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Introduction to tools to support ecosystem based management of South Florida's coastal resources

The South Florida Coastal Marine Ecosystem (SFCME) includes Florida and Biscayne Bays, the Caloosahatchee Estuary, the Florida Keys, the Southwest Florida Shelf, and the Southeast Florida Coast (Fig. 1). Much of the SFCME lies within the Everglades, Dry Tortugas and Biscayne Bay National Parks and the Florida Keys National Marine Sanctuary. It contains some of the richest and most diverse marine communities in the United States, which attract tourism, diving, recreational fishing, and commercial fishing. The SFCME is extremely important not just to the local economy, but also to the overall state of Florida economy (Fedler, 2009; Johns et al., 2001; Leeworthy et al., 2004). Over the past century, the living marine resources in the SFCME have been progressively degraded as a direct and indirect consequence of increasing population, urban and suburban development (ONMS, 2011). The agricultural industry made possible by draining the historical Everglades has also played its part (Lapointe et al., 2004). These trends in combination with anticipated sea level rise and climate change put these invaluable resources at significant risk.

South Florida is also the site of the world's largest and most expensive ecosystem restoration effort: the Comprehensive Everglades Restoration Plan (CERP) (Ogden et al., 2005). Purportedly, CERP is being implemented through "adaptive management guided by the best available science". Accepting that at face value, progress has been slowed by disagreement about the final goals of restoration and fundamental differences in perspective amongst various agencies and stakeholders. While a great many natural system scientists have participated in CERP it is difficult or impossible to determine the impact of their contributions. On the other hand, human dimension scientists (e.g., economists, sociologists, and cultural anthropologists) have had minimal opportunity to participate in CERP planning or assessment. Moreover, CERP has focused primarily upon the southern portion of the Florida peninsula itself, and only considered the most nearshore regions of the surrounding SFCME.

From 2009 to 2013, the National Oceanic and Atmospheric Administration's National Centers for Coastal Ocean Science (NOAA/NCCOS) funded MARES (MARine and Estuarine goal Setting) to address these deficiencies and develop scientific consensus and synthesis for ecosystem-based management (EBM) of the SFCME. EBM was mandated in the National Ocean Policy of 2009 (Lubchenco and Sutley, 2010) and is described as a standardized implementation strategy that seeks to sustain coastal and ocean resources and their associated ecosystem services. EBM is an adaptive, holistic approach to dealing with the complexity of environmental challenges. Since 2010, implementing EBM has become a guiding directive in the federal management of U.S. coastal resources (Lubchenco and Sutley, 2010). From an EBM perspective, it is essential to consider social, cultural, and economic factors, in both the research and management context, along with ecological variables (Cheong, 2008; Lubchenco, 1998; Turner, 2000; Visser, 1999; Weinstein, 2009). Few people live in the remaining natural area of the Everglades, and the conceptual models developed for CERP do not explicitly include human activities, such as hunting, fishing, and sightseeing, as part of the ecosystem, except as drivers of change in the natural ecosystem. By contrast, most of the 6.5 million people residing in South Florida live near the coast, and many residents and visitors receive benefits from the SFCME resources and services. Forging a vision of the ecosystem shared by all, managers and stakeholders, is an essential initial step in EBM. The overall goal of the MARES project addresses this need directly.

The overall goal of **MARES** has been to reach a science-based consensus on the defining characteristics and fundamental regulating processes of a SFCME that is both sustainable and capable of providing the diverse ecosystem services upon which our society depends. This includes continuing to provide the tourism, recreational and fishing opportunities we have come to expect. The hypothesis advanced was that through participation in a systematic inclusive, holistic process of reaching consensus, scientists would be able to contribute more directly and effectively to the critical decisions being made by policy makers and by natural resource and environmental management agencies.

Issues of interest with respect to ecosystem based management are defined both at the scale of the SFCME in its entirety, essentially surrounding and overlapping with the geographic scope of the South Florida Ecosystem Restoration Task Force (see http://www.sfrestore.org/) which includes but is considerably broader than that of CERP, and at smaller legal or jurisdictional boundaries (cities and counties). The MARES project uses the terms "local," "regional," and "global" to distinguish different spatial scales at which drivers and pressures act on the ecosystem, as well as the scope of management actions. With respect to management, the local scale corresponds to the smallest scale at which management occurs, i.e., at the county level: Monroe, Miami-Dade, Broward, Palm Beach, Martin, Collier, and Lee. The regional scale corresponds to the area that contains the entire SFCME, while the global scale refers to factors arising from causes outside South Florida.

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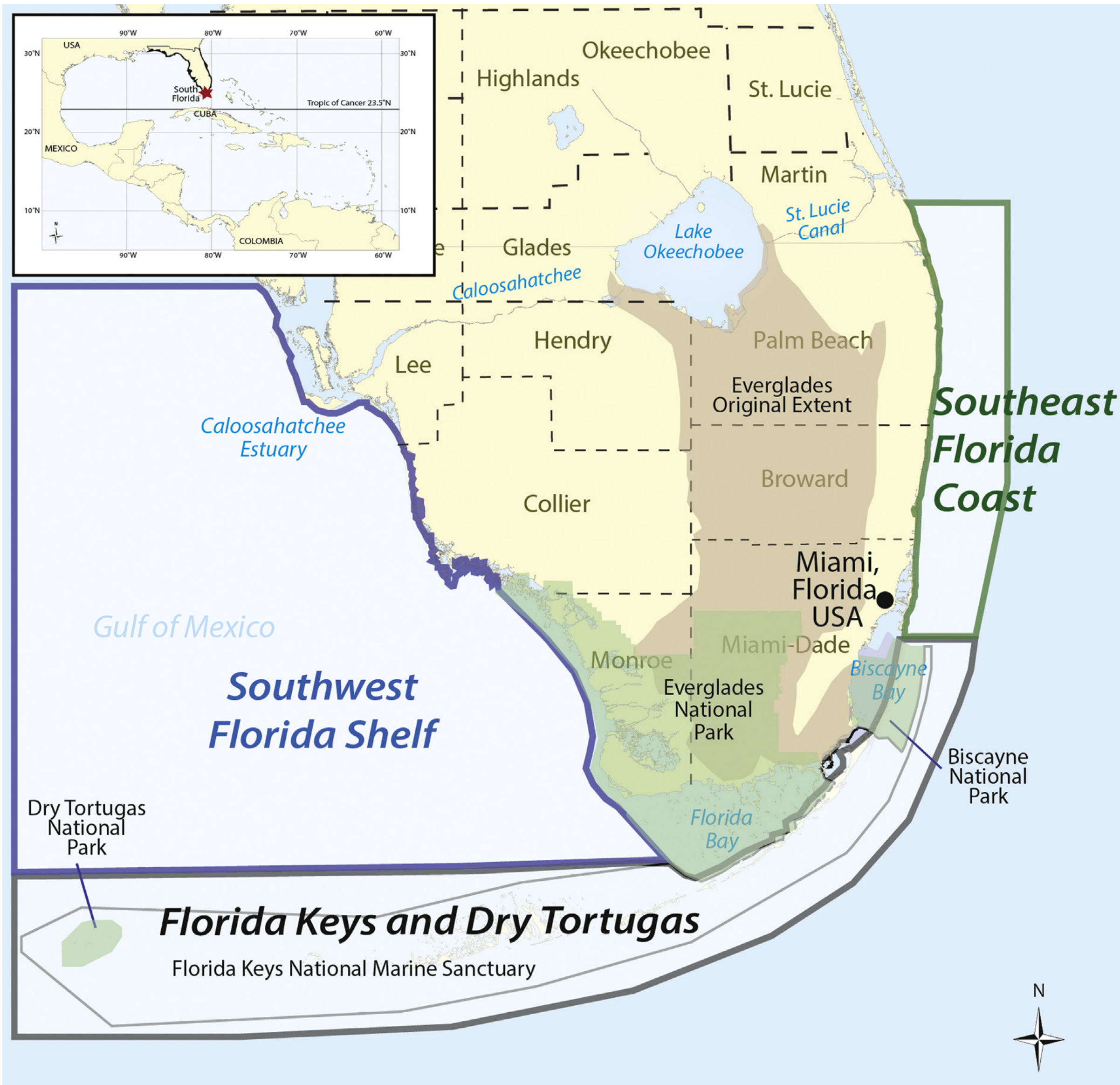

Fig. 1. The MARES study site consists of Florida Bay and Biscayne Bay, the Caloosahatchee Estuary, the Florida Keys and Dry Tortugas, the Southwest Florida Shelf, and the Southeast Florida Coast.

The SFCME varies considerably due to geomorphology and to local and regional oceanographic processes and can be understood as consisting of three distinct but highly interconnected sub-regions. From west to east, the three coastal sub-regions are the Southwest Florida Shelf (SWFS), the Florida Keys/Dry Tortugas (FK/DT), and the Southeast Florida Coast (SEFC). As noted earlier the SFCME also includes two large estuarine embayments—Florida Bay and Biscayne Bay—and several smaller estuarine systems, such as the Caloosahatchee Estuary (Fig. 1).

Each sub-region exhibits distinct characteristics. The SWFS encompasses the broad, shallow Florida Shelf. Oceanographic conditions therein, in particular long residence times and susceptibility to strong stratification, favor the development of phytoplankton blooms. The FK/DT sub-region sits between the SWFS and Gulf of Mexico, to the north, and the energetic Florida Current system offshore to the south and encompasses the shallow, subtropical waters surrounding the Florida Keys. The SEFC sub-region consists of a relatively narrow shelf bounded on its seaward side by the Florida Current and includes the northern extensions of the Florida Reef Tract.

The overall pattern of water flow is south along the west Florida coast in the Gulf of Mexico, east through the Florida Straits, and then north along the Southeast Florida Shelf. Recirculation and connectivity are provided by the combination and merger of four distinct current systems: (1) downstream flow of the Loop Current and Florida Current offshore of the SWFS and Florida Keys; (2) returning countercurrent flows in the Lower Keys and Dry Tortugas from prevailing westward winds; (3) enhancement of the countercurrent along the Florida Keys with the passage of Florida Current cyclonic frontal eddies (which also act to retain particles within interior eddy recirculations), and (4) net southward flow through the SWFS that can return waters to the Florida Keys Atlantic Coastal Zone (Fig. 2).

The SWFS is the southern domain of the wide, shallow West Florida Shelf. It receives moderate freshwater from small rivers and estuaries and undergoes seasonal stratification in the spring and summer (Weisberg et al., 1996). Currents over the mid to inner shelf are due primarily to wind and tidal forcing that align with the shelf's smooth north-south oriented topography (Mitchum and Sturges, 1982). Outer shelf flows are controlled by the Loop Current and

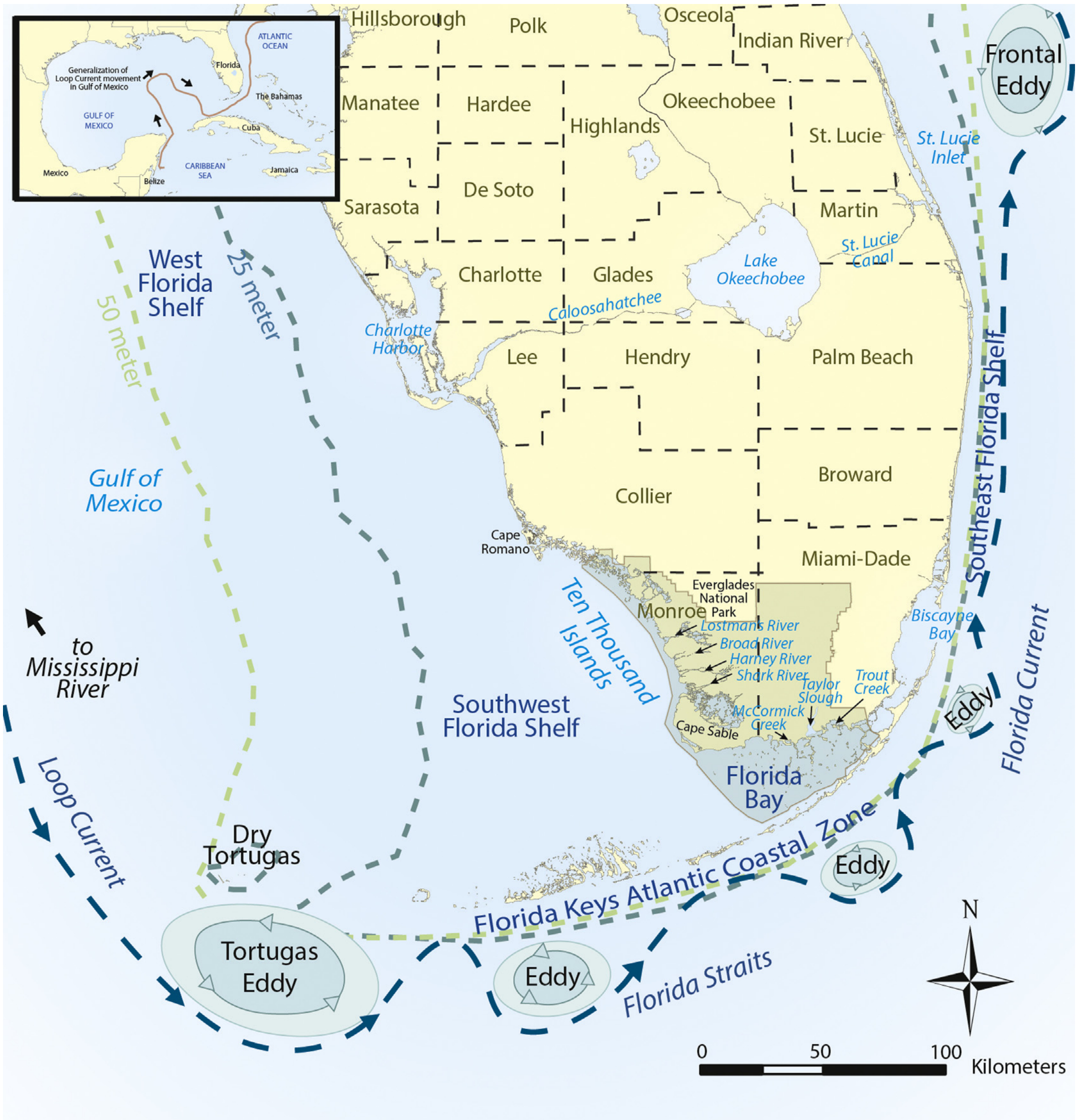

Fig. 2. Oceanographic processes connect the South Florida Coastal Marine Ecosystem sub-regions (Kruczynski and Fletcher, 2012).

eddies that move downstream along its shoreward boundary and vary considerably on day-to-month time scales. Warm eddies can separate from the Loop Current and move along the Dry Tortugas and Florida Keys Reef Tract. These separations cause instabilities that result in cold (upwelling), cyclonic frontal eddies that can be carried around the Loop Current and into the Straits of Florida and strongly interact with outer shelf waters (Fratantoni et al., 1998; Hamilton and Lee, 2005; Lee et al., 2002; Paluszkiewicz et al., 1983).

The FK/DT coastal region has a narrow shelf with a complex shallow reef topography that parallels the north-south (Upper Keys) to east-west (Middle and Lower Keys) curving chain of islands. Coastal waters tend to remain well mixed throughout the year, and there are no significant freshwater sources. Mid-to inner-shelf currents are primarily toward the west in the Lower Keys, due to prevailing westward (downwelling) winds. Northward currents in the Upper Keys are due to winds from the southeast and the close proximity of the northward flowing Florida Current (Lee and Williams, 1999; Lee et al., 2002).

Waters of the SEFC are highly connected to the upstream regions of the FK/DT and SWFS by the strong northward flow along the edge of the Florida Current. The SEFC region consists of a narrow coastal zone stretching north-south 176 km from Biscayne Bay to the St. Lucie Inlet. The portion of the shelf between Miami and Palm Beach counties is unusual in that it is extremely narrow and shallow, varying in width from 1 to 3 km, with only 30 m water depth at the shelf break. Coastal waters here are bounded by the highly developed shoreline of southeast Florida and the strong northward flowing Florida Current at the shelf break.

MARES brought together natural system and human dimensions scientists from academia, non-governmental organizations, federal, state, and local agencies to study the SFCME. In a real sense, MARES was a sociological experiment that sought to overcome two principal challenges of conducting scientific synthesis to inform EBM: first, how to represent human dimensions aspects of this ecosystem in the set of indicators and in the underlying conceptual model; and second, how to summarize information about such an ecologically and societally diverse and spatially extensive system in a way that is both comprehensive and comprehendible (Kelble et al., 2013). A systematic process was used to develop conceptual infographics, conceptual models, quantitative ecosystem indicators, and decision support tools for EBM.

MARES is already yielding practical benefits. The knowledge gaps identified through the process are being used by government agencies to prioritize research funding. The **MARES** process has provided a forum for interagency coordination and communication unavailable since the termination of the Interagency Florida Bay Science Program in 2008 (Hunt and Nuttle, 2007). Various environmental groups, including Florida's Coral Reef Conservation Program and the Sanibel-Captiva Conservation Foundation, are using the infographics created. MARES EBM-DPSER models are guiding the ecosystem valuation efforts being undertaken by NOAA's National Marine Sanctuaries program and will contribute to the Florida Keys National Marine Sanctuary re-zoning process. The Everglades National Park is relying upon **MARES** to inform its internal re-assessment of zoning in Florida Bay. Inquiries and invited briefings by **MARES** principals (e.g., in the northern Gulf of Mexico and in North Carolina) suggest that the process will soon be emulated in other coastal regions throughout the United States. The measure of ultimate benefit with respect to South Florida, however, will be if and when the participation of scientists and mid-level managers and administrators in **MARES**, is expressed in decisions made by those to whom they report; in other words, when decisions are truly being made through "adaptive management guided by the best-available-science".

The volume that follows is diverse. Overview articles range from contributions specifically addressing applications to EBM, the transfer of MARES products to management and the overall MARES process (Fletcher et al., 2014), to mathematical extensions of conceptual models (Cook et al., 2014; Elmer and Riegl, 2014), to the need for including social values in ecosystem management (Loomis and Patterson, 2014), and a theoretical framework for integrated indices equally applicable to human dimensions and ecological indicators (Loomis et al., 2014). These overview articles are followed by articles focused upon developing ecosystem indices for human dimensions components and a suite of articles focused upon ecosystem indices for natural system components. This diversity reflects not only the diversity of perspective and expertise amongst **MARES** participants but also the project's evolution as something of a test-bed for applied social and ecological science; in particular, the extent to which their insights can be truly integrated to address the challenges facing our threatened coastal ecosystems and the human communities dependent upon them.

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