regional environmental management cannot happen here, it is unclear where it could happen. What happens in South Florida in the next few years will be an important indicator of the future of the environment in this nation for the next century.

ACKNOWLEDGMENTS

This article is contribution number USMAB HDS 011 of the U.S. Man and the Biosphere (USMAB) Human-Dominated Systems Directorate (HDS) Series. The USMAB HDS has implemented a core research project on ecosystem management for ecological sustainability, using case studies on selected Biosphere Reserves. USMAB is administered by the U.S. Department of State as a multi-agency, collaborative, interdisciplinary research activity to advance the scientific understanding of human/environment interactions. The contents of this article reflect the opinions of the author and do not necessarily represent the policies of USMAB, the U.S. Department of State, or any member agency of USMAB. Funding for this case study has been provided by Grant #1753-400108 to the University of Miami from the U.S. Department of State, and supplemented by support from the U.S. Army Corps of Engineers Waterways Experiment Station under Contract #DACW 39-94-K-0032 to the University of Miami for research on ecosystem management and ecological risk assessments and from the NOAA Coastal Ocean Program under Grant #NA67RJO149 to the University of Miami for research on the cumulative effects of stressors on the South Florida coastal ecosystem.

The contributions made by the scientists and support staff of the Center for Marine and Environmental Analyses of the University of Miami, and by the more than 150 natural and social scientists who have participated in the USMAB charette and workshops, have been a major positive factor in advancing the role of science in the decision-making process of South Florida. I especially thank Victoria Myers and Christine Harwell for comments and suggestions on the manuscript, and for continually pressing for relevancy of the science to the decision making.

LITERATURE CITED

Agee, J. K., and D. R. Johnson. 1988. Ecosystem management for parks and wilderness. University of Washington Press, Seattle, Washington, USA.

Ankerson, T. T., and R. Hamann. 1996. Ecosystem management and the Everglades: a legal and institutional analysis. Journal of Land Use and Environmental Law **11**(2):474–536.

Armentano, T. V., R. F. Doren, W. J. Platt, and T. Mullins. 1995. Effects of Hurricane Andrew on coastal and interior forests of southern Florida: overview and synthesis. Journal of Coastal Research **21**:111–144.

Blake, N. B. 1980. Land into water—water into land: a history of water management in Florida. University of Florida Press, Gainesville, Florida, USA.

Boesch, D. F., N. E. Armstrong, C. F. D'Elia, N. G. Maynard, H. W. Paerl, and S. L. Williams. 1993. Deterioration of the Florida Bay ecosystem: an evaluation of the scientific evidence. National Fish and Wildlife Foundation, National Park Service, and South Florida Water Management District. U.S. Department of the Interior, Washington, D.C., USA.

Borden, J., and A. Landers. 1996. An annotated bibliography on ecosystem management and South Florida. US MAB Secretariat, OES/EGC/MAB, SA-44C, U.S. Department of State, Washington, D.C., USA.

Bottcher, A. B., and F. T. Izuno, editors. 1994. Everglades agricultural area: water, soil, crop and environmental management. University of Florida Press, Gainesville, Florida, USA.

Chapman, A. E. 1991. History of South Florida. Pages 31–42 *in* Thomas D. Boswell, editor. South Florida: winds of change. Department of Geography, University of Miami, Coral Gables, Florida, USA.

Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. D' Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Ross, D. J. Parsons, C. H. Peterson, M. G. Turner, and R. G. Woodmansee. 1996. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. Ecological Applications **6**:775–747.

Craighead, F. C., Sr. 1964. Land, mangroves, and hurricanes. The Fairchild Tropical Garden Bulletin **19**:1–28.

Cummins, K. W., and C. N. Dahm. 1995. Restoring the Kissimmee. Special issue. Restoration Ecology **3**(3).

Davis, J. H., Jr. 1943. The natural features of Southern Florida, especially the vegetation and the Everglades. Bulletin 25, Florida Geological Survey, Tallahassee, Florida, USA.

Davis, S. M., L. H. Gunderson, W. A. Park, J. R. Richardson, and J. E. Mattson. 1994. Landscape dimension, composition, and function in a changing Everglades ecosystem. Pages 419–444 *in* S. M. Davis and J. C. Ogden, editors. Everglades: the ecosystem and its restoration. St. Lucie Press, Delray Beach, Florida, USA.

Davis, S. M., and J. C. Ogden, editors. 1994*a*. Everglades: the ecosystem and its restoration, St. Lucie Press, Delray Beach, Florida, USA.

Davis, S. M., and J. C. Ogden. 1994*b*. Introduction. Pages 3–7 *in* S. M. Davis and J. C. Ogden, editors. Everglades: the ecosystem and its restoration. St. Lucie Press, Delray Beach, Florida, USA.

Davis, S. M., and J. C. Ogden. 1994*c*. Toward ecosystem restoration. Pages 769–796 *in* S. M. Davis and J. C. Ogden, editors. Everglades: the ecosystem and its restoration. St. Lucie Press, Delray Beach, Florida, USA.

Douglas, M. S. 1988. The Everglades: river of grass. Pineapple Press, Sarasota, Florida, USA.

Duever, M. J., J. F. Meeder, L. C. Meeder, and J. M. McCollom. 1994. The climate of South Florida and its role in shaping the Everglades ecosystem. Pages 225–248 *in* S. M. Davis and J. C. Ogden, editors. Everglades: the ecosystem and its restoration. St. Lucie Press, Delray Beach, Florida, USA.

Fava, J. A., L. Barnthouse, J. Falco, M. Harwell, and K. Reckhow. 1992. Chairpersons' summary report on the EPA draft document: framework for ecological risk assessment. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, D.C., USA.

Florida Statutes. 1995. Everglades Forever Act. Florida State Statute 373.4592, Tallahassee, Florida, USA.

Frederick, P. C., and M. G. Spalding. 1994. Factors affecting reproductive success of wading birds (Ciconiiformes) in the Everglades ecosystem. Pages 659–691 *in* S. M. Davis and J. C. Ogden, editors. Everglades: the ecosystem and its restoration. St. Lucie Press, Delray Beach, Florida, USA.

Gannon, M. 1996. The new history of Florida. Tallahassee: University Press of Florida, Tallahassee, Florida, USA.

GAO (General Accounting Office). 1994. Ecosystem management: additional actions needed to adequately test a promising approach. GAO/RCED-94-111.

Gentile, J. H., M. A. Harwell, W. van der Schalie, S. Norton, and D. Rodier. 1993 Ecological risk assessment: a scientific perspective. J. Hazardous Materials **35**:241–253.

Gentile, J. H., editor. 1996. Workshop on South Florida ecological sustainability criteria. Center for Marine and Environmental Analyses, University of Miami, Coral Gables, Florida, USA.

Governor's Commission for a Sustainable South Florida. 1995. Final report to Florida Governor Lawton Chiles. October 1995. Coral Gables, Florida, USA.

Governor's Commission for a Sustainable South Florida. 1996. A conceptual plan for the C&SF restudy. Report submitted to Governor Lawton Chiles. Coral Gables, Florida, USA.

Grumbine, E. 1994. What is ecosystem management? Conservation Biology **8**(1):27–38.

Gunderson, L. H. 1994. Vegetation of the Everglades: determinants of community composition. Pages 323–340 *in* S. M. Davis and J. C. Ogden, editors. Everglades: the ecosystem and its restoration, St. Lucie Press, Delray Beach, Florida, USA.

Hanna, A. J., and K. A. Hanna. 1948. Lake Okeechobee, wellspring of the Everglades. Bobbs-Merrill, Indianapolis, Indiana, USA.

Harwell, C. C. 1989. Regulatory framework for ecotoxicology. Pages 497–516 *in* S. A. Levin, M. A. Harwell, J. R. Kelly, and K. Kimball, editors. Ecotoxicology: problems and approaches. Advanced Texts in the Ecological Sciences Series, Springer-Verlag, New York, New York, USA.

Harwell, M. A. 1997. Ecosystem management of South Florida. BioScience **47**(8):499–512.

Harwell, M. A., W. Cooper, and R. Flaak. 1992. Prioritizing ecological and human welfare risks from environmental stresses. Environmental Management **16**(4):451–464.

Harwell, M. A., and J. H. Gentile. 1992. Report of the EPA Ecological Risk Assessment Guidelines Strategic Planning Workshop, Miami, Florida, May 1991. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, D.C., USA.

Harwell, M. A., and C. C. Harwell. 1989. Environmental decision-making in the presence of uncertainty. Pages 517–540 *in* S. A. Levin, M. A. Harwell, J. R. Kelly, and K. Kimball, editors. Ecotoxicology: problems and approaches. Advanced Texts in the Ecological Sciences Series, Springer-Verlag, New York, New York, USA.

Harwell, M. A., C. C. Harwell, D. A. Weinstein, and J. R. Kelly. 1990. Characterizing ecosystem responses to stress. Pages 91–115 *in* W. Grodzinski, E. B. Cowling, A. I. Breymeyer, A. S. Phillips, S. I. Auerbach, A. M. Bartuska, and M. A. Harwell, editors. Ecological risks: perspectives from Poland and the United States. National Academy of Sciences Press, Washington, D.C., USA.

Harwell, M. A., and J. F. Long. 1992. US MAB human-dominated systems directorate workshop on ecological endpoints and sustainability goals. University of Miami Rosenstiel School of Marine and Atmospheric Science, Miami, Florida, USA.

Harwell, M. A., J. F. Long, A. M. Bartuska, J. H. Gentile, C. C. Harwell, V. Myers, and J. C. Ogden. 1996. Ecosystem management to achieve ecological sustainability: the case of South Florida. Environmental Management **20**(4):497–521.

IEMTF (Interagency Ecosystem Management Task Force). 1995*a*. The ecosystem approach: healthy ecosystems and sustainable economies volume I overview. Report of the

Interagency Ecosystem Management Task Force. National Technical Information Service, Springfield, Virginia, USA.

IEMTF (Interagency Ecosystem Management Task Force). 1995*b*. The ecosystem approach: healthy ecosystems and sustainable economies volume II implementation issues. Report of the Interagency Ecosystem Management Task Force. National Technical Information Service, Springfield, Virginia, USA.

Kelly, J. R., and M. A. Harwell. 1990. Indicators of ecosystem recovery. Environmental Management **15**(5):527–545.

Leopold, A. 1949. A Sand County almanac and sketches here and there. Oxford University Press, New York, New York, USA.

Light, S. S., and J. W. Dineen. 1994. Water control in the Everglades: a historical perspective. Pages 47–84 *in* S. M. Davis and J. C. Ogden, editors. Everglades: the ecosystem and its restoration. St. Lucie Press, Delray Beach, Florida, USA.

Long, J. F., and M. A. Harwell. 1992. US MAB human dominated systems directorate workshop on societal issues. US Man and the Biosphere Program. Washington, D.C., USA.

McIvor, C. C., J. A. Ley, and R. D. Bjork. 1994. Changes in freshwater inflow from the Everglades to Florida Bay including effects on biota and biotic processes: a review. Pages 117–146 *in* S. M. Davis and J. C. Ogden, editors. Everglades: the ecosystem and its restoration, St. Lucie Press, Delray Beach, Florida, USA.

Myers, R. L., and J. J. Ewel. 1990. Ecosystems of Florida. University of Central Florida Press, Orlando, Florida, USA.

NRC (National Research Council). 1983. Risk assessment in the federal government: managing the process. National Academy Press, Washington, D.C., USA.

NRC (National Research Council). 1996. Understanding risk: informing decisions in a democratic society. National Academy of Sciences Press, Washington D.C., USA.

Ogden, J. C. 1994. A comparison of wading bird nesting colony dynamics (1931–1946 and 1974–1989) as an indication of ecosystem conditions in the southern Everglades. Pages 533–570 *in* S. M. Davis and J. C. Ogden, editors. Everglades: the ecosystem and its restoration. St. Lucie Press, Delray Beach, Florida, USA.

Robblee, M. B., T. B. Barber, P. R. Carlson, Jr., M. J. Durako, J. W. Fourqurean, L. M. Muehlstein, D. Porter, L. A. Yarbro, R. T. Zieman, and J. C. Zieman. 1991. Mass mortality of the tropical seagrass *Thalassia testudinum* in Florida Bay (USA). Marine Ecology Progress Series **71**:297–299.

Robertson, W. J., Jr. 1962. Fire and vegetation in the Everglades. Proceedings of the Tall Timbers Fire Ecology Conference **1**:67–80.

Science Sub-Group of the South Florida Management and Coordination Working Group. 1993. Federal Objectives for South Florida Restoration. The South Florida Management and Coordination Working Group, Miami, Florida, USA.

Shelford, V. E. 1933. Ecological Society of America: a nature sanctuary plan unanimously adopted by the Society, December 28, 1932. Ecology **14**:240–245.

Slocombe, D. S. 1993. Implementing ecosystem-based management. BioScience **43**:612–621.

Snyder, G. 1994. Soils of the EAA. Pages 27–41 *in* A. B. Bottcher and F. T. Izuno, editors. Everglades agricultural area: water, soil, crop and environmental management. University of Florida Press, Gainesville, Florida, USA.

Snyder, G. H., and J. M. Davidson. 1994. Everglades agriculture: past, present and future. Pages 85–115 *in* S. M. Davis and J. C. Ogden, editors. Everglades: the ecosystem and its restoration. St. Lucie Press, Delray Beach, Florida, USA.

Solecki, W. D., R. Walker, S. Hodge, and A. Landers. 1995. Use of Geographic Information Systems: a data dictionary for South Florida. Washington (DC): Bureau of Oceans and International Environmental and Scientific Affairs, U.S. Department of State Publication 10180, US MAB Secretariat, OES/EGC/MAB, SA-44C.

Stephens, J. C., and L. Johnson. 1951. Subsidence of organic soils in the upper Everglades region of Florida. Soil Science Society of Florida Proceedings **11**:191–237.

Tansley, A. G. 1935. The use and abuse of vegetational concepts and terms. Ecology **16**:284–307.

Tisher, S. S. 1994. Everglades restoration: a constitutional takings analysis. Journal of Land Use & Environmental Law **10**(1):1–44.

USACOE (U.S. Army Corps of Engineers). 1960. Central and Southern Florida Project. General Design Memorandum, Part I, Supplement 33.

———. 1994. Central and Southern Florida Project (C&SF) Comprehensive Review Study. U.S. Army Corps of Engineers, Jacksonville District, Jacksonville, Florida, USA.

U.S. Congress. 1996. Water Resources Development Act of 1996. Public Law 104-303, Section 528. U.S. Congress, Washington, D.C., USA.

USEPA (U.S. Environmental Protection Agency). 1987*a*. Unfinished business: a comparative assessment of environmental problems. Overview Report. Office of Policy Analysis, U.S. Environmental Protection Agency, Washington, D.C., USA.

———. 1987*b*. Unfinished business: a comparative assessment of environmental problems. Appendix III. Ecological Risk Work Group. Office of Policy Analysis, U.S. Environmental Protection Agency, Washington, D.C., USA.

———. 1990*a*. Reducing risk: setting priorities and strategies for environmental protection. SAB-EC-90-021. U.S. Environmental Protection Agency Science Advisory Board. Washington, D.C., USA.

———. 1990*b*. The Report of the Ecology and Welfare Subcommittee, Relative Risk Reduction Project. Reducing Risk. Appendix A. EPA SAB-EC-90-021A. U.S. Environmental Protection Agency Science Advisory Board (SAB), Washington, D.C., USA.

———. 1992. Framework for ecological risk assessment. EPA/630/R-92/001, Washington, D.C., USA.

USMAB (U.S. Man and the Biosphere Program). 1994. Isle au Haut principles: ecosystem management and the case of South Florida. Department of State Publication 10192, NTIS # PS-94-201977, Bureau of Oceans and International Environmental and Scientific Affairs, Washington, D.C., USA.

Webb, S. D. 1990. Historical biogeography. Pages 70–100 *in* R. L. Myers and J. J. Ewel, editors. Ecosystems of Florida. University of Central Florida Press, Orlando, Florida, USA.

Wright, G. M., and B. Thompson. 1935. Fauna of the national parks of the U.S. Department of Agriculture, Washington, D.C., USA.