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# Ecological Research for Aquatic Science and Environmental Restoration in South Florida

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By

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**Abstract**

The theme of this special volume - the land-water interface: science for a sustainable biosphere - provides a forum to highlight the relationship between science and resource management, using restoration of the Kissimmee-Okeechobee-Everglades (KOE) ecosystem of South Florida as a case study. This subtropical ecosystem encompasses 16 counties and 44,000 $km^2$, from the Kissimmee Chain of Lakes in Central Florida to the shallow estuarine waters of Florida Bay, and is within the jurisdiction of the South Florida Water Management District. During the next two decades, the floodplain and channel of the Kissimmee River will be re-coupled into a meandering river system with riparian wetlands and a more natural hydrology. An evaluation program on this restoration has been designed using ecological concepts and will provide opportunities to corroborate river-floodplain theory and document the varied responses of biotic communities to hydrological restoration. The evaluation program will provide the information needed for adaptive management of the river/floodplain ecosystem. Scientists and engineers are testing an array of ecological hypotheses on Lake Okeechobee, a central feature of the KOE Ecosystem, to reduce uncertainty in predicting responses to nutrient loading, lake stage variation and exotic species invasion. Research on the lake has clarified the linkage between physical factors, nutrient levels and biotic variables, and the frequency of algal blooms. This information has been used to support decisions and plans for managing the lake and its watershed. Restoration of the Florida Everglades is grounded in a diverse suite of scientific projects that are contributing to wetland science, ecosystem modeling and restoration ecology. Studies on the effects of nutrients on wetland ecosystem structure and function have provided information at several spatial scales that is being applied directly to management issues. Findings from research and monitoring have been crucial in supporting decisions on the completion of six large stormwater treatment areas in the Everglades Construction Project. At the southern edge of the ecosystem, Florida Bay has been the focus of intensive research leading to changing paradigms on the relative effects of nutrients, turbidity, physical factors and fresh water on the functions of this unique estuary. Scientific findings on the bay support the current direction of management actions to increase freshwater inputs

from the southern Everglades, although much remains to be learned about this subtropical system.

Management-oriented research has contributed to a large increase in the rate of scientific publication on the KOE ecosystem. Approximately 1500 articles have been published on the system in the 1990s, and contribute to advancing basic science as well as resource management. Ecological reports being published on the ecosystem use state-of-the-art approaches to time and space scales, and appropriate blends of monitoring, experimentation and modeling. Peer review and interagency cooperative planning have fostered relevant, timely and objective science. The application of science to decision–making in adaptive resource management plays an important role by clarifying those facts and concepts with the most significant predictive value for management and heuristic value for fundamental science. Improvement of the science-management linkage in south Florida and elsewhere awaits better interaction between scientists and managers in planning research and more effective communication of research findings. Relevant scientific information of high quality, particularly when published in the peer reviewed literature, can not be distorted easily and is vital to support informed and equitable social choices in the decision-making process.

Key Words: Florida Everglades, Lake Okeechobee, Kissimmee River, Florida Bay, ecosystem management, applied research, water resource management, environmental decision-making, aquatic ecology

## Introduction

The science of ecology has accepted a mission: to provide the basis for environmental decision-making (e.g., National Research Council, 1986). A substantial amount of ecological research is now being designed, funded and conducted under the auspices of resource management agencies. This approach has real benefits: science gains understanding and management gains increased certainty in decision-making. This journal, 'Ecological Applications,' began publishing in 1991 and illustrates the growing interest in the application of science and in science created for application. The journal has published dozens of excellent examples of ecology being conducted and applied to real world problems, e.g., ecosystem management (Christensen, et al. 1996) and resource conservation (Mangel et al. 1996). The environmental restoration efforts currently underway in the Chesapeake Bay, the Laurentian Great Lakes and south Florida ecosystems are among the many examples in which ecological science continues to be generated and used in an ecosystem management context. These restoration efforts follow from classic environmental restorations that have produced solid scientific contributions such as Lake Washington (Edmondson, 1991), the Thames River/Estuary (Gameson and Wheeler, 1977) and shallow lakes in the Netherlands (van Liere and Gulati, 1992). This paper examines the roles of science generated under the guidance of resource management agencies in southern Florida as a case study for the synergy between research and management.

Moving environmental science closer to the information needs of management enhances the overall scientific and societal value of research. A close relationship with resource management is a sign that a discipline is rigorous enough to grapple with the complex challenges facing natural resources and their management in an ecosystem context (Christensen et. al 1996). While proximity to the needs of management adds visibility, it also requires new levels of communication, participation, and information exchange by scientists (Cullen, 1989; Pringle et al. 1993; Norton, 1998). Bradshaw (1987) develops the theme that application (i.e., restoration) is an acid test of our predictive understanding. To be considered truly rigorous, ecological theory must be able to provide a predictive basis for solving environmental management problems. Jordan et al. (1987a) point out that environmental restoration gives ecological science a **goal** (to understand and demonstrate that understanding) and a **mission** (to restore the ecosystem); this idea of central challenge applies to environmental management as a whole. Even if some management-related science does not generate wholly new information, it can be of value by clarifying the relative importance of extant facts, concepts and principles. Interest in lake management and eutrophication, for example, focused research on those factors most important to a predictive understanding of the role of nutrients in lake ecosystems (e.g., Welch and Cooke, 1987; Edmondson, 1991; National Research Council, 1992).

The chronology of environmental issues and policies in southern Florida (Anderson and Rosendahl, 1998) reveals the same suite of conflicts between water quality, urbanization, agriculture and land conservation seen in many other areas of the world. These issues in south Florida provide the impetus for environmental monitoring and applied research to support resource management decisions. Principle V from Mangel et al. (1996), developed for the field of conservation biology, applies to resource management in general and expresses this need for ecological understanding: "Regulation of the use of living resources must be based on understanding the structure and dynamics of the ecosystem of which the resource is a part ......". In spite of this pressing need for information, some scientists fear applied science as a threat to the limited funding available for basic research. Others might even perceive a challenge to academic freedom if university administrators attempt to force faculty to do applications-oriented studies, particularly if researchers consider applied science as an impediment to the development and testing of new theory. The examples in this paper and elsewhere (e.g., Pringle, 1996; Jordan et al. 1987b) argue for the opposite perspective - science done for management benefits from the synergy between the needs of environmental decision-making and those of fundamental science. Focusing information on management decisions helps to clarify what facts are important and useful for large-scale, long-term predictions. Documented successes or failures in resource decisions provide one means for testing theory and contributing to the body of scientific knowledge at the same time. A net benefit is accrued by science and society through the improved value of information useful to both.

Havens and Aumen (in press) provide a useful conceptual model for research done in the context of resource management; their model links resource management to observational and experimental research. They also argue convincingly that the quality of research is what matters, not whether the effort is funded, executed and published as "applied or basic" research. Aumen and Havens (1997) highlight the need for a new cadre of students to meet the challenges of such decision-oriented research. These students can look forward to careers in which they can contribute to both scientific knowledge and its application to decision-making. However, whether one is a student or a seasoned researcher, the analytical skills and scholarship commonly associated with basic research are just as essential in management-oriented studies. It is important to add, however, that knowledge of ecological systems is always going to be incomplete relative to their complexity at the level of ecosystem management (e.g., Walters and Holling, 1990; Holling, 1993). Unfortunately, the forces driving ecosystems are moving targets due to the pervasive effects of land-use changes, exotic species introductions, global climate change and other factors (Botkin, 1990; DeAngelis, 1994). Long-term changes are an important reason to approach resource management in an adaptive manner, adjusting management and research strategies in response to changing conditions.

This article draws on research studies in south Florida to examine aspects of ecological science in environmental management. The practical definition of ecology for this study is more inclusive than traditional definitions (e.g., Art, 1993); information that contributes to a predictive understanding of ecosystems at any level of interest is included here as ecological science. Examples are given on the dual role of management-motivated research in generating and testing theory, and increasing certainty in management decisions. Specific cases are drawn from science conducted on the ecosystem components of southern Florida: the Kissimmee River, Lake Okeechobee, the Florida Everglades and Florida Bay. The majority of examples of published literature used in this evaluation are from projects initiated and funded by the South Florida Water Management District, Florida Department of Environmental Protection, U.S. Geological Survey and other agencies. After a brief introduction to the environment and management challenges of south Florida ecosystems, examples will be provided to illustrate cases in which both science and management have benefited from applied research. These cases are followed by a more general discussion of trends in research publication, lessons learned on the scientific process underlying rigorous research, on signs of maturity in the discipline of ecology as practiced by professionals in south Florida and on obstacles and opportunities in the science-management linkage. The final area of discussion is the use of management-relevant science as a means to help maintain an appropriate ethical basis for resource management with long-term view of the public trust and a strong sense of equity in resource allocation.

## Major Features of South Florida's KOE Ecosystem

A brief introduction to the Kissimmee River, Lake Okeechobee and Everglades (KOE) Ecosystem from north to south gives an overview for system interconnections and the spatial extent of the hydrological system (Figure 1). This valued ecosystem lies within the boundaries of the South Florida Water Management District (District), an agency of the State that has its origin as a flood control district dating from 1949. Florida Water Resources Act of 1972 (Chapter 373 Florida Statutes) broadened the District's mission to include water supply, water quality protection and natural systems management, as well as flood protection. The District encompasses all or part of 16 counties, 44,000 $km^2$, from the Chain of Lakes in Central Florida to the shallow estuarine waters of Florida Bay. Florida's five water management districts are unique as agencies in that their boundaries are those of watersheds rather than political jurisdictions. A concise review of the hydrology, climate, geology, and environmental stressors of the south Florida environment can be found in McPherson and Halley (1996). Anderson and Rosendahl (1998) provide a chronology of the many ecosystem changes made through water resources development in southern Florida. The natural assets of the KOE Ecosystem, its large geographic area and the needs of a rapidly expanding human population (approaching 6 million) within the District are all factors driving the agency and other organizations in the region to conduct extensive environmental research and monitoring.

The KOE Ecosystem begins south of the City of Orlando in central Florida with the Kissimmee Chain of Lakes (Figure 1). These lakes were connected artificially by canals dredged in the 1880s, and they discharge to the Kissimmee River. Originally, the

Kissimmee River meandered over 166 km and was linked almost continuously to riparian wetlands. The 166-km river was altered drastically between 1965 and 1971 by a 90-km canal dredged through the river valley. The Kissimmee River Restoration, now an approved project between the District and the U.S. Army Corps of Engineers, will result in the recreation of 70 km of braided river channel and the restoration of 102 $km^2$ of river/floodplain ecosystem (Koebel, 1995).

The Kissimmee River is a major tributary to Lake Okeechobee (Figure 1) which is the central feature of the KOE Ecosystem with a surface area of about 1,730 $km^2$ and a volume of over 2 billion $m^3$. The lake originally conveyed water, somewhat enriched with nutrients, southward to the Everglades marshes during high water periods. All inflows and outflows except one now are regulated, and the lake's connection southward is wholly regulated through canals and control structures. During high water periods, outflows from the lake are shunted east and west into the St. Lucie Canal and Caloosahatchee River and their associated estuaries. Discharges from the lake combine with local inputs to stress the estuaries with nutrient loading and excessive freshwater. The depth of the lake also is regulated on an annual schedule for flood control and water supply. The Everglades Agricultural Area (EAA), located south of Lake Okeechobee, encompasses approximately 2,900 $km^2$ of productive agricultural land comprised of organic peat or muck soils. Once a transitional zone between the Everglades and the littoral shelf of Lake Okeechobee, the area is considered one of Florida's most important agricultural regions for sugar cane, vegetables and sod.

The remaining Florida Everglades (Figure 1) covers approximately 8,000 $km^2$ in South Florida and is the largest subtropical wetland in the United States. The historic Everglades marshes extended over an area approximately 65 km wide by 160 km long, from the south shore of Lake Okeechobee to the mangrove estuaries of Florida Bay. More than half of the original Everglades has been lost to drainage and development, and the system has been stressed by multiple changes over the last century (see Davis and Ogden, 1994a). The remaining Everglades is comprised of the three Water Conservation Areas (WCAs) and Everglades National Park (Park); the Park includes most of Florida Bay. The three WCAs are a major component of the remnant Everglades and are located south of Lake Okeechobee and west of the heavily urbanized Lower East Coast; they comprise an area of about 3,500 $km^2$. These Everglades wetlands today serve as: a) detention areas for storm water runoff; b) groundwater recharge areas for water supply to agricultural lands and urban areas; c) sources of water for Everglades National Park; d) important habitat for wildlife; and e) public recreational areas. Water Conservation Area 1 (WCA-1; 566 $km^2$) is designated as the Arthur R. Marshal Loxahatchee National Wildlife Refuge. WCA-2 is mostly an extensive sawgrass wetland with large areas of cattails in the northern and western sections; it encompasses an area of 538 $km^2$. More than half of the inflow water entering this area originates from the EAA and contains high concentrations of nitrogen and phosphorus. As a consequence of this enrichment and changes in fire frequency and hydrology, WCA-2 vegetation in some areas has been shifted to dense and expanding stands of cattail, particularly along its northern border. WCA-3 covers an area of 2,342 $km^2$ and is predominately a vast sawgrass marsh dotted with tree islands, wet prairies and sloughs.

The Park encompasses about 6,000 $km^2$ of freshwater sloughs, sawgrass prairies, marl-forming wet prairies, mangrove forests and saline tidal areas located at the southern end of the Florida peninsula. It is the second largest national park in the United States and has been declared a World Heritage Site and an International Biosphere Reserve. The 2,280 $km^2$ Big Cypress National Preserve provides an ecological buffer zone to the west and protects the Park's water supply. The Preserve is also highly valued as a forested wetland and worthy of preservation in its own right. Florida Bay is located at the extreme southern tip of the Florida peninsula between the mainland and Florida Keys. The bay covers a total area of about 2,200 $km^2$, of which approximately 1,800 $km^2$ lie within the Park.

## Science and Conceptual Models for the Kissimmee River Restoration

A recent overview of the Kissimmee River Restoration by Toth (1996) includes a summary of a demonstration project and test fill designed to validate the approach to restoring the river-floodplain linkage through canal back-filling, reshaping the remnant channel and removing two water control structures. The history and general design of the Kissimmee River Restoration provided by Koebel (1995) includes a discussion of the role of an evaluation program in tracking and documenting ecosystem recovery. This restoration evaluation program will provide the scientific framework for addressing ecological problems and management issues during the 15-year project. This unique restoration effort is based on refilling a 35 km portion of the canal that destroyed the river habitat, and restoring the hydrological dynamics of the River and its riparian wetlands. A general conceptual model for the restoration links hydrology and river habitat structure with floodplain structure and other ecosystem components (Toth, 1995). The restoration is designed to the reach the goal of restoring ecological integrity (*sensu* Karr, 1991) to the river/floodplain ecosystem. Restoration ecologists should note that the Kissimmee River Restoration has been successful in using ecological integrity as a central goal for the project, funded jointly by federal and state sources.

An entire issue of Restoration Ecology (Volume 3, #3) is devoted to the conceptual models for biotic components of the Kissimmee River ecosystem (e.g., Toth, 1995). These papers document one of the most direct science-management linkages in south Florida. The models have been used directly in the design of a monitoring program to track recovery and guide adaptive management of the Kissimmee River. They also are a contribution to aquatic restoration ecology, useful to other scientists as they consider research studies on river/floodplain systems or management options on regulated rivers and their riparian wetlands. Aspects of the restoration related to ecosystem science are reviewed by Ehrenfeld and Toth (1997), and they emphasize the opportunities provided by management actions for ecosystem studies, a theme echoed in research on other components of south Florida ecosystems and elsewhere (e.g. Cairns, 1987).

**The Limnology and Management of Lake Okeechobee**

The Lake Okeechobee seen by the early settlers in the nineteenth century must have been an impressive hydroscape (see Aumen, 1995). A vast expanse of water moderately enriched with nutrients was coupled to a vast littoral marsh (ca.1000 km$^2$) that gradually transitioned into the northern Everglades in the region now drained and used for agriculture. The lake is linked to a large (22,500 km$^2$), relatively low-gradient watershed which includes the Kissimmee River and Chain of Lakes. The lake has been changed dramatically by the construction of levees, dredging of canals, alteration of water level dynamics, invasion by exotic species and enrichment by nutrients from its watershed (Aumen, 1995; Havens et al., 1996a). Inflows and outflows are now controlled through water control structures, and the southward movement of water by sheetflow into the Everglades is no longer possible. Lake levels now are regulated to be shallower than in the original system with unnatural patterns of fluctuation. It has become more nutrient enriched and turbid from agricultural and urban land uses in the watershed. Finally, the littoral marsh, while still a 400 $km^2$ natural asset, is under constant threat from exotic plant invasions, nutrient enrichment and stressful water level fluctuations, particularly high water levels.

Public attention was drawn to the lake in the mid-1980s when severe algal blooms impeded recreational and water supply uses of the resource and threatened its long-term viability (Jones, 1987). In the process of developing a management plan for restoring the lake, the need for a major research effort emerged as a high priority for responsible agencies; very little ecological information was available for the system. Studies on the lake were aimed primarily at improving the prediction of the effects of depth, nutrient levels and suspended solids on the frequency and severity of algal blooms. Watershed research has been focused on the fate and transport of P (the nutrient most limiting to plant growth) and means to control its discharge into the lake.

Research on Lake Okeechobee and its watershed was designed and funded by management agencies and has provided information useful to managers and scientists alike. Published work on the limnology of Lake Okeechobee emphasizes the fundamental science on topics associated with nutrients and water depth. At the same time, understanding the interactions of these parameters with lake ecology is essential for managing the resource. Phlips et al. (1995 and 1997) used nutrient responses to define ecological zones for the lake. Havens et al. (1996b) reported on the relative responses of periphyton and phytoplankton to nutrient enrichment, and Steinman et al. (1997) found that charophytes are more affected by light than by nutrients. Light and wind suspended particles interact to determine the composition of cyanobacteria in the lake and the probability of an algal bloom (Havens et al. 1995 & 1998).

Articles in Aumen and Wetzel (1995) document the basic ecology of the biotic communities of the lake, emphasizing the role of depth and nutrients. For example, hydrological factors were most associated with vegetation community structure in the littoral zone, and springtime draw-down periods were found to be critical to wading bird foraging success in the littoral marshes of the lake. The frequency of algal blooms varied greatly in different regions of the lake and was associated positively with nutrient concentrations and negatively with wind velocity and lake depth (James and Havens, 1996; Havens, 1997).

Phosphorus (P) biogeochemistry in sandy, subtropical soils has been a major area of contribution from research in the Lake Okeechobee watershed. An entire volume of Ecological Engineering was devoted to publications on P fate, transport and control in the Lake Okeechobee watershed (Reddy and Flaig, 1995). Flaig and Reddy (1995) provide a complete summary of P movement through wetlands, uplands and streams of the watershed. Other papers in this volume document the dynamics and distribution of P in this subtropical watershed and examine effectiveness of management practices in altering P transport to the lake. Steinman et al. (1999) describe the linkages between the fate and transport of P in the watershed and impacts on P levels and water quality in the lake. Modeling results indicate that even drastic reductions in P loading from land-use changes will have limited benefits to lake water quality in the short-term because of the buffering effect of internal P loading from sediments in Lake Okeechobee.

These accomplishments and many other publications from research on the lake and its watershed have been used to support resource management of the lake. Aumen and Gray (1995) summarize key findings and implications from research conducted as part of the Lake Ecosystem Study. Flaig and Reddy (1995) integrate findings from phosphorus research in the watershed and link the findings to the efforts to control P loading to the lake. Bottcher et al. (1999) provide information on agricultural best management practices validated by research in the watershed. Steinman et al. (1999) relate research findings on P dynamics and distribution in the lake and watershed to management strategies for the ecosystem, such as sediment dredging in the lake and tributaries, and improvements in agricultural best management practices in the watershed. Many research findings were used to support programs and management strategies in an updated management plan for the lake (SFWMD, 1997). Watershed research has been vital for the calibration and validation of decision-support models used to apply management practices to reduce P exports from agricultural activities in the watershed

(Negahban et al. 1995; Zhang et al. 1996). Management agencies continue to work towards a 40% reduction of P loading from the watershed, better control of exotic plants, construction and recreation of wetlands in the watershed, and additional information on internal P storage and cycling. Information from ecological research is among the many sources of information that is being used to develop a minimum depth criterion for the lake required by Florida Statute (Section 373.042) as an aid in water allocation planning for the State (SFWMD, 1998). In addition, a science-based conceptual model links ecosystem stressors and sources with ecological values, effects and measures of status. The model is a tool to evaluate the interconnected effects of managing the lake under various hydraulic and nutrient loading scenarios (USACE, 1999). This information is being used by staff of the District, the U.S. Army Corps of Engineers and other agencies participating in restoration planning to evaluate responses of the lake to major regional restoration projects being planned through the year 2050. Watershed-based research now is concentrating on the agro-ecology of cattle ranching and fertilization practices to optimize beef cattle production while developing management practices to reduce nutrient exports from cow-calf operations, a major land use in the watershed.

**Wetland Ecology and Management of the Florida Everglades**

The basic ecology of the Everglades is described in detail through the chapters of Davis and Ogden (1994a). The hydrology and interconnections of the ecosystem have been changed greatly by water management projects, particularly the dredging of four major canals completed in 1917 (Light and Dineen, 1994). As mentioned previously, the remnant Everglades marshes are contained in three Water Conservation Areas (WCAs) and Everglades National Park (Figure 1). Attention to ecological research in these areas increased greatly during the second half of the 1980s. Government agencies and university researchers realized the pressing need to gain a more predictive understanding of factors controlling the landscape mosaic. Information on the effects of nutrient enrichment from urban and agricultural runoff and the role of hydrology in wetlands structure and function was seen as particularly important for Everglades restoration.

Research projects exploring the role of hydrology, nutrients, fire, exotic species invasions and other aspects of marsh ecology have increased in number and diversity during the decade of the nineties. The U.S. General Accounting Office reported recently that the Federal government spent about 128 million dollars on research and monitoring in south Florida from 1993 through 1999 (GAO, 1999). Together with State, District and local technical programs, this aggressive research and monitoring effort has expanded our knowledge of many components of the Everglades ecosystem. The Everglades Interim Report (SFWMD, 1999) provides a thorough update on much of this recent work. Water quality, ecological effects of P enrichment, hydrological needs of the ecosystem, mercury transport and fate, and effectiveness of constructed wetlands are the primary research topics covered in substantial detail in this synthesis. While management and science both have benefited from new data in many of these areas, the products from research on nutrient effects are excellent examples of a science-management synergism and will be considered briefly below.

The trade-off between nutrients, fire and hydrology must be understood for successful Everglades management and to advance fundamental wetland ecology. Research in south Florida is clarifying these processes, as illustrated in the a few recent examples. Experiments in field mesocosms have documented nutrient effects on three wetland macrophyte species (Newman et al. 1996) and provided important evidence regarding the competitive advantage of cattails (Typha spp.). Newman et al. (1998) used a comparative approach to determine that fire, nutrients and hydrology can each influence the expansion of cattails. The nutrient history of an area appears to be the major factor determining which of these three variables is most important and the effect of hydrology in promoting cattail expansion is more pronounced when nutrient levels are higher. Miao and Sklar (1998), and Miao and DeBusk (1999) observed patterns of P and nitrogen (N) in sawgrass and cattail stands along the nutrient gradient in WCA-2; the effects of enrichment are clearly reflected in plant physiology and community structure. Everglades periphyton is an excellent indicator of nutrient enrichment (e.g., McCormick and Scinto, 1999). Studies of periphyton in WCA-2 used a gradient approach to document the effects that spatial changes in nutrient levels had on species composition and productivity (Grimshaw et al. 1993; McCormick et al. 1996; McCormick et al. 1998). Their results are consistent with the effects documented by McCormick and O'Dell

(1996) using synoptic field experiments. Changes in species composition associated with enrichment begin to occur at very low ambient P concentrations (10 -- 20 μg P/L).

The results of these studies and many others on the Florida Everglades are being synthesized and extended using mathematical models (see SFWMD, 1999 Chs.2&3), including landscape models. For example, one version of the Everglades Landscape Model, the Conservation Area Landscape Model (Fitz and Sklar, 1999) has been used to look at tradeoffs between the effects of nutrients, hydrology and other factors. Evaluations using this model suggest that available nutrients increase during drier conditions and can alter productivity without additional external nutrient loading. The model also predicts that ecosystem responses are somewhat buffered from changes in external nutrient loading. The Everglades Landscape Model, in combination with other models, promises to aid in predicting responses of this complex ecosystem to adaptive management actions (e.g.,Walters and Holling, 1990) as part of the regional restoration of the KOE ecosystem (USACE, 1999), and should contribute to both Everglades science and management in coming years.

Davis and Ogden (1994b) used Everglades science to propose guidelines for restoring the ecosystem. Research conducted since this 1994 synthesis, has been used as a cornerstone for important management decisions. For example, the Everglades Forever Act (Section 373.4592, Florida Statutes) requires that six large stormwater treatment areas be built to reduce P inputs to the remnant Everglades. Research on nutrient effects is not only fulfilling research requirements of the Act, but also is providing data to be used by the Florida State Department of Environmental Protection to develop a numeric water quality criterion for P in the Everglades. The Act also mandates that construction of the last and largest of the treatment wetlands (Stormwater Treatment Area 3/4) not begin until 90 days after the research summary in the Everglades Interim Report (SFWMD, 1999) was submitted to the Governor and Legislature, January 1, 1999. Water quality monitoring data combined with findings on nutrient effects formed a critical mass of information on the status of nutrient loading to the system and ecological sensitivity of flora and fauna. This body of information was used in the Report to conclude that Stormwater Treatment Areas are effective in removing P and that they are needed to complete the process of reducing inflow P concentrations to less than 50 ppb, the interim level required by the Everglades Forever Act. As a result of this analysis, the largest of the treatment areas will be constructed, a multi-million dollar decision resting directly on the results of ecological, hydrological and water quality research.

Another example of the application of published science is in the development of criteria for success in the restoration of the South Florida ecosystem (Science Subgroup, 1997). This cooperative multi-agency effort used published information as the primary basis for developing criteria to be used in tracking the success of the restoration effort being planned for south Florida ecosystems. Information gained through monitoring and research efforts also formed the basis a series of conceptual models for components of the south Florida ecosystem. These models and related measures of performance allowed various restoration alternatives to be evaluated and cross-compared in a multi-agency and public process to select approaches to restoring the south Florida environment (USACE, 1999).

**Estuarine Ecology and Long-Term Management Strategies for Florida Bay**

Florida Bay is a shallow subtropical estuary composed of interconnected areas of open water separated by mud banks. The bay is a valuable natural resource and is critical to the Florida Keys/southern Everglades economy. By 1991, there was a major concern for the environmental health of the bay due to increased frequency and extent of phytoplankton blooms and rapid spread of a seagrass die-off; seagrasses are an important source of primary production in this shallow, marine ecosystem. These events were coincident with an increase in the magnitude and extent of hypersalinity. The watershed for the bay is the southern Everglades and it was hypothesized that major changes in freshwater inputs had culminated in the salinity problem. Changes in the hydraulic loading to the bay were thought to be a product of water management upstream (Light and Dineen, 1994; SFWMD, 1999, Ch.2) which has diverted water from the bay for agriculture, urban uses and flood control. The effects of long-term variations in rainfall patterns and sea level rise were also thought to be involved in these changes.

A predictive level of understanding of the linkages between seagrass mortality, phytoplankon blooms, suspended particles, nutrient loading and freshwater inflows was sorely needed on Florida Bay. A review panel in 1993 concluded that hypotheses on all these factors and others must be tested through additional research and monitoring. With this impetus, the South Florida Water Management District, Everglades National Park, U.S. Geological Survey and other agencies funded research to increase the information base on the bay. Many of the findings from these recent studies are summarized in an issue of the journal Estuaries (Volume 22, #2, 1999). Fourqurean and Robblee (1999) introduced the journal issue and provided a thorough summary of the problem, a description of the bay environment and a summary of research accomplished in recent years on Florida Bay ecology. A major finding supported by several papers in this volume is that the water budget and circulation in the bay were altered greatly in the first half of this century. These changes were associated with construction of the Overseas Railroad to Key West and the many alterations in Everglades hydrology mentioned earlier. Construction of the railroad was done by filling in areas between keys (small islands), thereby limiting the connection between eastern Florida Bay and the Atlantic Ocean. The seagrass die-off has had substantial effects on Bay fauna, and has shifted the Bay to a more plankton-dominated food web. Information on freshwater inflows and nutrient loading from the southern Everglades to eastern Florida Bay does not indicate significant eutrophication from upstream sources (Boyer and Jones, 1999; Rudnick et al. 1999), confirming earlier observations of Fourqurean et al. (1993) based on a spatial analysis of nutrient data. The nutrient ecology of western Florida Bay is dominated by inputs from the Gulf of Mexico and may therefore be influenced by regional water quality in the Gulf of Mexico.

From a management perspective, information generated over the last decade has improved greatly the understanding of the Florida Bay ecosystem, particularly in relation to nutrients and altered salinity. Science developed on the Bay forms the foundation for a conceptual model that links stressors to ecosystem attributes and performance measures (USACE, 1999). This integration of predictive science on the Bay is sufficient to set general directions for adaptive management. However, additional information is needed on this spatially complex Bay to evaluate and track specific management actions. Valiela et al. (this volume) provide a good example of science as an underpinning to specific management goals for the Waquoit Bay estuary in Massachusetts. The District has worked in cooperation with other agencies to implement a series of actions to deliver more water to Florida Bay from the southern Everglades. These actions are supported by existing science as a step in the right direction even though the end-points of restoration can not be predicted with certainty at this time.

**Resource Management Initiatives and Scientific Publication**

Has the increased interest in the management and restoration of the KOE ecosystem resulted in a substantial output of scientific publications? To answer this question, a literature search was conducted for the key words Kissimmee River, Lake Okeechobee, Everglades and Florida Bay in five databases for technical literature: Agricola, Ei Compendex, Biosis Reviews, NTIS and Sci Search. The search was executed in 5-year intervals, beginning in 1970 and ending with 1998. The resulting files were purged of duplicate citations and data for the 1995–1999 interval were corrected by multiplying the 1995-1998 total by 1.25 to extrapolate to the number of papers published through 1999. Note that no effort was made to limit this search to ecology, so that the resulting trends reflect overall scientific productivity over the last 3 decades on south Florida environments.

The examples of research discussed above are part of increased attention to technical information in south Florida driven largely by the needs of responsible state and federal agencies. The Federal government alone has invested about $128 million in research support between 1993 and 1998 (GAO, 1999). Although the magnitude of the increases differs with each ecosystem component, data in Figure 2 document that all four parts of the KOE Ecosystem show large increases in publications. Information flow on Florida Bay is particularly impressive - only 16 articles were published in the 1970s and over 400 were published in the decade of the 1990s. There was a clear recognition that ecosystem research was needed desperately to support long-term management of the Bay. As noted earlier, staff involvement and financial support of several agencies is an important factor underlying this increase in the output of Florida Bay information. Similarly, published Everglades science expanded from 261 papers in the 1970s to nearly three times that number in the 1990s. The synthesis of Everglades ecology by Davis and Ogden (1994a) focused much needed attention on Everglades publication and highlighted the need for additional information on this unique ecosystem. Over 200 publications on the KOE ecosystem have been published by staff of the South Florida Water Management District during the 1990s. This agency has adopted peer-reviewed publication as the preferred avenue for distributing technical information from agency-sponsored research. While this output of peer-reviewed science can not assure sound ecosystem management, it does provide the public with a pool of rigorous science for use in resource decision-making.

The rate of publication on south Florida environments is substantial by any measure. However, the quantity of publications on south Florida environments is not necessarily equivalent to, or even correlated with, scientific importance or impact. While it is very difficult to quantify scientific impact, it is safe to assume that researchers on these systems are contributing important concepts to the literature based on the examples given in this paper. Publication in peer-reviewed journals gives some assurance of scientific value. This is particularly true in highly competitive journals at the national and international level (e.g., Ecological Applications, Estuaries, Oikos); see the literature cited section of this paper for one sampling of journals publishing south Florida science.

Equally impressive as the number of papers, however, is the demand for information on the system components and on the integrative science of the region as a whole. The Comprehensive Review Study of the Central and Southern Florida Project, known as the Restudy, is a massive planning process to rethink environmental management on an ecosystem-wide (46,000 $km^2$) and long-term (50-year) basis (see SFWMD, 1999, Ch.10; USACE, 1999). Run jointly by the District and the U.S. Army Corps of Engineers, the Restudy has now produced a recommended alternative plan proposing major changes in the water control structures and management regimes for the KOE ecosystem as a whole. A key objective is to increase the amount of high quality water available to the remaining Everglades and Florida Bay, while continuing to provide for the needs of human communities in the region. The recommended plan carries a preliminary price tag of nearly 8 billion dollars for 50 project components. Science has not only been used extensively in the Restudy planning process, but will continue to be vital for decisions during implementation over the next two decades. The Restudy recognizes that adaptive environmental management (*sensu* Walters and Holling, 1990) must be grounded in continuous research and monitoring of the system. It is anticipated that the rate of publication on south Florida will continue to be fueled by the demands of the Restudy and associated environmental management. Monitoring data will undoubtedly play a large role in the restoration designed through the Restudy. The value of such observational data will be far greater for management if it is augmented by data from well-focused studies using a variety of approaches, as described by Havens and Aumen (in press).

## Thoughts on the Maturity of Ecology Based on Science in South Florida

In the introduction, the point was made that ecology is maturing as a science with a mission of restoring and protecting the environment. Looking across examples of science in ecosystem management generally (e.g., Christensen et al. 1996) and management of the KOE ecosystem specifically, there are signs of maturity and an increasing ability to deal with environmental problems by bridging disciplines. First, there is a growing recognition of the importance of interpreting data in the context of appropriate spatial and temporal scale (e.g., Holling, 1993; DeAngelis and White, 1994) and a willingness to deal with issues at the high levels of aggregation needed for management. Awareness of scale has developed to the point that Schneider (1994) provides a detailed discussion of scale in ecological science, including practical metrics to be used to express and analyze scale-dependent problems. DeAngelis (1994) and White (1994), for example, synthesize large amounts of information on the Everglades into a conceptual framework of the driving forces that must be understood if we are to restore the ecosystem. Likewise, data on Lake Okeechobee provided an opportunity to synthesize biological and chemical information to differentiate five ecological zones (Phlips et al. 1995). These zones, in turn, each provide very different ecological predictions for the effects of nutrients and depth on ecosystem function, particularly algal blooms (Aumen and Gray, 1995). Understanding this spatial aspect of the Lake's ecology is essential for setting appropriate management goals for the watershed and realistic expectations for responses of the Lake to management.

A second sign of maturity is the acceptance of constant change in the environment that is occurring simultaneously across levels of time and space. The concept of a balance in nature has proven to be of limited utility, although the public continues to believe in its value. The omnipresence of change occurring at multiple scales is now viewed as an important force modifying the matrix of factors that mold the landscape mosaic (e.g., Botkin, 1990; DeAngelis, 1994). Peters et al. (1991) examine the relationship between the scope of studies, and environmental predictors and responses. They point out that uncertainty and risk of misunderstanding tend to increase at the level of aggregation associated with resource decisions. Steele (1991) suggests that dominant processes change with the level of aggregation and that the interaction of processes across scales is a central problem for ecology. He emphasizes major differences in spatial and temporal scales operating on physical and ecological processes and between aquatic and terrestrial environments. Management issues not only cross scales and environments, but often occur at the longer, larger and more aggregated levels with greater uncertainty. The only way to assure relevant information for management is to do research at multiple scales, as exemplified by studies on nutrient effects in the Everglades and Lake Okeechobee, discussed earlier.

Continuous environmental change and the importance of scale are being incorporated into planning by agencies as they seek to manage landscape mosaics like Florida Bay, the Everglades and Lake Okeechobee for long term sustainability. For example, the fundamental questions being addressed on Florida Bay are oriented to understanding natural bounds for structure and functions of this dynamic estuary and the long-term driving variables. Fourqurean and Robblee (1999) conclude," The insight to be drawn from this volume (Estuaries 22, #2) is that the objectives for a restored Florida Bay must take account of its inherently variable nature." Studies on nutrient effects in the Everglades have been conducted deliberately to measure change across scales from short-term experiments, to mesocosm trials in the field, through longer-term transect measurements across gradients in the remnant Everglades (see SFWMD, 1999, Ch.3). Only with this recognition of the dynamic nature of the system and use of appropriate scales can information contribute to new theory or management decisions.

Looking at ecological science over the last several decades reveals a third sign of maturity: a trend from descriptive studies to those more focused on hypothesis testing and prediction. Experimental work plays an increasingly important role in management-relevant research in south Florida; many examples are given earlier in this paper.

Experiments are most effective when expectations are explicit, the domain of the data is quite narrow and causality is direct and univariate (Pickett et al. 1994). While experimentation may be essential for determining cause and effect (Havens and Aumen, in press), more aggregated approaches to information also are required for the system-level problems being addressed by resource management. Management agencies are far more likely to have a wealth of monitoring data since they often are charged with documenting status and trends for areas of responsibility (i.e., water quality). Therefore, agency researchers need to be well versed in using uncontrolled observational data to extract useful information and gain predictive understanding. Such observational data may also be useful as a means of gathering information from comparative studies, but must not be taken as complete evidence of causation without additional information from more controlled studies (Peters et al. 1991). Pickett et al. (1994, ch.2) provide a concise and convincing case for the effectiveness of using positive testing or confirmation as opposed to negative testing or experimental falsification to advance ecological understanding. Multivariate statistical analyses, synthesis of corroborating evidence and other modes of confirmation can be used in a complementary manner to test concepts from observational data; the specific blend of approaches is less important than the scholarship, objectivity and rigor of the science.

A final important sign of maturity in ecological studies is that human beings are finally being accepted as a component of ecosystems (Botkin, 1990; McDonnell and Pickett, 1993; Vogt et al. 1997). Human effects cut across spatial scales and vary from the obvious to the subtle. McDonnell and Pickett (1993, p.316) concluded from the 4th Cary Conference that: "Humans are indeed part of nature, and must therefore become a part of the subject matter of modern ecology." Others have stressed that human values and societal support are essential if ecosystem management and restoration are to succeed (Cullen, 1989; Cairns, 1993; Mangel et al. 1996; Vogt et al. 1997). Anyone who looks at the compartmentalized landscape of south Florida (Figure 1) can not help but conclude that humans are pervasive in modifying the environment. Adjacent social systems must be considered in any strategy for restoring the Everglades ecosystem. A consortium of federal, state and tribal agencies (Working Group, 1998), recently published the following vision statement for the restoration of South Florida that integrates humans into ecosystem restoration: "Vision: A landscape whose health, integrity and beauty is restored and is nourished by its interrelationship with South Florida's human communities."

Applied ecological science is helping to inculcate this 'human in nature' paradigm into our thinking to the benefit of the entire discipline. The long-range plan of the Ecological Society of America places applied ecology and human interests squarely into the mainstream of the Society's mission: "Promotion of the science of ecology is the central activity of the ESA. This is accomplished by fostering basic and applied research, making the results of that work available to practitioners and decision makers, and providing information about the science of ecology to the public" (ESA, 1999). Human effects and interests are an integral part of ecosystem management in south Florida and elsewhere (Christensen et al. 1996; Vogt et al. 1997).

## Obstacles and Opportunities in the Science-Management Linkage

The published science reviewed in this paper provides ample evidence of successes at producing sound information to support decision-making on the four primary components of the KOE ecosystem. However, it is common knowledge that science is not always successful at meeting the needs of management. Walters (1997), for example, laments that researchers can sometimes allow their self interest to override the broader information needs of adaptive management. He details a set of examples in which weaknesses in research, modeling and monitoring programs were part of the reason for failures in adaptive environmental management. The scientific endeavors in south Florida are not free of these flaws. Science-management disconnects have not been discussed in this paper because such cases are usually not published and their description would involve implicit and subjective criticism of scientists and/or the management agencies funding research. Nevertheless, obstacles to success and opportunities for improving the science-management linkage do merit some consideration, as done elsewhere by Pringle et al. (1993) and Walters (1997).

The South Florida Water Management District and the U.S. Geological Survey, in cooperation with other agencies working in south Florida, recently conducted a conference with the purpose of communicating science to decision-makers and analyzing ways in which science can be more effective as an agent of information flow. This conference, titled "South Florida Restoration Science Forum", attempted to communicate science directly to senior managers and to find ways to improve communication; summaries of U.S.G.S. projects from the Forum can be found in Gerould and Higer (1999). Five questions were used to guide scientific deliberations on the science-management linkage at the Forum. These questions provide a useful framework to discuss obstacles and opportunities in the science-management linkage:

1. *How can science be scaled and designed to support decision-making?*

The challenge is to provide information that is applicable to management-level issues. Managers are most often interested in responses at the ecosystem scale, while research projects tend to be done at smaller scales in the laboratory or field mesocosms. Statistical and technical rigor is no assurance that findings will have utility for resource decisions. As Rogers (1998) stresses, **the client determines the value** of scientific products and will use the best available information, not necessarily the best possible scientific product. There is no substitute for on-going communication between scientists and managers in developing objectives for research efforts. Scientists tend to perceive projects as 'science of the parts', while managers need information from 'science of the integration of the parts' (*sensu* Walters and Holling, 1990).

2. *How can management interests be better incorporated into research planning?*

There is often little overlap between the practical knowledge base of scientists and managers regarding what issues are important and what data are needed for their resolution. Again, we must strive to communicate better with managers on a continuing basis. The South Florida Restoration Science Forum, mentioned above, is one example of a process that can improve the linkage, and Vogt et al. (1997) provide many valuable concepts for incorporating research into ecosystem management. We must also develop research plans that are benefit from substantive input from managers in deriving an objectives hierarchy (see Rogers, 1998) and are designed from the ground up to provide information for decision support. This partnership does not necessarily produce boring science, and, as noted by Pringle (1996), there is no reason why outstanding contributions to fundamental science can not be forthcoming from research designed to address the needs of managers.

Technical professionals need to do a better job of showing the value of multiple approaches to generating useful data, including hypothesis-driven experimental work. Havens and Aumen (in press) use research on nutrient effects, cattail expansion and salinity criteria from south Florida to illustrate the strength of using data from several approaches to generate management relevant information. A recent peer review panel on the evaluation program for the Kissimmee River Restoration stressed the need and opportunity to do experimental projects on river-floodplain linkages as the construction phase of the restoration begins. In addition, the research reviewed by Fourqurean and Robblee (1999) on Florida Bay is largely observational by design, and yet a better understanding of cause and effect, particularly regarding nutrients and fresh water inputs, is vital for long-term management and restoration of this ecosystem. Prediction is a far more powerful tool for management, and therefore, managers need to appreciate and support experimental research as part of a mix of ways to garner information for decision making (e.g. Cullen, 1990).

3. *How can we do better as purveyors of objective information to minimize the impact of scientific advocacy?*

Our litigious society fosters the use of scientific information for special interests of all kinds. Scientists can not stop the selective or inappropriate use of information in decision-making, but we can continue to publish relevant and timely findings, and be more proactive in synthesizing information in ways that facilitate appropriate and timely applications (see #4, below). A recent report from the Federal government (GAO, 1999) noted that the linkage between research and restoration projects was unclear for south Florida and may impede progress of the Everglades initiative in the future.

4. *How can scientists maintain credibility from the perspective of managers?*

Publication in the scientific literature is one fundament of credibility, but there must be more. Scientists must digest and communicate technical material to managers in a manner that is understandable and trustworthy. Cullen (1990) stresses the great differences in the perspectives and training of scientists, engineers and planners, and suggests several ways through which these cultural differences can be bridged. He concludes that scientific brokering may be essential to synthesize and communicate technical information to planners and other decision-makers. In south Florida, this brokering role is often played by researchers, sometimes reluctantly so, or by senior scientists and engineers in governmental agencies. Cullen (1990) notes that placing scientists in the brokering role can subvert the process, and leads to frustration on all sides of management issues. The problem is that brokering information is a service that may be difficult to sustain in resource management agencies; non-scientists may find the service to be less than high priority for staff and budgetary resources. This tendency may be one reason why many agencies end up being data rich and analysis poor. Technical interpretations are often done only when they are critically needed and then in the form of 'white papers', not what one would recommend for maintaining credibility.

Several federal agencies publish technical information in formats designed to meet the needs of various client groups. An excellent example of this tiered approach is the publishing strategy of the U.S. Geological Survey. This agency publishes fact sheets, circulars (e.g., McPherson and Halley, 1996) and several forms of technical reports (e.g., Miller et al. 1999) that are designed to communicate information to a diversity of potential users. Likewise, the Ecological Society of America not only publishes the classic journals 'Ecology' and 'Ecological Monographs' conveying fundamental science, but also produces the journal 'Ecological Applications' that stresses science with immediate utility. The Society also publishes 'Issues in Ecology', a series aimed at reaching a very broad readership on environmental issues of relevance to the public at large. Other agencies and organizations would be well served by following these publication strategies.

5. *How can scientists resolve technical disputes outside the decision-making arena?*

When differences of opinion on technical issues have real consequences for decisions, it is self-destructive to deliberate them in front of laypersons or managers. Agencies need to encourage open debate, particularly presentations to outside panels, and peer review of project plans, execution and products. Whatever process is developed to deal with inter-agency conflict for south Florida in response to GAO (1999) could also be applied to the resolution of technical issues, hopefully outside the courtroom.

**Peer Review, the Process of Science and the Value of Research**

Humans bring a legacy of special interests into the decision-making process with varying perspectives on how science should be involved. The public seeks clarity and often does not understand the provisional and uncertain nature of science (Cullen, 1989; Pickett, et al. 1994, Ch.9). The public view of ecology often is based on notions such as 'balance of nature' and ecosystems as closed systems, and the public finds it all too easy to mistrust research scientists, particularly those supported directly by resource management agencies. There is plenty of room for optimism, however. High quality, peer reviewed science builds public trust and is the only kind of science that can stand the legal and scientific scrutiny often a part of management decisions (e.g., phosphorus standard for the Everglades, completion of the Everglades Construction Project, minimum water level for Lake Okeechobee). As courts are forced to deal with complex technical information and conflicting claims, they seek scientific information that has been subject to objective testing and peer review (Ayala and Black, 1993).

Open review of programs, projects and publications has played an important role in the science-management relationship in south Florida, as illustrated in the following examples. Peer review panels have been convened repeatedly since 1993 to help guide Florida Bay studies and facilitate communication between researchers. Everglades National Park oversees the Program Management Committee that has convened the Florida Bay panels, reviewed research projects and set funding priorities. In 1997, under the auspices of the Florida Department of Environmental Protection, a panel of experts reviewed the three Everglades research programs conducting investigations related to the effects of P on Everglades flora and fauna. An advisory panel has reviewed scientific activities being undertaken in the evaluation program for the Kissimmee River Restoration. Likewise, several panels have been involved in oversight of the Lake Okeechobee research efforts, including a panel that examined the entire P control program for the Lake Okeechobee watershed. Through its staff and contractors, the South Florida Water Management District encourages open dissemination of information through publication in peer reviewed journals. In any form, review serves to improve the quality and focus of research and monitoring efforts; its application to management oriented studies is just as appropriate as it is for more academic research pursuits.

The value of quality management-relevant science goes beyond proximal legal issues or decision-making: it helps to foster and support equity and long-term sustainability in resource management. Leopold (1990) chronicled the disheartening lack of ethos (fundamental values) for equity and sustainability in water resource management. He provided examples illustrating how this deficiency has resulted in a myopic view of resource allocation, and a lack of fairness and equity in water resource decisions, particularly when plied by special interests. Certainly, science alone can not rebuild or maintain an appropriate ethos in the management of public resources. However, information from research that is relevant, objective and timely does provide an 'anchor to windward' in the decision-making arena. Such quality scientific information, particularly when published in the open literature, can not be distorted easily by special interests or systematically ignored by decision-makers. Rigorous and useful science can serve to bridge the turbulent boundary between science and management (*sensu* Cullen, 1990), and can support informed social choices in the decision making process (Cullen, 1989). Ultimately, excellence in management-driven scientific research guides resource management in directions that benefit the public, including special interests, for today and for future generations.

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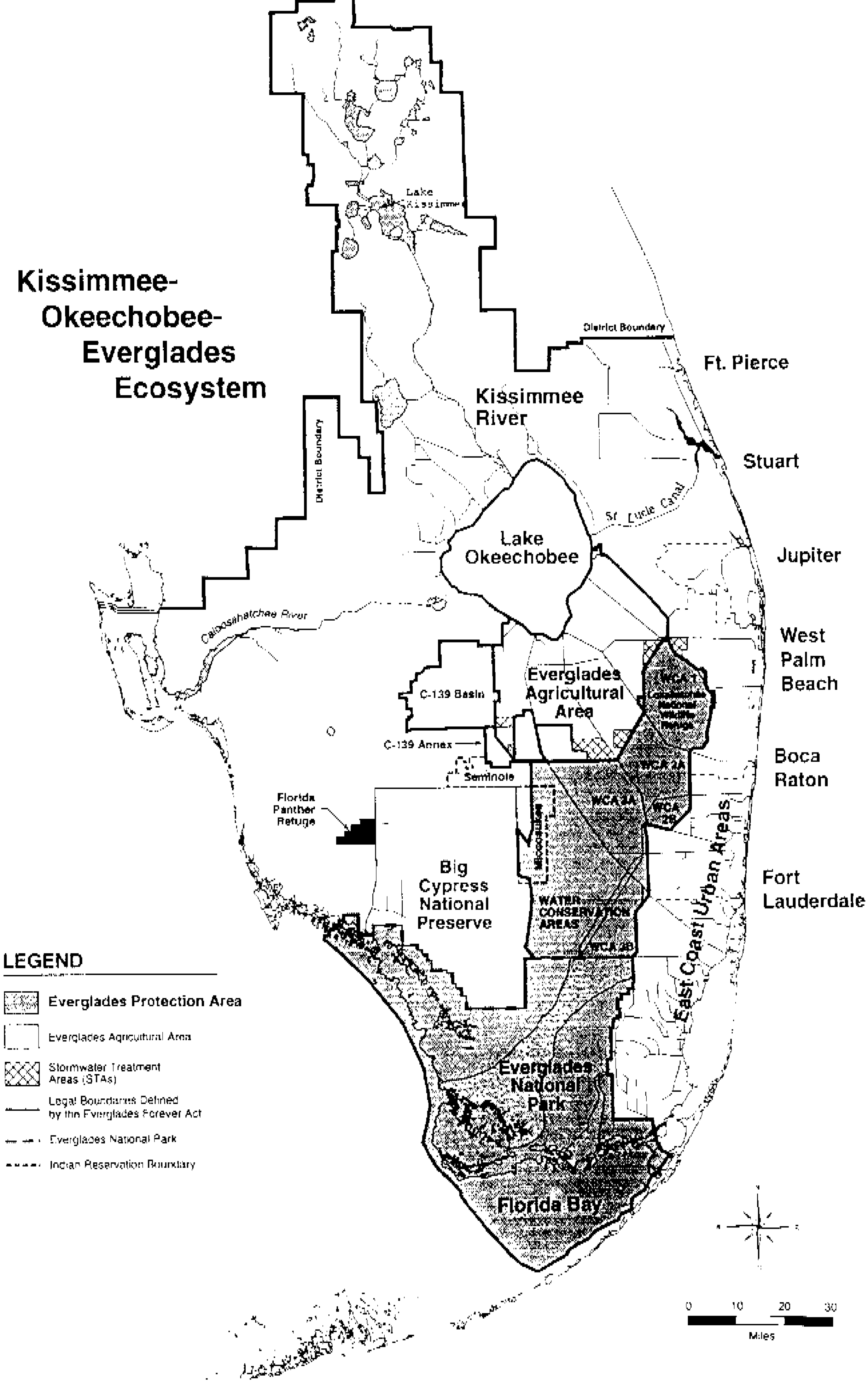
**Figure Legends**

Figure 1. Major Features of the Kissimmee-Okeechobee-Everglades (KOE) Ecosystem. The Kissimmee River Restoration is taking place in the northern half of the existing C-38 Canal connecting Lake Okeechobee with the Kissimmee Chain of Lakes. Lake Okeechobee is the second largest lake in the continental U.S. and is separated from the Everglades by the Everglades Agricultural Area (EAA). The remnant Everglades is composed of three Water Conservation Areas (WCAs) and Everglades National Park. These wetlands are adjacent to the urban areas along the east coast of the Florida peninsula. Florida Bay is the southernmost feature of the ecosystem and lies largely within Everglades National Park.

Figure 2. Scientific Publications on the KOE Ecosystem. The total number of publications for each 5-year interval, centered on the year labeled, are presented for each of the components of the KOE ecosystem. *Values for 1999 were estimated by multiplying the total of 1995 – 1998 by 1.25. Management-driven initiatives for research and monitoring were begun primarily after 1990, and are associated with a major increase in peer reviewed publications.



Kissimmee-
Okeechobee-
Everglades
Ecosystem
Lake Kissimmee
District Boundary
Ft. Pierce
Kissimmee River
Stuart
St. Lucie Canal
Lake Okeechobee
Jupiter
Caloosahatchee River
West Palm Beach
Everglades Agricultural Area
C-139 Basin
C-139 Annex
Boca Raton
Seminole
Florida Panther Refuge
WCA 2A
WCA 3A
WCA 2B
Big Cypress National Preserve
WATER CONSERVATION AREAS
WCA 3B
East Coast Urban Areas
Fort Lauderdale
LEGEND
Everglades Protection Area
Everglades Agricultural Area
Stormwater Treatment Areas (STAs)
Legal Boundaries Defined by the Everglades Forever Act
Everglades National Park
Indian Reservation Boundary
Everglades National Park
Florida Bay
0 10 20 30
Miles

# Publications on the KOE Ecosystem of South Florida