Marine and Estuarine Goal Setting for South Florida

Integrated Conceptual Ecosystem Model for the Florida Keys / Dry Tortugas Marine Ecosystem

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Introduction

The integrated conceptual ecosystem model (ICEM) for the Florida Keys – Dry Tortugas marine ecosystem organizes existing scientific information on the regional ecosystem in a form relevant to the needs of coastal managers. The concept of ecosystem-based management guides the management of coastal resources at regional scales in the US.[1] Ecosystem based management is adaptive, geographically specific, takes account of ecosystem knowledge and uncertainties, considers multiple external influences, and strives to balance diverse societal objectives. In common with the conceptual ecological models previously developed for freshwater and estuarine areas of South Florida (Ogden et al, Gentile et al), the ICEM identifies 1) the major drivers and stressors affecting the Florida Keys – Dry Tortugas region, 2) their ecological effects, and 3) expected changes in the ecosystem in response to the drivers and stressors.

However, the ICEMs being developed for the coastal marine areas of South Florida differ from the CEMs developed for the Everglades in one important aspect. The “integrated” nature of the ICEMs refers to the fact that these conceptual models describe the effects of human activities in the regional ecosystem. Humans are recognized as an integral part of coastal ecosystems.[2] The human dimensions component of the ICEM for the Florida Keys – Dry Tortugas region includes the interactions between the communities of the Florida Keys and the surrounding coastal waters and the activities of agencies responsible for environmental management in the region.

Objectives for this Report

The overall goal of the MARES (**Mar**ine and **Es**tuarine Goal Setting) project is “to reach a science-based consensus about the defining characteristics and fundamental regulating processes of a South Florida coastal marine ecosystem that is both sustainable and capable of providing the diverse ecosystem services upon which our society depends.” This directly addresses the NOAA Ecosystem Goal: *to protect, restore and manage the use of coastal and ocean resources through an* ***ecosystem approach*** *to management*.

Development of an ICEM for the Florida Keys – Dry Tortugas region is the first substantive product of the MARES project. ICEMs play and essential role in regional ecosystem management; they help establish consensus, set goals and define those ecological indicators one must measure to assess the productivity, diversity, stability, and resilience of the ecosystem (i.e. the health and status of that ecosystem). This report articulates an ICEM for the Florida Keys – Dry Tortugas ecosystem based on the expertise of the Lead Principal Investigators for this region and input received from other scientists, resource managers and environmental organizations at a workshop held for this purpose in December 2009.

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[1] (insert ref on ecosystem based management of coastal resources)

[2] NOAA, 2003. Making “ecosystems” part of NOAA’s shared vocabulary. NOAA internal communication attached to memo from M. Sissenwine (NOAA Fisheries) to J. Kelly, Jr. (NOAA Executive Panel) dated November 7, 2003.

DPSER Framework

The conceptual ecosystem model for the Florida Keys – Dry Tortugas region integrates information about changes in the marine environment and information about how people respond to these changes, but without attempting to completely describe all human activities in the region, Figure 1.1. The model uses the DPSER framework (Drivers, Pressures, State, Ecosystem Services, Response; Table 1.1), which is a slightly modified form of the DPSIR framework.[3] The DPSER framework shares elements with the framework used as the basis for the conceptual models developed for the Everglades.[4] Therefore, the approach taken here can be considered to be an extension of the approach taken elsewhere in South Florida that addresses the problem of how to account for the human dimension of ecosystems in the region.

The DPSER framework incorporates people's values and goals for sustaining the regional ecosystem by linking changes in attributes of the environment with ecological services. The first three elements of the model framework (Drivers, Pressures, State) describe causal links in the processes behind environmental change. These elements correspond more or less directly with the Drivers-Stressors-Ecological Change elements of the CERP conceptual models.[5] Ecological services are the benefits that people derive from the environment. Ecological services can be evaluated and ranked using various techniques developed by resource economists.[6] The Response element describes decisions and actions that individuals and management agencies make in response to changes in the environment. These decisions are based on an evaluation of changes in ecosystem services, and they can influence conditions in the ecosystem by altering the Drivers and Pressures and their impact on the State of the environment. Therefore, the Response element introduces the notion of feedback and control into the conceptual model of the integrated ecosystem.

An important feature of this integrated conceptual model is that it changes the conversation from the false dichotomy between the economy and the environment, which has been a major barrier to policy/management actions to protect and restore the environment. By integrating the full human system into the model, the benefits of environmental protection and restoration are explicitly recognized, which breaks the false dichotomy between the economy and environment. The conversation is now changed to who benefits and who suffers costs when there are changes in ecological attributes. Policy/management is now more informed about the nature of the possible trade-offs involved, which can help break down the barriers to change.

Within the Driving Forces-Pressure-State-Impacts-Response (DPSIR) model, socioeconomics/human dimensions enter by contributing towards understanding the driving forces behind the pressures being placed upon the natural resources and environment; the "impacts section" addresses the state of the human system vis-à-vis the dependence of the human system on the state of the natural resources and environment; and the "response section" contributes to the understanding of individual and organizational behavioral responses.

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[3] The **DPSIR** framework is finding broad application in environmental assessments of terrestrial and aquatic ecosystems (Christian et al. 2005). We substitute the term "Ecosystem Services" for "Impacts" to avoid the negative connotation of the later term.

[4] Ogden et al. 2005

[5] Ogden et al. 2005

[6] Farber et al. 200x

The main difference between the traditional ecosystem risk assessment models, which provide the foundation for the “Pressure-State-Response” Model, is the inclusion of the “Impacts” component. The “Impacts” component of the model begins with the links to the state of the natural resources/environment component of the model with a focus on “attributes” of the natural resources/environment that people care about, thus addressing the question of “Who Cares?” or what are the benefits or costs associated with changes in the state of the natural resources/environmental attributes. Humans now are represented in the model not as just putting pressure on the natural resources/environment, but also dependent on the state of the natural resources/environment. And, most importantly, the same people stressing the natural resources/environment may not be the same people who are dependent on the state of the natural resources/environment. In the “response’ section of the model, this leads to addressing trade-offs across different user groups.

Figure 1.1: Florida Keys / Dry Tortugas Regional ICEM

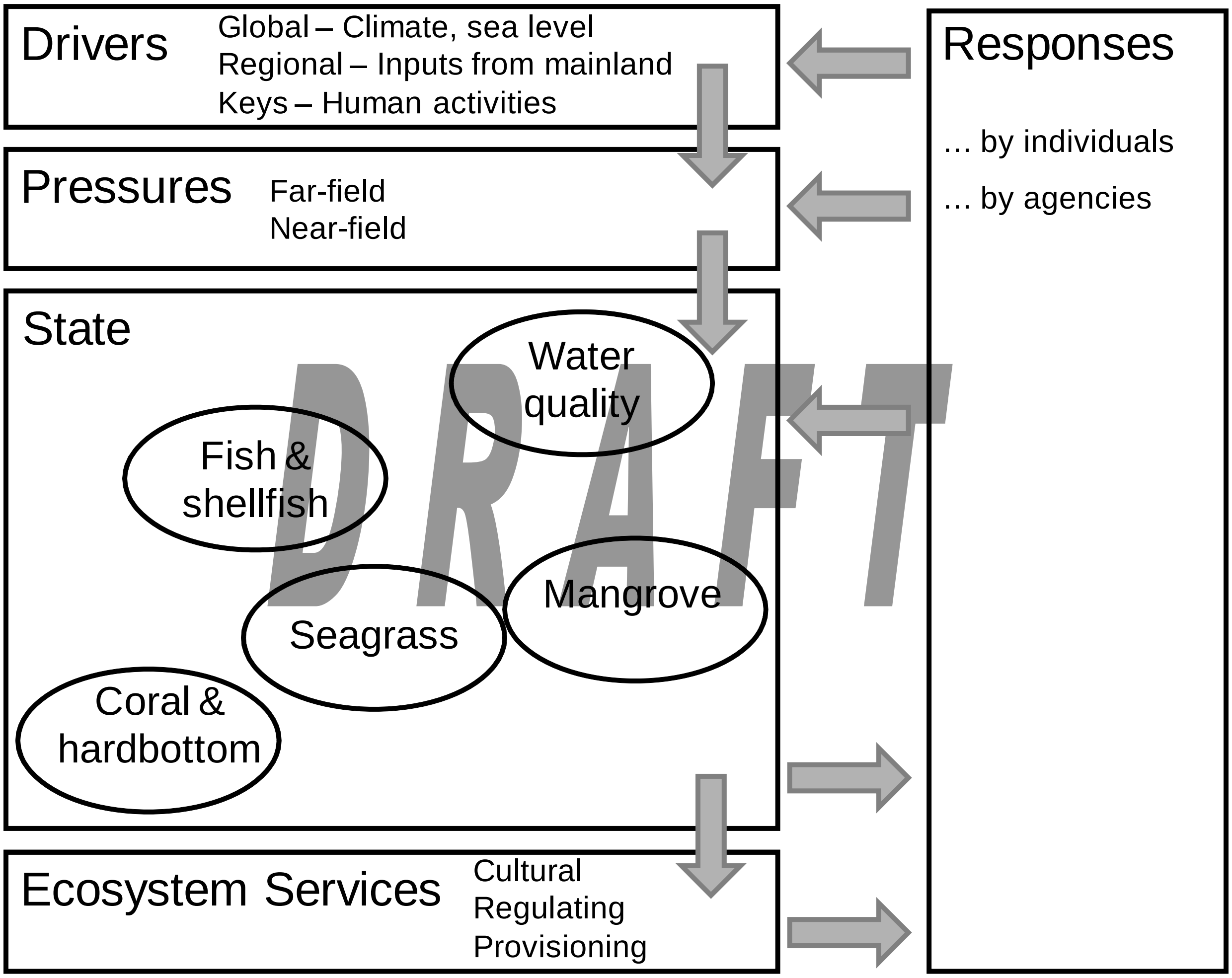


Table 1.1: Elements of the DPSER model framework

Drivers	– the large-scale factors that are the ultimate cause of change to the ecosystem. External, or farfield, drivers influence the ecosystem from outside of the region. Internal, or nearfield, drivers exert influence from within the ecosystem. For example, global climate change represents an external driver because it acts at the scale of the entire globe. Increased tourism represents an internal driver because it selectively influences the nature and intensity of certain human activities within the Florida Keys – Dry Tortugas region.
Pressures	– the regional-scale effects of the Drivers that are the proximate causes of change in the environment. Some pressures act by altering conditions at the boundary of the region, and their effects propagate into and throughout the ecosystem. For example, ocean currents carry changes in ocean water nutrient concentrations, perhaps related to freshwater discharge along the Southwest Florida coast, into the Florida Keys – Dry Tortugas region. Other pressures are generated internally and vary intensity across the region. For example, damages to benthic habitats caused by boat groundings are highest in shallow water areas either near the Keys or near shipping lanes. (Figure – graphic representation of pressures affecting the FK-DT region)
State	– the condition of the environmental (physical & chemical) and ecological (biological) components of the ecosystem. Physical, biological, and chemical processes interact to affect different structures (chemicals, species) that are measured by their attributes. Attributes are characteristics that contribute to ecosystem services. The State of the ecosystem also takes into account the various interaction amount different environmental attributes. For example, changes in water quality affecting seagrass habitat and fisheries.
Ecosystem Services	– the benefits that humans derive from the environment. Ecosystem services are related directly to "attributes [of the environment] that people care about." Changes in the quality and functioning of the ecosystem affect the welfare (well-being) of humans through changes in ecosystem services. Ecosystem services provide benefits to people both living within and outside of the region, over the short term and the long term, and have value that reflects human need and use (e.g., market value). Values depend on the attributes of the state and characteristics of the drivers and pressures. For example, corals can provide shoreline protection, but the value depends on the frequency of hurricanes and the number of hotels/houses near the coast. Values, in turn, can affect the drivers and pressures. For example, fish biomass can sustain fisheries and influence shipbuilding.
Response	– the changes in human activities that come about with desired changes in the ecosystem. Responses reflect the assessments and decisions made by individuals and agencies charged with managing the components of the ecosystem. In the DPSER framework, the response component represents the feedback mechanisms through which changes in human activities influence Ecosystem Drivers, Pressures, State and Services. Ideally, decisions to effect a change should weigh all available information about ecosystem functioning, ecosystem service values, and management goals.

The Florida Keys – Dry Tortugas Coastal Region

Geographic Setting

The Florida Keys comprises a chain of islands extending from Key Largo to Key West and connected by 110 miles of US Highway 1, Figure 1.2. The Keys is one of the most ecologically diverse, and most imperiled, ecosystems in the United States. They are the location of North America's only coral reef, and it is the third largest coral reef system in the world. The surrounding marine waters includes the Florida Keys National Marine Sanctuary, the second largest marine sanctuary in the United States.

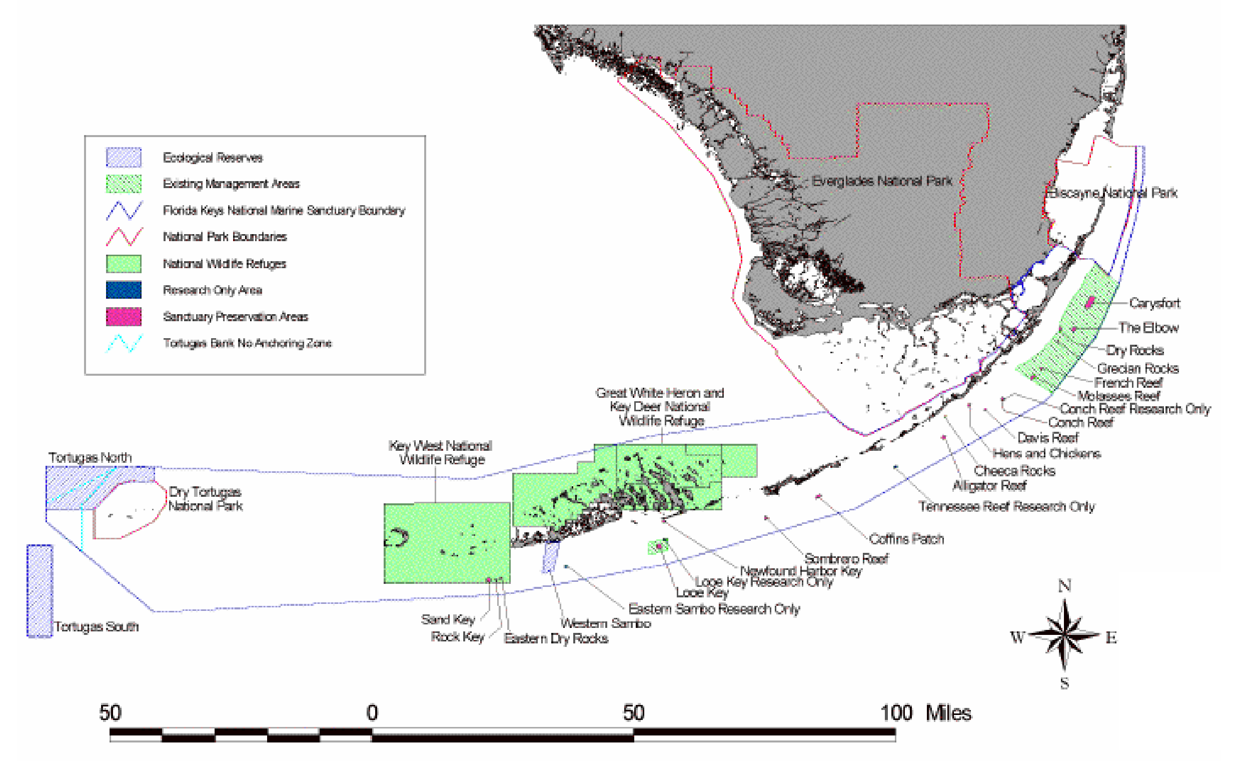
The marine component of the ecosystem is composed of tropical to subtropical waters that contain diverse benthic community types, including bank barrier coral reefs, patch reefs, hard bottoms, and sea grass. This diversity of community types results in high species richness. The Keys are a popular tourist destination, in part because the faunal richness provides interesting snorkeling and diving venues. Furthermore, the shallow water environments surrounding the Keys contain extensive nursery areas and fishing grounds for a variety of commercially and recreationally important marine species.

The FKDTR domain, like the southwest Florida shelf, is integrally connected with respect to hydrology and ecosystem response with the main Everglades fresh water thoroughfare. Prevailing ocean currents link the Florida Keys to the Everglades, Florida Bay, and the southwest Florida shelf. Water generally flows from the Gulf of Mexico, through the Keys passes, to the Atlantic Ocean, and is eventually entrained by the Florida Current and flows northeastward. Thus, the health of the Florida Keys ecosystem requires that projects developed as part of the CERP need to factor in the effects that those projects will have downstream.

Conditions in Florida Bay have been linked to Everglades' runoff from both Taylor Slough (in eastern Florida Bay) and Shark River Slough (on the southwest Florida shelf). Salinity changes have been dramatic in the 20th century (Brewster-Wingaard et al., 1998). Tidal mixing through the Keys passes can result in a direct influence of Florida Bay water quality on the ecosystems of the FKNMS (Boyer and Jones, 2002).

Upwelling of deep waters is another source of nutrients to the Keys (Leichter et al., 2003). Because of the volume of the water involved, upwelling events may overwhelm other sources of nutrients to the reef tract. Storm events may also result in changes in circulation patterns that can result in nutrient enrichment. Also, storm events may flush nutrients from land-based sources in the Keys to near-shore waters.

Figure 1.2: Florida Keys region map



Natural Resources

Florida Keys National Marine Sanctuary

The Florida Keys National Marine Sanctuary extends approximately 220 nautical miles southwest from the southern tip of the Florida peninsula. The Sanctuary's marine ecosystem supports over 6,000 species of plants, fishes, and invertebrates, including the nation's only living coral reef that lies adjacent to the continent. The area includes one of the largest seagrass communities in this hemisphere. Attracted by this tropical diversity, tourists spend more than thirteen million visitor days in the Florida Keys each year. In addition, the region's natural and man-made resources provide livelihoods for approximately 80,000 residents.

The Sanctuary is 2,900 square nautical miles of coastal waters, including the recent addition of the Tortugas Ecological Reserve. The Sanctuary overlaps six state parks and three state aquatic preserves. Three national parks have separate jurisdictions, and share a boundary with the Sanctuary. In addition, the region has some of the most significant maritime heritage and historical resources of any coastal community in the nation.

The Sanctuary faces specific threats, including direct human impacts such as ship groundings, pollution, and overfishing. Threats to the Sanctuary also include indirect human impacts, which are harder to identify but seem to be reflected in coral declines and increases in macroalgae and turbidity.

Dry Tortugas National Park

Dry Tortugas National Park lies at the western end of the Florida Keys along the Straits of Florida. The seven islands of the Dry Tortugas are composed of sand, limestone, and coral reef fragments and are surrounded by shoals and water to depths of 25 m (82 ft). A significant characteristic of the park is its ratio of land to water: 99.8% of the park consists of marine ecosystems.

Congress established the park to "preserve and protect for the education, inspiration, and enjoyment of present and future generations nationally significant natural, historic, scenic, marine, and scientific values in south Florida." The enabling legislation stipulates that the park must be managed so as to protect, among other values, "a pristine subtropical marine ecosystem, including an intact coral reef community."

In support of these objectives, the National Park Service and the Florida Fish and Wildlife Conservation Commission manage the Research Natural Area of Dry Tortugas National Park. The Research Natural Area complements protection afforded by the adjacent Tortugas Ecological Reserve of the Florida Keys National Marine Sanctuary established by the National Oceanic and Atmospheric Administration and the state of Florida. Together, the Research Natural Area and the larger Tortugas Ecological Reserve will help to ensure the success of both marine and terrestrial ecosystems while offering outstanding opportunities for scientific research and public education.

Human Dimensions

The Florida Keys Area of Critical State Concern includes Monroe County and the municipalities of Key Colony Beach, Layton, Islamorada and Marathon. The current population of the Keys is about 73,000 permanent, year-round residents U.S. Dept. of Commerce, Bureau of the Census 2009). On an average day during the winter season (December through May) there are an additional 43.6 to 44.5 thousand visitors in the Florida Keys making the functional population between 116 and 177 thousand people. On a peak day, the functional population is estimated to be between 151 and 152 thousand people.[7]

Monroe County

Unincorporated Monroe County is composed of 31 major islands and contains approximately 47,191 acres of land above mean high water in the archipelago and 1,070,362 acres on the mainland encompassing portions of Everglades National Park and Big Cypress National Preserve. The 2007 population estimate by the Bureau of Economic and Business Research is 35,749.

Key Colony Beach

The City of Key Colony Beach incorporated in 1957. The City of Key Colony Beach is comprised of a 286 acre key created by fill. Key Colony Beach is near the City of Marathon between Vaca Key and Grassy Key. Key Colony Beach has 857 residents.

Layton

The City of Layton incorporated in 1963. The City is comprised of 85 acres on Long Key. The City of Layton currently has a permanent population of approximately 196 residents. The Village is comprised of four main islands including Plantation Key, Upper and Lower Matecumbe Keys and Windley Key. The Village contains 3,796 acres of upland area. The 2007 population estimate by Bureau of Economic and Business Research is 7,149. The Village of Islamorada's Comprehensive Plan became effective on December 6, 2001.

Marathon

The City of Marathon incorporated in 1999. The City of Marathon is composed of 13 islands and contains approximately 5,505 acres. The 2007 population estimate by the Bureau of Economic and Business Research is 10,396.

Key West

The City of Key West incorporated in 1828. Key West is the southern-most city in the continental United States. The island-community is located about 90 miles north of Cuba and 150 miles southwest of Miami. The City has an area of 5.79 square miles. The 2007 population estimate by the Bureau of Economic and Business Research is 24,629.

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[7] (Leeworthy, Loomis and Paterson 2010)

Integrated Conceptual Ecosystem Model

Drivers

Changes in the marine environment of the Florida Keys share the same underlying causes as environmental changes in the Everglades and the rest of South Florida. The drivers of change act at three scales. Globally, changes arise from the effects of climate change, rising sea level, and economic and demographic factors that drive changes in land use and exploitation of the regions natural resources. At the scale of the South Florida region, agricultural, municipal and regional water management practices affect water quality and other characteristics of nearshore, coastal waters, and these changes are carried into the waters of the Florida Keys. Locally, human activities in the Florida Keys impose their own set of pressures on the surrounding marine environment.

Global - Climate Change and Rising Sea Level

Climate and sea level have shaped the ecology and geology of the Florida Keys and surrounding marine waters at the most basic level. Owing to its sub-tropical climate, coastal waters of South Florida support an assemblage of flora and fauna not found in other parts of Florida or elsewhere in the conterminous United States. The islands of the Florida Keys are comprised of portions of a relic (Holocene ?) coral reef, in the Upper and Middle Keys, and deposits of oolitic sediments (Lower Keys) that formed under conditions of higher sea level xxxxx years ago. Among the organisms unique to this region are those organisms responsible for producing its distinctive calcareous sediments; these include corals, mollusks, calcareous green algae, and various epiphytic organisms of the seagrass beds (spirorbid polychaetes, sortid foraminiferans, encrusting coralline algae, etc.).[8]

"Over the next century, global climate change will interact with and magnify other stresses on South Florida ecosystems (Twilley et al. 2001). Global climate models suggest significant temperature increases and an amplified rate of sea-level rise over the next 100 years with summer highs increasing between 2 degrees and 4 degrees Celsius and winter lows temperatures increasing 3 degrees Celsius in South Florida (Twilley et al. 2001). These warmer temperatures will result in fewer freezes, changes in rainfall and storm frequency, and possible shifts in ranges of plant and animal species and alterations in the composition of biological communities."[9]

Regional - Inputs from the South Florida Region

Human activities on the South Florida mainland influence conditions in the Florida Keys marine ecosystem through their effect on the discharge of freshwater, nutrients and contaminants into coastal waters of the Southwest Florida Shelf. The Southwest Florida Shelf is upstream of the Keys in the general pattern of ocean currents in this area of the South Florida coast. Changes to land-use in South Florida, mostly during the 20th century, converted vast areas of freshwater wetland to urban and agricultural uses and drastically altered the regional hydrology. A regional water management system provides serves flood control and water supply needs of a booming growth in human population but with the consequence that water management and agricultural

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[8] Fourqurean and Robblee 1999

[9] (from Ogden et al. 2005)

and urban land-use practices have altered the timing, distribution, quantity and quality of freshwater discharge into coastal waters. Further changes in inputs from the South Florida region can be anticipated into the foreseeable future.

Human impacts have grown as a result of Florida's ten-fold population growth from 1.5 million people in 1930 to 16 million in 2000. In 2000, over 5 million residents, nearly a third of Florida's population, lived in the five southern counties adjacent to coral reefs (Palm Beach, Broward, Miami-Dade, Monroe and Collier). The long-term aim of the Comprehensive Everglades Restoration Plan is to restore a more natural hydrologic regime even while making other changes in the regional water management system that will be needed to increase water supplies.

Marine waters of the Florida Key are vulnerable to impacts from human activities outside of the South Florida region. The Florida Keys occupies a crossroads for large-scale oceanic and atmospheric processes. Within the Gulf of Mexico, the Loop Current drives a clockwise circulation within the Gulf of Mexico, ending just west of the Dry Tortuga. The Florida Current flows east from this point, then northeast along the Florida Keys before joining the Gulf Stream in the Atlantic Ocean. Through these currents, the marine waters of the Key are vulnerable to impacts from extensive oil and gas exploration and production activities in the Gulf, as demonstrated by the Deepwater Horizon spill (2010).[10] On a global scale, human use of fossil fuels is changing the chemistry of the atmosphere. This contributes to climate change, accelerates the rate of sea level rise, and affects chemical characteristics, e.g. pH, of marine waters.

Local - Human Activities in the Florida Keys

Human activities in the Florida Keys generate a different set of pressures and have a more direct effect on environmental conditions in the ecosystem, especially in the vicinity of the main islands that support habitation. The Florida Keys attract visitors from throughout the world for tourism and recreational activities that exploit its unique coastal marine environment. Over three million tourists visit the Keys annually, and in 2007-08 tourism accounted for 60% of the economy of the Keys.[11]

"Coral reefs in the Florida Keys are impacted by fishing and indirectly by habitat degradation from other human activities including coastal development, altered freshwater flow, and changes in water quality from pollution, sedimentation, and excess nutrients (CERP 1999, Cowie-Haskell and Delaney, 2003).[12] Up until the 1970s, unregulated use of the marine ecosystem for both commercial and recreational activities resulted in an increasing instance of damage to vulnerable coral and seagrass communities. Concerns over degradation of the marine environment led to the creation of the Florida Keys National Marine Sanctuary and efforts to reduce degradation through public education and regulation of water-related activities.

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[10] Ortner et al. (200x, confirm ref) detected the influence of Mississippi River carried into the Keys waters by this transport mechanism.

[11] (Leeworthy , Loomis, and Paterson 2010)., (Leeworthy and Ehler 2010)

[12] (from Ault et al. 2005)

Pressures

Pressures are the direct, proximate effects of drivers causing change in the ecosystem. It is useful to distinguish between pressures arising from far-field drivers, i.e. drivers that act on the global scale and the scale of the South Florida region, and near-field drivers that act within the region of the Florida Keys and Dry Tortugas, Figure 2.2. The distinction between pressures from far-field and near-field drivers has practical implications in deciding how to respond to the resulting changes in the ecosystem. The effects of pressures arising from near-field drivers can be addressed by taking actions within the region of the Keys that alter the drivers and/or the pressures they create. For example, the impacts of increased residential development (driver) through additional nutrient loading (pressure) on nearshore water quality is being addressed by restricting development and upgrading sewage treatment. Different options must be considered in responding to the effects of pressures arising from far-field drivers. For these, actions within the Keys are limited to adapting to environmental change and taking actions that promote the recovery of the ecosystem from these impacts. Actions to reduce the impact of far-field drivers requires coordination and actions over a scale larger than the Florida Keys and Dry Tortugas, and possibly over a much larger scale than the South Florida region, e.g. climate change.

Far-field Pressures

Ocean water quality

Changes in the quality and characteristics of ocean water surrounding the Florida Keys exert a major influence on the quality of coastal waters in the Keys and on other elements of the environment. Changes in sea surface temperature, nutrient concentrations, contaminants, pH and the occurrence of harmful algal blooms are particularly important. Sea surface temperature is affected by global climate change. Concentrations of nutrients and contaminants are affected by inputs from the South Florida mainland and from other, more distant sources. Rising concentrations of carbon dioxide in the atmosphere, related to the use of fossil fuels, cause a decrease in the pH of seawater, increasing acidity. Harmful algal blooms form over the Southwest Florida Shelf when conditions there are right, and these are carried into the Florida Keys by the prevailing mean current.

“Corals are affected by warming of surface waters (Chapter 6, Box 6.1; Reynaud et al., 2003; McNeil et al., 2004; McWilliams et al., 2005) leading to bleaching (loss of algal symbionts – Chapter 6, Box 6.1). Many studies incontrovertibly link coral bleaching to warmer sea surface temperature (e.g., McWilliams et al., 2005) and mass bleaching and coral mortality often results beyond key temperature thresholds (Chapter 6, Box 6.1). Annual or bi-annual exceedance of bleaching thresholds is projected at the majority of reefs worldwide by 2030 to 2050 (Hoegh-Guldberg, 1999; Sheppard, 2003; Donner et al., 2005). After bleaching, algae quickly colonise dead corals, possibly inhibiting later coral recruitment (e.g., McClanahan et al., 2001; Szmant, 2001; Gardner et al., 2003; Jompa and McCook, 2003). Modelling predicts a phase switch to algal dominance on the Great Barrier Reef and Caribbean reefs in 2030 to 2050 (Wooldridge et al., 2005).[13]

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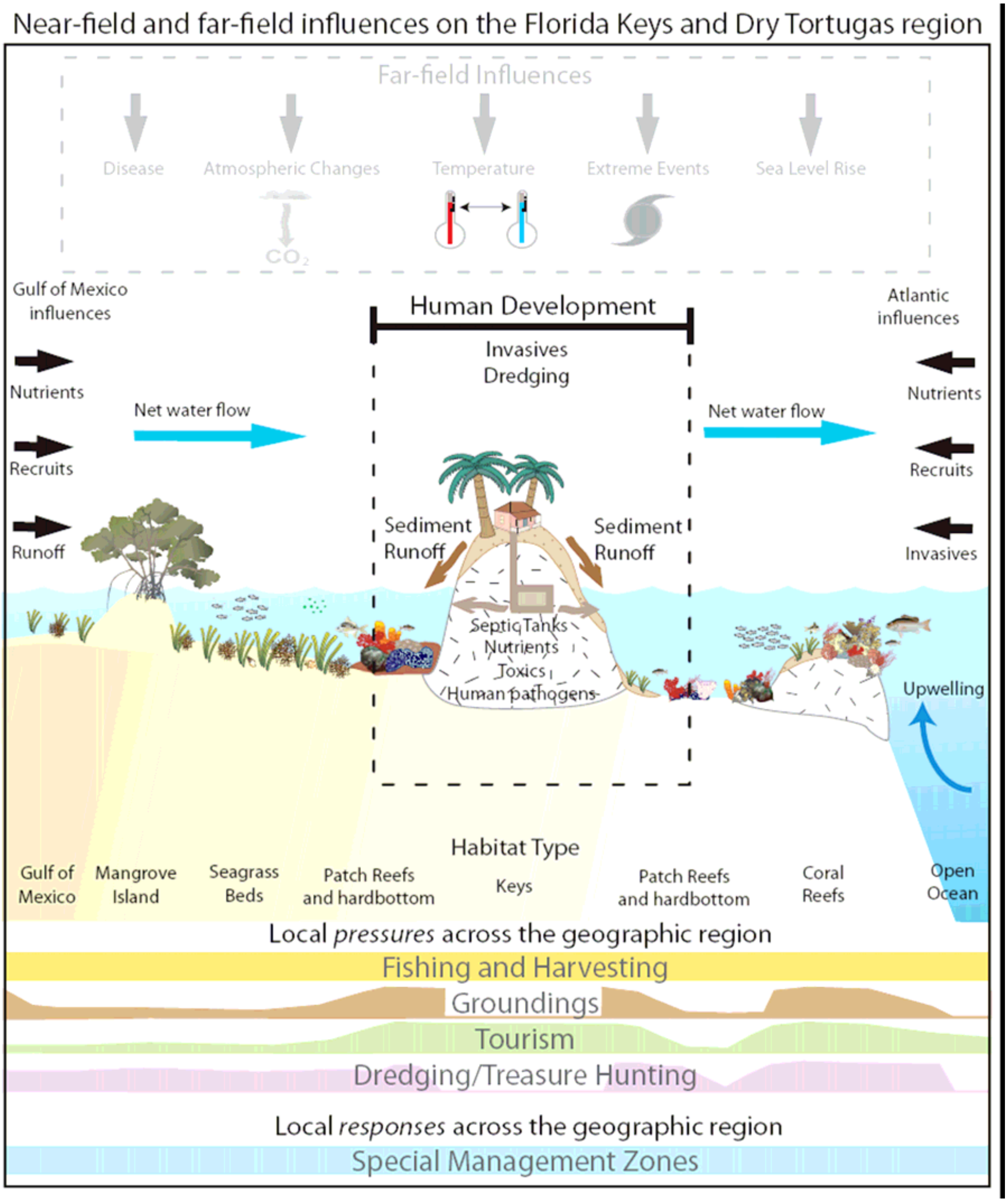
[13] (text extracted from - Fischlin, A., G.F. Midgley, J.T. Price, R. Leemans, B. Gopal, C. Turley, M.D.A. Rounsevell, O.P. Dube, J. Tarazona, A.A. Velichko, 2007: Ecosystems, their properties, goods, and services. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, 211-272.)

Figure 2.2: Pressures from near-field and far-field drivers on the Florida Keys marine ecosystem



"Coral reefs will also be affected by rising atmospheric CO2 concentrations (Orr et al., 2005; Raven et al., 2005; Denman et al., 2007, Box 7.3) resulting in declining calcification. Experiments at expected aragonite concentrations demonstrated a reduction in coral calcification (Marubini et al., 2001; Langdon et al., 2003; Hallock, 2005), coral skeleton weakening (Marubini et al., 2003) and strong temperature dependence (Reynaud et al., 2003). Oceanic pH projections decrease at a greater rate and to a lower level than experienced over the past 20 million years (Caldeira and Wickett, 2003; Raven et al., 2005; Turley et al., 2006). Doubling CO2 will reduce calcification in aragonitic corals by 20%-60% (Kleypas et al., 1999; Kleypas and Langdon, 2002; Reynaud et al., 2003; Raven et al., 2005). By 2070 many reefs could reach critical aragonite saturation states (Feely et al., 2004; Orr et al., 2005), resulting in reduced coral cover and greater erosion of reef frameworks (Kleypas et al.,2001; Guinotte et al., 2003).[14]

Sea level, tides and currents

The global phenomenon of climate change and sea level rise affect sea level fluctuation, tides and currents in the Florida Keys. The geomorphology of the extensive shallow water areas surrounding the Keys, including numerous small mangrove islands found in these waters, reflect the influence of a stable regime of slowly rising sea level (< 4 cm/100 years) during the past ~3200 years (Wanless et al. 1994 – is this the right ref?). Since about 1930, the relative rate of sea-level rise has increased substantially, averaging 30-40 cm/100 years (Wanless et al. 1994). As a result, marine waters have encroached significantly landward (on low-lying mainland, at same time seaward progression of mangroves has occurred in many areas of the Keys). Continuation of this rate and a possible increase up to 60 cm/100 years by the middle of the twenty-first century (Wanless et al. 1994) (update with IPCC sea level rise scenarios) will push marine water far into freshwater environments, resulting in a substantial loss of freshwater wetlands (on mainland South Florida) and diminished groundwater resources.[15]

Atmospheric processes

Atmospheric processes that control temperature, rainfall, evaporation, and the frequency and occurrence of extreme weather conditions, such as tropical storms, affect conditions in the Florida Keys marine ecosystem. Atmospheric deposition can also be a significant source for nutrients (Rudnick et al. 1994) and disease organisms (ref on African dust impacts on Caribbean). In addition, hurricanes have an annual 16% probability of striking the Keys.

Diseases

Affects coral… need more text here

Invasive Species

(add text, need example illustrating invasive species impacts on Keys marine ecosystem)

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[14] (text extracted from - Fischlin, A., G.F. Midgley, J.T. Price, R. Leemans, B. Gopal, C. Turley, M.D.A. Rounsevell, O.P. Dube, J. Tarazona, A.A. Velichko, 2007: Ecosystems, their properties, goods, and services. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, 211-272.)

[15] (Wanless et al. 1994, Twilley et al. 2001, Ross et al 2xxx).

Near-field Pressures

Water-related Activities

The fishery has been extensively exploited over the past 75 years. Mortality from fishing, both for recreation and for commercial harvest, has had perhaps the greatest impact of all the pressures acting on the Florida Keys marine ecosystem. The snapper-grouper complex of 73 species of reef-dwelling fish is overfished relative to established benchmarks for sustainability of the stocks (Ault et al. 2005). This complex of species have experienced high rates of exploitation since the 1970s, precipitating a condition known as "serial overfishing" in which the fishery first depletes more valuable species (usually large, long-lived grouper and snapper) and then progressively switches to less valuable species (Ault et al. 1997, 1998, 2001, 2002). Despite the long and storied history of the fishery, active monitoring, management and regulation of the fishery began only in the 1980s in response to growing public conflicts and sharp declines in catches. The weight of scientific evidence suggests that, for the Keys reef fishery, existing management controls are insufficient to ensure its long-term sustainability (Ault et al. 2005).

"Fisheries in southern Florida are complex (Bannerot 1990, Chiappone and Sluka 1996). Adult reef fishes are caught for food and sport around bridges and on offshore patch and barrier reefs. Commercial and sport fisheries also target spiny lobster, marine aquarium fishes and invertebrates, inshore and offshore. Pink shrimp, a principal prey item of the snapper-grouper complex, are intensively exploited. Offshore, a substantial commercial food fishery targets adult pink shrimp inhabiting softbottom habitats near coral reefs. In coastal bays and near barrier islands, juvenile pink shrimp are commercially targeted as live bait for the recreational fishery. Both food and sport fisheries target pre-spawning subadult pink shrimp as they emigrate from coastal bay nursery grounds to offshore spawning grounds. Inshore, sport fisheries pursue highly prized game fishes, including spotted seatrout, sheepshead, black and red drum, snook, tarpon, bonefish, and permit, while commercial fisheries primarily target sponges and crabs. Offshore of the deep margin of the barrier reef, commercial and sport fisheries capture an assortment of species including amberjack, king and Spanish mackerel, barracuda, sharks and small bait fishes (e.g. Exococtidae, Mullidae, Carangidae, Clupeidae, and Engraulidae). Farther offshore (seaward of the 40 m isobaths), commercial and sport fisheries catch dolphin fish, tunas, and swordfish, and sport fishers target sailfish, wahoo, and white and blue marlin.[16]

"Precise data on coral reef fishing effort trends do not exist, but are reflected by state-wide fishing statistics and numbers of registered boats. In 2001, for example, an estimated 6.7 million recreational fishers took 28.9 million marine fishing trips in Florida and caught 171.6 million fish, of which 89.5 million (52%) were released or discarded (U.S. Department of Commerce, 2002). From 1964-2002 the number of registered recreational boats in southern Florida grew by more than 500%. Many of these vessels are used for fishing and for non-extractive activities, such as sailing, sightseeing, transportation, snorkeling, and SCUBA diving. Increased fishing fleet size has been accompanied by a number of technological advances that have been estimated to have quadrupled average fishing power (Mace 1997), i.e., the proportion of stock removed per unit of fishing effort (Gulland 1983). These advances include improvements in fishing tackle, hydroacoustics (depth sounders and fish finders), navigation (charts and global positioning

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[16] (extracted from Ault et al. 2005)

systems), communication, and inexpensive, efficient, and more reliable vessel and propulsion unit designs (Bonsack and Ault 1996, Ault et al. 1997, 1998). These fishing trends have thus become an obvious concern to the fishery sustainability and persistence of the coral reef ecosystem.[17]

Accidental damage to benthic habitat

Commercial and recreational boating activities in the Keys marine waters leads to unintended damage to coral, hardbottom and seagrass benthic habitats from groundings, impact and scarring from propellers, contact by divers and snorkelers, and damages caused by anchors, lobster traps and other types of fishing gear. The response has been to limit damages through education on safe boating practices, providing mooring buoys and restricting motor use in sensitive areas.

Effects of Development in the Keys

Impacts from human development in the Keys date from around 1912, the year in which Henry Flagler, the wealthy industrialist who developed much of the Florida east coast, completed a railroad link between Miami and Key West. The railway ceased operation due to damage from the 1935 hurricane, but a roadway built on the old track bed reestablished land transportation through the Keys in the early 1940s. This opened the entire island chain to development pressure. From this start, the human population spread to all of the islands along the rail route, growing exponentially until about 1990. Booming growth in tourism drove rapid development through the 1970s and 1980s.

The initial impact of human development on the surrounding marine waters resulted from alteration of the shoreline by excavation and dredging and filling in mangrove wetlands and in nearshore waters. Perhaps the principal, immediate impact of the construction of the railway was to alter water movement through channels between the islands along the route, which were either filled completely or obstructed by viaducts constructed to carry the track bed. The extensive development during the 1970s and 1980s fueled the loss of natural mangrove shoreline habitat and the construction of numerous canals, which became hotspots for water quality problems resulting from the input of nutrients and contaminants.

Human habitation imposes a different set of continuing pressures on the marine ecosystem. These include altered freshwater inflows, e.g. from stormwater and associated contaminants; nutrient loads related to sewage disposal; and incidental/accidental inputs of contaminants and trash. The two main problems associated with pollution from wastewater are fecal contamination and nutrient enrichment. Cesspits installed for the disposal of domestic sewage constructed during the development boom of the 1970s and 1980s are ineffective at reducing nutrient levels before the discharged wastewater reaches marine waters, and many of these systems are still in use. Stormwater runoff carries nutrients and other pollutants, such as oil and metals, that accumulate on roadways. Facilities for collecting and treating stormwater before discharge to marine waters are largely non-existent. Stormwater runoff accounts for about 21%

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[17] (extracted from Ault et al. 2005)

of the nitrogen and 45% of the phosphorous discharged to marine waters in developed areas of the Keys.[18]

State

The marine waters of the Florida Keys encompass an ecologically-diverse environment. In order to better describe its attributes and the processes that sustain them, we divide the marine environment into five submodels: water quality, fish and shellfish and three benthic communities – mangroves, seagrass beds, and coral and hardbottom, Figure 2.3. Each component encompasses a set of closely related attributes.[19] The conditions in the submodels change in response to the pressures acting on the regional marine environment, and they are interrelated by supporting ecological services that are essential to sustaining the vitality of the regional marine ecosystem, Table 2.2. For example, coral and hardbottom communities provide essential habitat for fish, and in return fish contribute to maintaining the coral and hardbottom communities by controlling algae growth through grazing.

Water Quality

The water quality submodel encompasses the physical, chemical and biological characteristics of the water column, including characteristics related to sediment, phytoplankton and zooplankton suspended in the water column. The water column serves as a habitat for plankton communities as well as an agent of transport and communication between benthic habitats, the atmosphere, upland watersheds, and adjacent marine areas. A unique geophysical setting promotes dynamic oceanographic conditions comprised of intricate recirculating gyres and surface currents with some of the highest current speeds in the world (Stommel 1976, Olson 2001, 2002). Oceanographic dynamics are influenced by the Loop Current in the southeastern Gulf of Mexico, which merges with the Florida Current near the Dry Tortugas and then flows parallel to the barrier reef through the Straits of Florida towards Miami. The seaward edge of the barrier reef tract is usually subjected to open tidal exchange from the Florida Straits with its warm, clear, low nutrient waters conducive to coral reef development. These conditions are periodically interspersed with pulses of nutrient-rich waters from locally-intense upwelling events along certain deep reef margins where some of the most luxuriant coral habitats are found (Miller et al. 2001, Olson 2001, 2002, Ault et al. 2002).

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[18] Kruczynski, W.L. and F. McManus, 2002. Water Quality Concerns in the Florida Keys: Sources, Effects, and Solutions. pp 827-881 in: (J.W. Porter and K.G. Porter, eds.) The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook. CRC Press, Boca Raton.

[19] See the appendices for detailed conceptual models of the components

Figure 2.3: Components of marine environment (expand caption to summarize interconnections, support services among submodels)

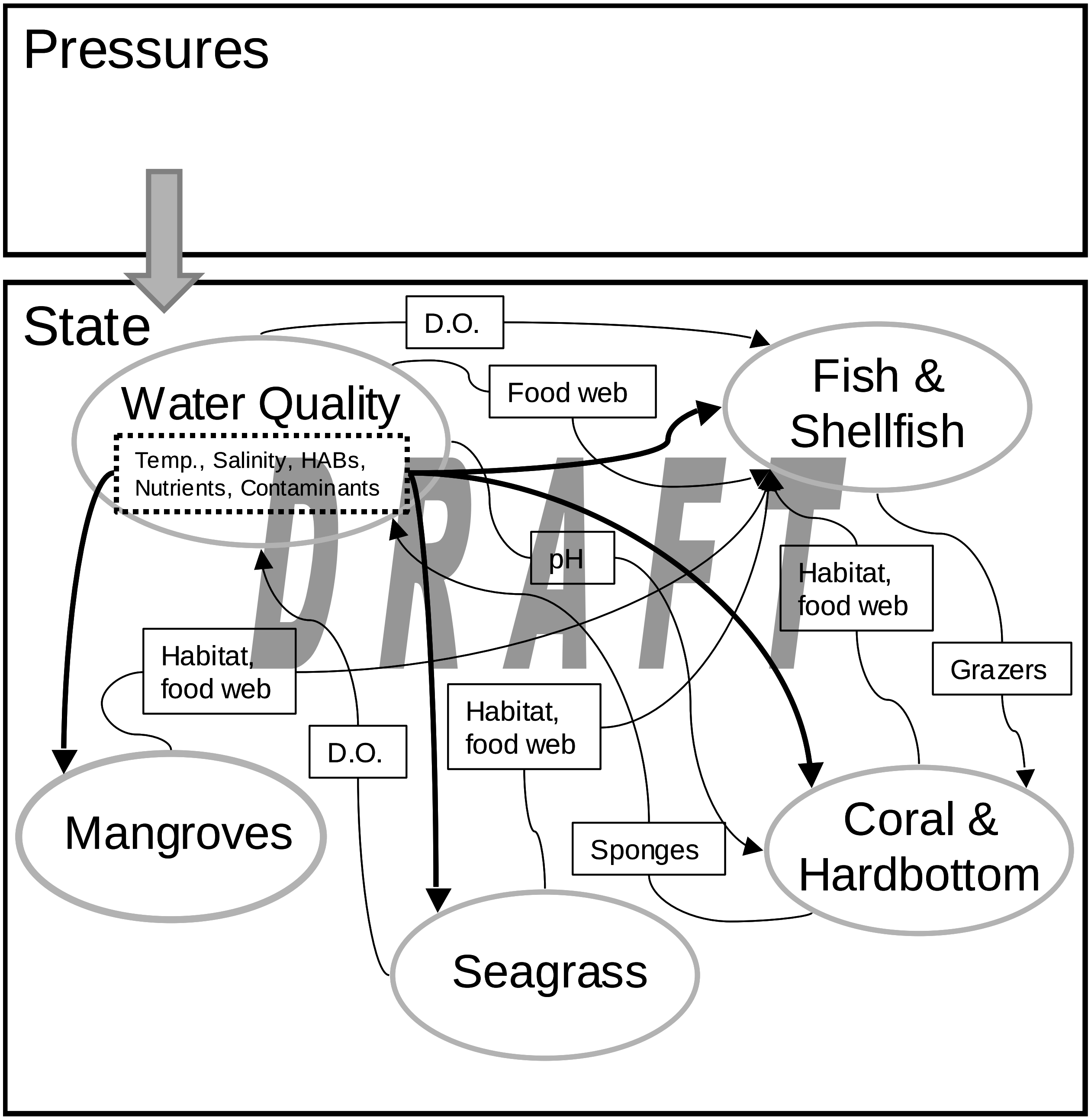

Table 2.2: Interactions among components of the marine environment (supporting ecosystem services)

Component	Supporting Services Provided to Other Components
Water Quality	**Mangrove, Seagrass, Coral and hardbottom -** Nutrient concentrations control primary productivity **Fish and shellfish** – plankton forms base of food web, plankton blooms implicated in sponge death **Seagrass** – turbidity (planktonic plus suspended sediment) attenuates light needed for photosynthesis **Fish and shellfish -**Toxics affect health of fish and shellfish **Fish and shellfish, Seagrass, coral and hardbottom -** Water temperature affects seagrass metabolism, coral (bleaching) and growth and survival of larval and juvenile fish **Fish and shellfish -**Dissolve oxygen affects higher trophic level health **Seagrass, Coral and hardbottom -** pH affects formation of coral and sediments by calcifying organisms
Fish and Shellfish	**Coral and hardbottom -** Grazers reduce epiphytic algae on coral and hardbottom
Mangroves	**Fish and shellfish** – Mangroves provide habitat: Coastal lakes, submerged aquatic vegetation habitat
Seagrass	**Water quality** – Seagrass respiration controls nighttime oxygen levels, **Seagrass** (self maintenance) -sediment formation and stabilization, **Fish and shellfish** – Seagrass provides larval and juvenile fish habitat
Coral and Hardbottom	**Fish and shellfish** – Coral and hardbottom provide habitat (reefs, sponges), mitigate wave height **Water quality -** Sponges reduce plankton-related turbidity

Fish and Shellfish

The fish and shellfish submodel encompasses the populations of fish and shellfish either exploited by commercial and recreational fisheries or protected by management and the prey species required to support them. Populations of fish and shellfish constitute another distinct component of the ecosystem that communicates freely throughout the region and beyond. “The Florida Keys have more than 500 fish species, including 389 that are reef-associated (Stark 1968), and thousands of invertebrates, including corals, sponges, shrimps, crabs, and lobsters. Species in the snapper-grouper complex utilize a mosaic of cross shelf- habitats and oceanographic features over their life spans (Ault and Luo 1998, Lindeman et al. 2000). Most adults spawn on the barrier reefs and sometimes form large spawning aggregations (Domeier and Colin 1997). The Dry Tortugas region, in particular, contains numerous known spawning aggregation sites (Schmidt et al. 1999). Pelagic eggs and developing larvae are transported from spawning sites along the barrier reef tract by a combination of seasonal wind-driven currents and unique animal behaviors to eventually settle as early juveniles in a variety of inshore benthic habitats (Lee et al. 1994. Ault et al. 1999b). Some of the most important nursery habitats are located in the coastal bays and near barrier islands (Lindeman et al. 2000, Ault et al. 2001) As individuals develop from juveniles to adults, ontogenetic habitat utilization patterns generally shift from coastal bays to offshore reef environments.[20]

Benthic Communities – Mangrove, Seagrass, Coral and Hardbottom

“Benthic habitats exhibit a distinct cross-shelf pattern, Figure 2.2. Fringing mangrove habitats occur on the land-sea edge of coastal bays and around barrier islands. Coastal bays have three main benthic habitats types: seagrass beds, bare unconsolidated substrates, and oolitic limestone hardbottom populated with sponges and octocorals. Seaward of the Keys, benthic habitat types include stony coral patch reefs and barrier reefs, sponge-gorgonian covered hardbottom, seagrass beds, and carbonate sands.

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Mangroves –

Prior to urbanization, there were 95,000 ha of mangrove forests in the Florida Keys/Dry Tortugas (FKDT) (Coastal Coordinating Council 1974). Ecosystem services provided by these mangrove

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[20] (above text extracted from Ault et al. 2005)

[21] (above text extracted from Ault et al. 2005)

forests include nursery habitat for numerous fishery species of economic importance and critical foraging habitat for adults of some of these same species (Odum et al. 1982, Lewis et al. 1985, Faunce and Serafy 2006). They provide foraging and nesting habitat for South Florida's ubiquitous fish eating birds (Odum et al. 1982) as well as nesting and stopover habitat for resident and migratory passerine bird species (Odum et al. 1982). They are highly effective at sequestering carbon dioxide, nutrients and protect shorelines from erosion and storm surges (Odum and McIvor 1990). Local, regional and global stressors, both natural and anthropogenic may result in loss of this habitat in the FKDT domain.

There are three species of mangroves in the Florida Keys: red (*Rhizophora mangle*) black (*Avicennia germanans*) and white (*Laguncularia recemosa*) mangroves. Buttonwood (*Conocarpus erectus*), a mangrove associate, is also common in mangrove forests in southern Florida. Tidal forces, climatic conditions and soil type result in these species forming six different forest types: overwash, fringe, riverine, basin, hammock and scrub forests (Lugo and Snedaker 1974). The arrangement of the species within forest type determines the biota that occur within the mangrove forests (Lugo and Snedaker 1974). Epiphytes and sessile invertebrates frequently grow on specialized root adaptations of mangroves (prop roots and pneumatephores) and these, plus the mangrove leaf litter are the basis of mangrove food webs (Odum and Heald 1975). Odum et al (1982) reported 220 species of fish, 21 reptiles, 3 amphibians, 18 mammals and 181 birds utilize the mangroves of southern Florida.

Seagrasses – encompasses the extensive seagrass beds found throughout the region.
(needs more text here)

Coral and Hardbottom –

Reefs of the Florida Keys, from Key West to Key Biscayne, are commonly divided into two main types, offshore shelf-margin bank reefs and lagoonal patch reefs. Offshore bank reefs with spur and groove habitats are generally oriented perpendicular to the shelf and are found on the seaward face of the shelf-margin (Marszalek et al., 1977). Patch reefs are high-relief features (up to 9 m of vertical relief) located within the inner lagoon between the Florida Keys and the shelf-margin reefs. Patch reefs are commonly dome- or linear-shaped, and range in diameter from a few meters to up to 700 m (Marszalek et al., 1977; Jaap, 1984; Lirman and Fong, 2007).

In addition to hermatypic, accreting reefs, low-relief hardbottom communities are a key component of coastal habitats of South Florida (CSA, 2009). Hardbottom habitats in the Florida Keys can be found adjacent to the mainland and islands at depths from < 1m to > 20 m. Hardbottom communities are characterized by of a limestone platform covered by a thin layer of sediments and consist of a sparse mixture of stony corals, soft corals, macroalgae, and sponges. Many of these communities are found on remnant, low-profile habitats lacking significant zonation and topographical development (<1 m of vertical relief) in areas where sediment accumulation is < 5 cm (Lirman et al., 2003). These habitats, which can be important nursery habitats for lobsters, are characterized by low coral cover and small coral colony size (Blair and Flynn, 1989; Chiappone and Sullivan, 1994; Butler et al., 1995).(needs more text here)

Environmental Attributes

Attributes are a parsimonious subset of all potential components of the marine environment that represent its overall condition.[22] The detailed descriptions of the submodels identify two types of attributes: key attributes and "attributes that people care about."

Key attributes are quantifiable characteristics of the environment that have a well-understood role in the response of the ecosystem to the effects of drivers and pressures. Therefore, key attributes are easily defined. Key attributes are the objects of scientific study, and environmental monitoring.

"Attributes that people care about" combine the characteristic of indicating the overall condition of the environment with a notion of what condition people value or desire. "Attributes that people care about" are less well defined, in quantifiable terms, but they are essential to understanding and defining the benefits that people obtain from the environment. From the detailed description of the submodels, we identify 18 different "attributes that people care about". These "attributes that people care about" and the environmental components that impact the value of each attribute are listed in Table 2.3. Some environmental components have a direct impact on the attribute. For example, the value of the attribute "Lots of healthy coral" is directly affected by the state of the coral and hardbottom communities. The states of water quality and mangroves indirectly affect "Lots of healthy coral" because they help determine the state of the coral and hardbottom communities. In the table, "D" means that the attribute is directly affected by the quality of the habitat and "I" means that the attribute is indirectly affected by the quality of the habitat.

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[22] Ogden et al. 2005

Table 2.3: "Attributes People Care About" and the environmental component in which they appear

Attributes People Care About	Environmental Component (*D = Directly affects the attribute; I = Indirectly affects the attribute*)				
	Water Quality	**Coral and Hardbottom**	**Fisheries**	**Mangrove**	**Seagrass**
Aesthetics - on land				D	DX
Aesthetics - water-based recreation	D, clear water	D	D	D	D
Lots of healthy coral	I	D		I, provides needed shade	
Lots of fish	I	I	D	I	I
Large variety of fish	I	I	D	I	I
Lots of large wildlife (manatees, dolphin, sea turtles, game fish, sharks)	I		D		I
Variety of large wildlife (manatees, dolphin, sea turtles, game fish, sharks)	I		D		I
Quality of Beaches / Shoreline	D			D	I
Intact habitat for quick species recovery	I	D		D	D
Coastal Erosion and Storm protection - buildings and boats		D		D	D
Air Quality / Odor	I				I
Environmental Education		D	D	D	
Seafood safety	I		D		
Large variety and numbers of Birds				I	
Critical habitat for protected species - orchids, key deer, goliath grouper, manatees, sea turtles		D		D	D
Natural filter for wastewater, stormwater runoff				D	D
Carbon Sequestration		D		D	D

Ecosystem Services

The world-wide recognition of the Florida Keys derives from the variety and quality of the goods and services provided by its unique coastal marine environment. Maintenance of the integrity and ecological health of marine and terrestrial environments is critical to the economy of the Keys. In 2007-08, approximately 3.3 million visitor-trips were made to the Keys, totaling over 13.9 million person days. Visitors generate d over $2.2 billion in output/sales and tourism supported over 32,000 jobs in the Keys (Leeworthy and Ehler 2010). Tourists come to the Keys for a variety of reasons. In 2007-08 about 53% of all recreating visitors engaged in an least one water-based activity, such as snorkeling (22%), scuba diving (4.9%), fishing (12.9%), wildlife observation (19.9%), beach activities (27.6%) and sightseeing (45%) (Leeworthy, Loomis and Paterson 2010). In addition, approximately 70% of Keys residents regularly participate in water-based activities, such as fishing (48%), snorkeling (45%), beach activities (38%), and observing wildlife and nature (36%) (Leeworthy and Wiley, 1997).

Services Provided by the Keys' Marine Environment

Ecosystem services are beneficial outputs or outcomes that people derive from the environment. We identify 16 ecosystem services and goods related to the "attributes that people care about" identified in the previous section. In Tables 2.4 a, b, and c, these services are categorized functionally by the type of benefit provided directly to people: cultural, regulating, and provisioning, respectively. [23] In this context, "Cultural" services and goods are defined as the non-material benefits obtained from ecosystems such as spiritual and religious, recreation and ecotourism, aesthetic, inspirational, educational, sense of place and cultural heritage. "Regulating" services and goods are benefits obtained from regulation of ecosystem processes such as climate regulation, disease regulation, water regulation, water purification and pollination. "Provisioning" services and goods are products obtained from ecosystems such as food, fresh water, fuelwood, fiber, biochemicals and genetic resources.[24]

Valuing Ecosystem Services

Ecosystem services are related to the "attributes that people care about," but unlike environmental attributes, ecosystem services have value.[25] Economic valuation tools provide monetary measures of ecosystem services that reflect their value relative to other things that people value. Some valuation methods are more appropriate for a particular ecosystem service than for others

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[23] as defined by the Millenium Assessment of Ecosystem Services (need citation, Chapter 2 Ecosystems and Their Services, page 57)

[24] A fourth type of service is called "Supporting Services which are services necessary for the production of all other ecosystem services such as soil formation, nutrient cycling and primary production.Supporting services, Figure 2.3 and Table 2.2, are included as ecosystem services because, by sustaining the ecosystem, they provide benefits to people indirectly.

[25] Farber et al. 2006

Table 2.4a: Cultural Ecosystem Services and Goods

Service or Good Provided	Attributes that People Care About	Value of Service
1. Beautiful, unique environment	• Aesthetics - land • Aesthetics - water-based recreation • Large expanse and variety of healthy coral • Large number and variety of fish • Large number and variety wildlife (e.g. manatees, dolphin, sea turtles, game fish, sharks)	*Use value* *Value to economy* *Non-use value*
2. Opportunity for beach activities and shoreline views	• Quality of beaches and shoreline	
3. Opportunity for wildlife recreation activities	• Critical habitat for protected species (e.g. orchids, key deer, goliath grouper)	
4. Protection of wildlife species		
5. Opportunity for bird watching activities	• Large number and variety of birds	
6. Opportunity for recreational fishing, diving, boat tours, etc.	• Intact habitat for quick species recovery	
7. Clean air and quality of life (in Keys communities)	• Air quality / odor	
8. Resources for research and development (inventions, new cures for illness)	• Environmental education	
9. Living laboratory for education (K-12, colleges and universities)	• Environmental education	
10. Protection of wildlife species and habitats for current and future generations	• Intact habitat for quick species recovery • Critical habitat for protected species - orchids, key deer, goliath grouper	

Table 2.4b: Regulating Ecosystem Services and Goods

Service or Good Provided	Attribute that People Care About	Value of Service
11. Protection of property from storm damages	• Coastal erosion and storm protection - buildings and boats	*Avoided damages* and property loss
12. Supply of high quality seafood Cultural uses (for example???)	• Seafood selection, availability, and safety	*Avoided damages* from illness *Market value* of products sold *Cultural values??* (other?)
13. Storm water retention, water treatment, nutrient cycling, and compliance with regulations	• Natural filter for wastewater, storm water runoff (mangroves and sea grasses)	*Replacement cost* of ecosystem services (wastewater treatment and storm water management)

Table 2.4c: Provisioning Ecosystem Services and Goods

Service or Good Provided	Attribute that People Care About	Value of Service
14. Opportunity to harvest commercial fish species	• Large number and variety of fish • Intact habitat for quick species recovery	*Market and Non Market value* of harvested fish *Value to economy*
15. Opportunity to catch recreational fish species	• Large number and variety fish • Large number and variety of wildlife (manatees, dolphin, sea turtles, game fish, sharks) • Intact habitat for quick species recovery (resilience)	*Use value* *Value to economy*
16. Opportunity for snorkeling, diving, boating	• Large number and variety of fish • Large expanse and variety coral • Large number and variety wildlife (manatees, dolphin, sea turtles, game fish, sharks) • Intact habitat for quick species recovery (resilience)	Use value Value to economy

Basic methods for assessing the value of ecological services, Table 2.4abc, are summarized here:

- *Use value* - Willingness to pay for ecosystem services for current and future use
- *Value to economy – C*ontribution of service to regional output, resident income, employment and tax revenues as tourists and residents spend money on these services
- *Market value*
- *Non-use value* -Willingness to pay to maintain or improve ecosystem services separate from actual or planned use
- Avoided damages and property loss
- Avoided damages from illness
- Market value of products sold
- Replacement cost of ecosystem services (wastewater treatment and storm water management)
- Cultural values??
- (other?)

Use and Non-Use values and avoided costs can be used in benefit-cost analysis of management actions deemed necessary to protect the quality of the environment. For example, the cost to improve wastewater and stormwater treatment in the Keys is in the neighborhood of $1 billion. Leeworthy and Bowker (1997) quantified the total nonmarket value of all the natural resources in the Keys based on the benefits based on the benefit to tourists. Their study estimated that the overall nonmarket value to visitors to the Florida Keys is $1.2 billion annually, of which $910 million is attributed to enjoyment of the Keys' natural resources. Base on this figure, the total asset value of the Keys' natural resources is estimated to range between $18.2 billion and $30.4 billion depending on the discount rate used to convert future streams of value to present values (discount rates between 3 and 5 %), just from tourism. Therefore, although the $1 billion price tag for improved wastewater treatment seems high, this is a small amount relative to the asset value of the natural resources that improved wastewater treatment will protect.

Ecological services that have a supportive function or that have indirect or less commonly understood effects on individual welfare (biodiversity, nutrient cycling, soil formation, etc.) are problematic for the use of valuation techniques that require direct expressions of value. In these circumstances, it may be necessary to construct values indirectly, by tying services to things people directly value. Nonmonetizing methods do not require a connection between values and money, but still provide information about relative values, equivalencies, or rankings. The equivalencies and relative rankings can be used to weigh changes in ecological services resulting from management decisions.

A simple conceptual model of the economics of natural resource and environmental change is provided in Leeworthy and Bowker (1997). This model shows how both actual and perceived changes in attributes can change the demand for and economic value for outdoor recreation/tourism. Economic values include both market (e.g. sales/output, income, employment and tax revenues generated in local and regional economies) and the nonmarket values received by both users (those doing recreation activities) and non users or what economist called passive economic use value or the willingness to pay to see a resource protected in a certain condition even though they never plan to directly use the resource. This kind of value has often been referred to on the basis of people's motives for the value: existence value or the willingness to pay to know that something exists in a certain condition or the bequeath value or the willingness to pay to leave resources in a certain condition for future generations. The market economic impacts also include multiplier or ripple effects throughout the economy.

While economic efficiency is an important criterion for measuring the impacts of management alternatives on social welfare, other considerations including equity, sustainability, ecological stewardship, and cultural and ethical values, are also important to consider in the decision making process (Costanza and Folke 1997). Equity analysis requires an estimation of who receives the benefits or pays the costs of management alternatives, while sustainability and stewardship analyses focus on the intertemporal distribution of those services. Cultural and ethical considerations may place constraints on acceptable decisions.[26]

Response

Within the DPSER framework, Response encompasses human actions motivated either by conditions in the environment (State) or by Ecosystem Services. Actions that have the effect of altering Drivers, Pressures or State of the ecosystem introduce a mechanism for feedback in the system, and therefore the possibility of control. Included in Response are the activities for gathering information, decision-making and program implementation that are conducted by agencies charged with managing the Florida Keys – Dry Tortugas regional ecosystem. Also included are changes in attitudes and perceptions of the environment by individuals and related changes in behavior that, while less purposeful than the activities of management agencies, can have a large effect on the Drivers and Pressures acting on the ecosystem.

The values that people assign to ecosystem services factor into decisions made by management agencies and individuals about how to respond to conditions in the environment. Ecosystem management involves making tradeoffs between conflicting needs or objectives. Earlier, we described how taking account of the economic value that visitor's assign to the Keys marine environment can be used to justify the expense of installing sewage treatment systems needed to prevent further degradation of nearshore waters. Research and monitoring activities provide managers with information they need to apply this same rational approach to deciding other tradeoffs, such as balancing between encouraging public uses and sustaining the unique fisheries on the reef.[27]

Response by Management Agencies

Assigning an agency of government to manage some aspect of the environment formalizes and institutionalizes Response. This is preceded by a political process that recognizes the existence of a problem and develops consensus around the general approach to be followed in dealing with the problem. The mandate to the agency identifies the environmental goals that are to guide it work and prescribes the manner in which these are to be pursued. Below, we discuss three aspects of this process in the Florida Keys that have formalized Response by instituting controls on development, regulations on human activities in marine waters, and information gathering through monitoring and research.

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[26] .(From – Farber, S., R. Costanza, D.L. Childers, J. Erikson, K. Gross, M. Grove, C.S. Hopkinson, J. Kahn, S. Pincetl, A. Troy, P. Warren, and M. Wilson, 2006. Linking ecology and economics for ecosystem management. Bioscience 56:121-133.)

[27] Ault et al. 2005 (?)

Controls on Development

The political process of institutionalizing Response in the Florida Keys – Dry Tortugas ecosystem started sometime in the early 1970s. Growing recognition that booming development posed a threat to the unique environment of the Keys led the state government to designate the Keys as an "area of critical concern" in 1975. This designation brought planning and development activities in Monroe County under the control of the Florida Department of Community Affairs (FDCA) with the overall goal to:

"*…to conserve and protect the natural, environmental, historical, and economic resources; the scenic beauty; and the public facilities within the Area of Critical Concern*."

Under guidance of FDCA, Monroe County adopted a rate of growth ordinance in 1992 (ROGO) that drastically reduced the pace of new development while at the same time encouraging replacement of ineffective cesspits by septic systems and preservation of natural habitat. More recently, FDCA and the county undertook a comprehensive study of the ecological carrying capacity in the Keys, with mixed results,[28] and Monroe County now is implementing a comprehensive plan to install centralized sewage treatment in densely populated areas of the Keys.

Regulations on activities in marine waters

Responding to increasing concern for the health and ecological future of the coral reefs in the Keys, the U.S. Congress acted in 1990 to immediately address two major concerns of Keys residents, by prohibiting drilling and exploration for oil and minerals in Keys waters and by excluding large vessels (>50 m in length) from these waters. The act also provided for long-term management by establishing the Florida Keys National Marine Sanctuary with the goals:

"to achieve the protection and preservation of living and other resources of the Florida Keys marine environment."

In particular, the Act mandates the sanctuary program to "consider temporal and geographic zoning to ensure protection of sanctuary resources." Since its inception, the sanctuary program and its local partners have initiated a number of different Response activities, including:

- Reducing or eliminating waste discharge to marine waters from boaters;
- Developing and implementing an infrastructure-based, rather than a standards-based, strategy for stormwater and waste water management in the Keys;
- Organizing a Keys-wide volunteer program;
- Developing and implementing a research and monitoring that support a science-based approach to dealing with environmental issues;
- Restoring damages caused by vessel groundings;
- Protecting unique maritime heritage resources;

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[28] NRC review of Carrying Capacity Study

- Installing mooring buoys to eliminate damage to benthic communities from boat anchors and to help enforce regulations on visitor use of marine resources; and

- Installing channel markers to improve navigation and reduce groundings.

Ecosystem Research and Monitoring
In implementing zoning regulations, as charged by Congress, the sanctuary has established a number of marine protected areas. The intent is that these refuges from exploitation by fishing will promote the recovery of fish populations impacted by overfishing. In 2007, Dry Tortugas National Park and the Florida Fish and Wildlife Commission established a program of ecosystem research and monitoring designed to evaluate the efficacy of marine protected areas as a conservation tool. This program operates within the Dry Tortugas National Park Research Natural Area, established as for the program with the goal to:
"*protect near pristine shallow water marine habitat, ensure species diversity, enhance the productivity and sustainability of exploited fish populations throughout the region, and provide a unique unexploited area that will be used to help assess the effects of fishing on exploited areas.*"[29]

Among other things, the research and monitoring program will provide managers with information and analysis tools needed to evaluate progress toward the goal of sustainability based on characteristics of fish populations that are readily observed and measured.

Response by Individuals

Ultimately, the nature and extent of actions taken in Response depend on decisions made by individuals. On might decide to pursue collective, political action leading to a formal, institutionalized response, as discussed above. Alternatively, one might decide to alter their use of the environment, which can also have a large effect on Drivers and Pressures affecting the ecosystem.

For example, there has been a significant shift by tourists away from participation in water-based activities toward land-based activities. Over the 12-year time period 1995-96 to 2007-08 the proportion of the Keys' economy dependent on tourism remained relatively constant at about 60 percent. Over this same time period, participation in all water based activities, except beach activities, declined.[30] If this trend continues one can anticipate that patterns of development will change as a result, with implications for impacts of development on water quality. This change in behavior might also be reflected in the political decision-making process, as constituencies most concerned with maintaining the quality of marine waters decline in representation and influence.

This raises the question as to what extent, if any, this shift is the result of an actual or a perceived change in water quality. An important point is that people's demand for and value of natural

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[29] MOU for DTRNA

[30] In terms of percent participation and number of participants, all water-based activities, except beach activities, declined over the 12-year period 1995-96 to 2007-08. In terms of person-days of activity (a better measure of intensity of use), all water-based activities, except beach use and diving (snorkeling and SCUBA diving) declined over the 12-year period (Leeworthy and Loomis 2010).

resource/environmental attributes is based both on actual and perceived conditions. People are often driven by their perceptions and sometimes perceptions do not square with the actual facts. This can influence the appropriate policy/management response. Are actual water quality conditions a problem requiring an investment to correct the condition or are people's perceptions out of line with actual conditions requiring and education/outreach effort? In either case, the policy/management response attempts to try and avoid the negative economic outcomes if people's values are impacted and they change their level of demand with impacts on the local and regional economies.

Effect on Drivers and Pressures

Response by agencies has demonstrable effects on Drivers, Pressures and the State of the marine environment. The rate of growth ordinance adopted in 1992 drastically reduced the rate of population growth in the Keys even as the population of the South Florida region (Broward, Collier, Miami-Dade, Monroe, and Palm Beach) continued a rapid expansion, Figure 2.4. Programs and regulations put in place with the sanctuary have reduced pressures associated with human activities in marine waters and introduced mechanisms for restoration.[31] Initial results from research and monitoring indicate that fish populations are recovering, as expected, in the new Dry Tortugas research natural area.[32]

Changes in the composition of the Keys' human population promise further changes. It is extremely important to understand the evolution of tourist-based economies to more permanent residence economies as people who formerly were tourists retire as permanent residents. Permanent residents require a whole different set of goods and services which leads to different footprint of development. This sets in motion multiplier impacts in providing for additional kinds goods and services required and thus the pattern of development. Experience elsewhere has resulted in "paradise lost" with the further results that the ecosystem can no longer deliver the ecosystem services once provided to the tourist population. This process is usually slow with incremental, but cumulative effects. There comes a "tipping point" when a threshold is reached and the entire pattern of supply and demand changes.

Most important is the change that Response actions have had on the whole ecosystem, not only the marine environment. The Florida Keys – Dry Tortugas ecosystem that exists today differs from the ecosystem that existed here in the 1980s. In response to threats to the marine environment evident in the 1970s and 1980s the human component adapted. New institutions and behaviors introduced into the ecosystem a capacity to regulate local Drivers on the ecosystem and nearfield Pressures. However, since that time global and regional Drivers have continued to increase unabated, Figure 2.4. Compared to the situation in the 1970s and 1980s, the ecosystem of the Florida Keys –Dry Tortugas today is threatened to a greater degree by Drivers and Pressures from outside.

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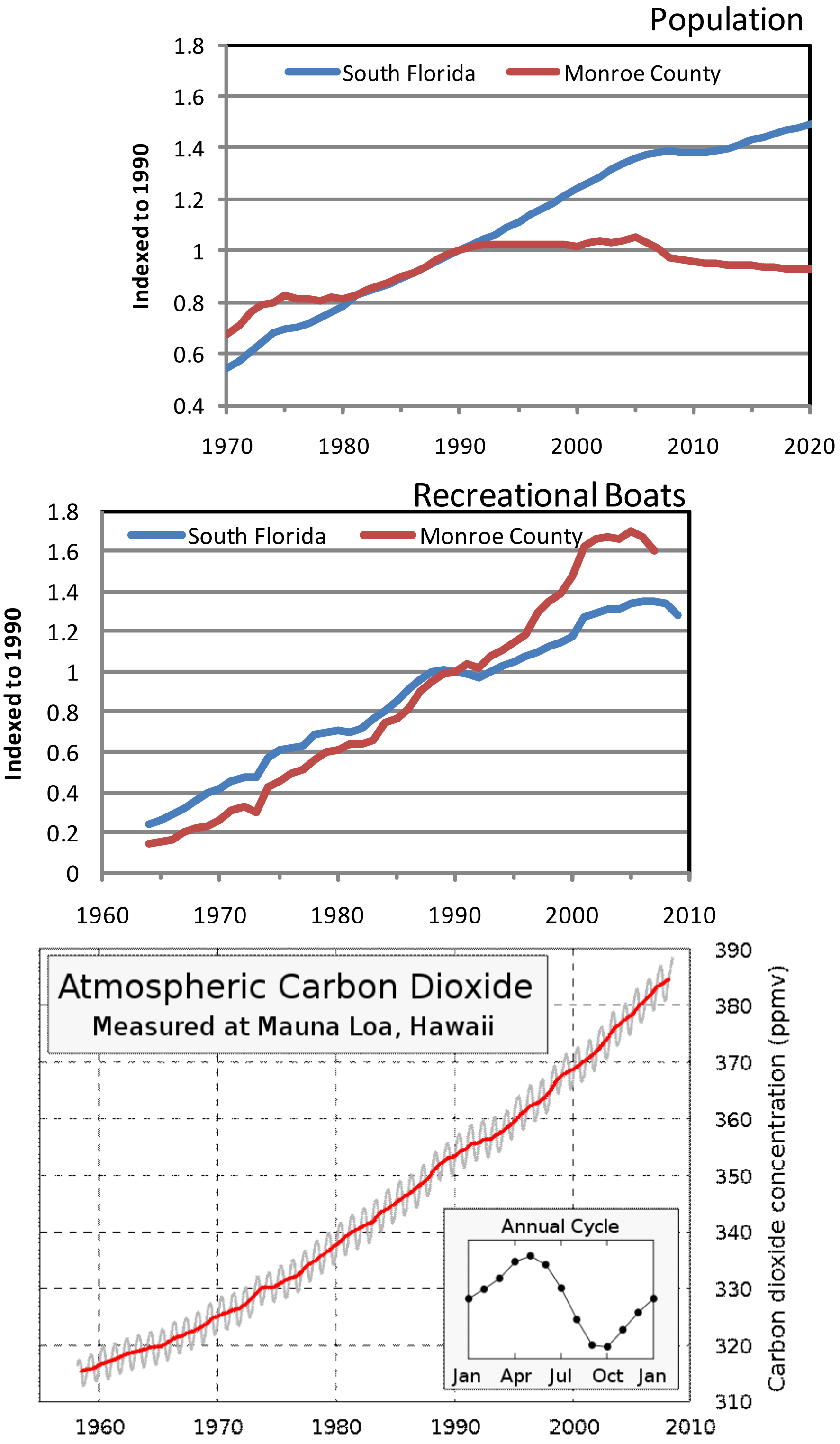
[31] Cite sanctuary annual report
[32] Cite DTRNA progress report yet to be released

Figure 2.4: Trends in global (atmospheric CO2), regional and local drivers (population and recreational boat registrations) showing continued growth in regional and global drivers relative to population in the Keys since a stringent rate of growth ordinance was enacted in 1992. Population and boat registration numbers are indexed to the value in 1990. (Date sources: population http://edr.state.fl.us/population.htm; boat registrations were compiled by Jerry Ault, recent years' statistics are available here http://www.flhsmv.gov/dmv/vslfacts.html; CO2 data plot is public domain from Wikipedia)



Ecosystem Science Needs for Management

(Need to add text on at least one or two topics related to each of the submodels and ecosystem services)

Water Quality

Fish and Shellfish

Mangroves

Snedaker (1989) indicated that, in Florida Bay, the primary research need in mangrove environments was for faunal studies. In the case of FKDT, faunal studies appear to be the primary need as well. Data collections in mangrove forests in southern Florida are inherently difficult. This habitat is rather inhospitable; frequently combining impenetrable root habitat with waist deep mud and myriad biting insects. This difficulty applies to whether the research is performed above or below the water line or whether the characteristics being measured are physical, floral or faunal. Often sampling techniques need to be developed for the specific forest or habitat and can not be reproduced in another location For example, Faunce and Serafy (2006) reviewed 111 primary literature manuscripts on fishes in mangrove habitats between 1955 and 2005 and they found numerous methodologies deployed with no set protocol across the studies. They found that 20% of the manuscripts purported to sample fishes in mangroves were actually sampling adjacent to the habitat rather than in it. Furthermore, the duration of the studies was typically less than 1.5 yrs in duration. They attributed these shortfalls in the literature to the inherent difficulties in sampling within mangrove habitats. Finally, only 1 of the 111 studies was performed within the boundaries of FKDT. Although systematic bird surveys are performed in Dry Tortugas National Park and within some portion of the National Wildlife Refuges, it is clear that, compared to the greater Everglades landscape, bird surveys are under represented in the FKDT. Other faunal surveys are relatively non-existent in these mangrove habitats.

Seagrasses

Coral and Hardbottom

Ecosystem Services Valuation

The values described in Table 2.5 are not routinely estimated. However, as explained above, knowledge of these values is useful for selecting the most valuable management alternatives. Basic research is needed to estimate these values in the Florida Keys on a regular basis such as every five years. In addition, research is needed to identify the relationship between these values and other variables that can be measured more easily and more frequently.

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Appendix – Water Quality Sub-model

Chris Kelble, NOAA/AOML

Water Quality sub-model

Pressures

1) *Climate Change*
2) *Nutrient Loading*
3) *Nutrient Cycling*
4) *Toxin Loading*
5) *Contaminant Spills*
6) *Sediment Loading*
7) *Land-use*

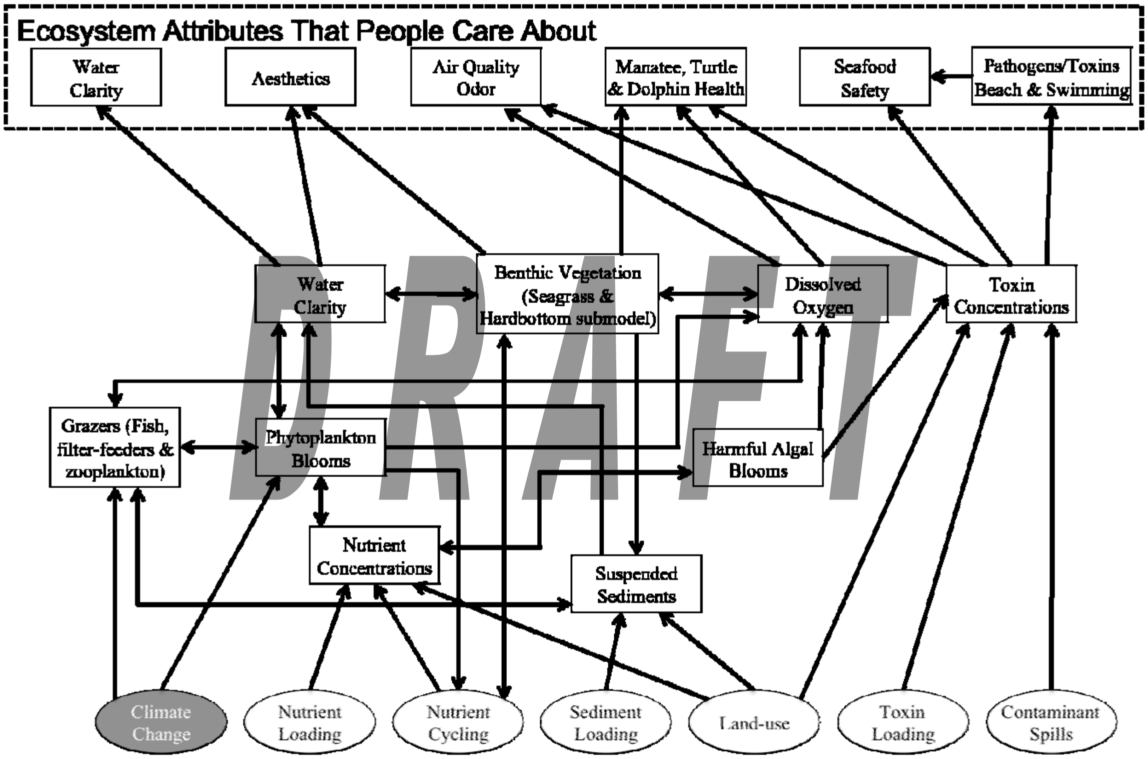
State

1) *Light Attenuation*
2) *Benthic Vegetation (Segarass & hardbottom sub-models)*
3) *Dissolved Oxygen*
4) *Toxin Concentrations*
5) *Grazers (Fish, benthic filter-feeders & zooplankton)*
6) *Phytoplankton blooms*
7) *Nutrient Concentrations*
8) *Suspended Sediments*
9) *Harmful Algal Blooms*

Attributes That People Care About

1) *Water Clarity*
2) *Air Quality (Odor)*
3) *Seafood Safety*
4) *Aesthetics*
5) *Pathogens/Toxins Water Safety*
6) Manatee, Turtle & Dolphin health

Figure xx: Water Quality ICEM



PRESSURES

Climate Change

The emission of greenhouse gasses including CO_2 provides a double-dose of stress to the Florida Keys ecosystem. First, the increase in CO_2 concentrations is causing a decrease in the aragonite saturation state of seawater and lowering the pH, which is commonly referred to as ocean acidification. This decrease can have detrimental effects on calcifying organisms including the coral reefs of the Florida Keys (Manzello et al. 2008). However, the exact magnitude and direction of this effect on different components of the ecosystem is unclear given the variety of responses between different organisms and the gradual nature of acidification over several generations allowing organisms to adapt (Hendriks et al. 2010). Secondly, according to the IPCC 2007 report the increase in CO_2 is likely resulting in warmer ocean temperatures that can stress coral and cause bleaching by increasing the maximum temperatures experienced during the summer.

Nutrient Loading

The Florida Keys is an oligotrophic system and as such minimizing nutrient loading is critical to maintain the health of this system (Collado-Vides et al. 2007). Nutrient loading can be both natural and anthropogenic. Natural sources are not harmful to the system and are likely beneficial as the ecosystem has adapted to this loading over a long time-period and it is required to maintain the across trophic level productivity that is characteristic of the Florida Keys. Recently, there has been concern that anthropogenic nutrient loading has increased resulting in macroalgal blooms over some Florida Keys coral reefs (Lapointe et al. 2004). The quantity of nutrient loading affects the concentrations of nutrients in both the water column and the sediments. This loading can be both near-field from the Florida Keys and Florida peninsula or far-field from sources such as the Mississippi River (Ortner et al. 1995).

Nutrient Cycling

The cycling of nutrients within the system can also affect the concentrations of nutrients in water column and sediments. Nutrient cycling rates can be affected by salinity and pH (Zhang and Huang 2007). Nutrient cycling rates can also be affected by changes in hydrodynamic patterns that alter the frequency and magnitude of upwelling events or eddy passages in the Florida Keys.

Toxin Loading

The loading of toxins to the system can have severe detrimental impacts on the biological aspects of the system. Sources of toxins can be both external from runoff and internal from harmful algal blooms and mercury methylization (Evans and Crumley 2005). External toxin loading primarily comes from sources polluted with chemical contaminants, such as untreated wastewater and urban runoff. Altering the frequency and magnitude of HABs in the Florida Keys ecosystem and upstream waters will alter internal toxin loading. Decreasing methylmercury is more difficult, although it is known to increase with freshwater runoff the exact process of the loading is poorly understood (Evans and Crumley 2005). This loading of toxins affects the concentration of toxins in the water column, the sediment and the organisms within the FKDT.

Contaminant Spills

This driver is closely related to toxin loading, but is separated, because of the direct impact of public activities. Contaminant spills in the form of oil spills are a common occurrence in many of the marinas that populate the Florida Keys and can have significant ecological impacts. These spills increase toxin levels and can be particular harmful to charismatic megafauna, particularly marine mammals.

Sediment Loading

The loading of sediments from the terrestrial system to marine ecosystem can affect the concentration of suspended sediments and toxins, because of pollutant bound in the sediments. The loading of sediments is a natural process whereby material derived from erosion is transported downstream to the coastal ocean; however, anthropogenic activities, such as land-use alterations and hydrological modification can alter natural sediment loading rates.

Land-use

Changing land-use to allow for economic expansion is an important process that can have ecological implications for the FKDT. The development of agricultural lands in the watershed can result in increased loading of nutrients, CDOM and toxins if not properly managed. Removal of mangrove forests and other plants that stabilize sediments can cause increases in suspended sediment. The development of high-density population structures can affect nutrient levels, toxin levels, and suspended sediment. This is not just due to the construction of the structure itself, but also due to increased human activities that land-use changes allow. For example, the development of a hotel on natural land is likely to increase fishing pressure, the number of divers and bathers. Also, this increase in population will result in more pollutants due to increased traffic and waste. Contrarily, these structures allow more of the population to experience the beauty of the Florida Keys and afford the opportunity to create better stewards of the FKDT.

STATE

Nutrient Concentrations

The oligotrophic nature of the FKDT is in large part responsible for human's affection for this ecosystem. It allows corals, seagrass and harbottom communities to thrive and clear water to dominate. Nutrient concentrations are likely to change in response to changes in nutrient loading or nutrient cycling that may be a result of land-use changes. If nutrient concentrations increase, it is likely that phytoplankton (Boyer et al. 2009), benthic macroalgae (Duarte 1995, Valiela et al. 1997) and potentially HABs will increase (Brand and Compton 2007). This could damage the key characteristics that make the Florida Keys a desirable ecosystem for tourism.

Toxin Levels

Toxin concentrations in the ecosystem not only affect ecological health, but could also potentially affect the health of humans. Contaminant spills (Moore and Swain 1991), Harmful Algal Blooms (Kirkpatrick et al. 2004), toxin loading and changing land-use patterns (Paul and Meyer 2001) all alter toxin concentrations in the water (Fig. WQ1). Specifically, increasing the percent of impermeable surface area increases the loading of toxins to coastal systems (Paul and Meyer 2001). In creases in water column toxin concentrations can be directly harmful to both marine organisms and humans. Charismatic species, such as mantees, turtles whales and dolphin exhibit degraded health and increased mortality in the presence of high toxin concentrations. Dolphin mortality has been associated with high brevetoxin concentrations and harmful algal blooms along the southwest coast of Florida (de la Riva et al. 2009, Fire et al. 2008). Loggerhead turtles, *Caretta caretta*, in south Florida have been found with a neurological disorder that suggests lethal toxin levels in their diet (Jacobson et al. 2006). The red-tide neurotoxin has been reported to have a high affinity for binding to specific nerve preparations in manatee brains likely increasing stranding and mortality in affected populations (Trainer and Baden 1999). The red-tide neurotoxin has also been implicated in degraded in health in whale species known to migrate through the Florida Keys (Doucette et al. 2006). Toxins degrade air quality and can cause respiratory distress in humans (Kirkpatrick et al. 2004). Moreover, consumption of seafood with high toxin levels can cause paralytic shellfish poisoning, gastrointestinal distress and developmental disorders (Kirkpatrick et al. 2010, Stewart 2008). Swimming in water with high pathogen and toxin levels can also negatively impact human health (Abdelzaher et al.).

Suspended Sediment

Concentrations of suspended sediment in the water column effect light attenuation and thus water clarity in the Florida Keys (Kelble et al. 2005). The effect on light attenuation is likely to be important given that the light field of nearby ecosystems is dominated by suspended sediment (Kelble et al. 2005). This concentration is effected by sediment loading from the terrestrial system that has been altered by land-use changes (Wood and Armitage 1997). Benthic vegetation alters the concentration of suspended sediment in the Florida Keys by stabilizing benthic sediments and minimizing re-suspension (Peterson et al. 2002). Suspended sediments can also clog filter feeders, particularly sponges and cause degraded, but depending on sediment type these species may also be able to filter suspended sediments out of the water column (Lohrer et al. 2006).

Phytoplankton Blooms

Phytoplankton are the pelagic primary producers of the ecosystem. The ecosystem requires low-levels of the right types of phytoplankton to maintain the proper productivity necessary to support higher trophic level species. However, too much phytoplankton will discolor the water, causing light attenuation to decrease (Phlips et al. 1995). The biomass of phytoplankton in the water column is too a large degree dependent upon nutrient concentrations and water temperature that may be altered by climate change. High phytoplankton biomass has the potential to cause senescence in seagrass and sponges, due to insufficient light at the benthos and clogging, respectively (Butler et al. 1995). These changes can then allow for more phytoplankton by decreasing the grazing pressure and increasing nutrient loading from the benthos by destabilizing sediments (Zieman et al. 1999). Phytoplankton blooms alter dissolved oxygen by producing oxygen during photosynthesis; however, blooms composed of phytoplankton types that are not easily consumed by secondary producers can lower dissolved oxygen at the benthos when phytoplankton senesce and are decomposed (Turner et al. 2006). Low dissolved oxygen after these blooms is particularly pronounced in stratified water columns (Livingston 2007).

Harmful Algal Blooms (HABs)

HABs are a naturally occurring part of the FKDT, but in recent years debate has intensified as to whether anthropogenic activities are increasing their frequency and duration. A recent metadata review suggested that increases in HABs along southwest Florida are related to increased nutrient availability (Brand and Compton 2007). HABs in the FKDT are primarily composed of the dinoflagellate , *Karenia brevis*. *Karenia brevis* contains a brevetoxin compound that can aerate and cause respiratory distress. It can also cause paralytic shellfish poisoning via consumption of contaminated shellfish from an area with a recent *Karenia brevis* bloom (Kirkpatrick et al. 2004). Moreover, large blooms of *Karenia brevis* result in hypoxic conditions (low dissolved oxygen) under specific oceanographic conditions (Hu et al. 2006).

Dissolved Oxygen

Hypoxia is a state of low oxygen levels in the water column. It typically occurs when a large amount of plant material is consumed or decomposed by bacteria or other organisms that are not readily available to the next trophic level. This process consumes oxygen and results in low oxygen concentrations. These events typically occur when stratification is present such that the oxygen produced by primary production is not readily mixed with the hypoxic waters (Livingston 2007). Dissolved oxygen concentrations are significantly affected by benthic vegetation that produce oxygen during the day and consume oxygen at night (Yarbro and Carlson 2008). Low dissolved oxygen concentrations can lead to air quality concerns. In particular, hypoxia can create a foul odor from the production of hydrogen sulfide by decomposers. This is most prominent when a stratified water column is turned over. Hypoxia can also affect the health of dolphins, turtle, manatees and whales by restricting their habitat and influencing the size of prey populations (Zhang et al. 2009).

Grazers (Primary Consumers)

Grazers play a crucial role in ecosystems via consumption of phytoplankton that minimizes blooms and transfers energy to higher trophic levels. Grazers can take many forms from benthic sponges and shellfish to microscopic zooplankton to parrotfish. Thus, for more detail on benthic grazers please consult the coral and hardbottom sub-model and for fish species please consult the fish sub-model. Zooplankton and provide a key pathway from phytoplankton to higher trophic level fish and shellfish species (Wiebe et al. 2000). Grazer biomass is tightly coupled to phytoplankton biomass and phytoplankton can both limit and be limited by grazer biomass. Grazers, in particular zooplankton, are also governed by kinetics and thus show a large temperature influence that may be altered by climate change (Huntley and Lopez 1992). Grazers also consume oxygen and thus decrease the dissolved oxygen concentration.

Light Attenuation

The attenuation of light in marine systems is a product of the combined effects of CDOM, phytoplankton, suspended sediment and seawater, itself (Kirk 1994). Too much light attenuation will not allow sufficient light to reach the benthos for seagrass to survive. However, too little light attenuation on the coral reefs can cause UV stress and lead to coral bleaching (Glynn 1993). The attenuation of light is also a key characteristic contributing to the aesthetic quality of the FKDT water coloration. Light attenuation is the scientific measure of water clarity.

Benthic Vegetation

The Benthic vegetation components are detailed in the seagrass, coral and hardbottom sub-models. Currently the system is dominated by benthic productivity. If pelagic primary productivity begins to dominate there are likely to be numerous detrimental effects on the fish and shellfish communities as well as the benthic habitat communities. This is likely to include seagrass and sponge dieoffs that decrease the habitat available for fish and shellfish (Butler et al. 1995).Recent investigations have seen an increase in diversity and abundance of macroalgae on coral reefs (Lapointe et al. 2004). These are detrimental to the health of the corals and are not as aesthetically pleasing to divers. Macroalgae also do not provide a good habitat for many important commercial and recreational fishery species. A healthy seagrass community is a byproduct of good water quality. Seagrass require greater than 10% of surface irradiance to reach the benthos (Duarte 1991). Healthy seagrass beds provide vital habitat for the juveniles of many commercial fishery species (Luo et al. 2009) and contribute to the aesthetically pleasing coloration of Florida Keys water. Moreover, megafauna such as turtles and manatees rely upon seagrass beds for their survival in the FKDT.

Ecosystem Attributes the People Care About

Pathogens/Toxins: Beach & Swimming

The quality of beaches and swimming locations in the Florida Keys is important to tourists that frequent the Florida Keys. The quality of these beaches refers to the likelihood of contracting a health issue from the beach or the adjacent swimming area and the aesthetics. The aesthetics can be impacted by the health of nearby seagrass beds that in poor health may cause large mats of seagrass blades to wash ashore. The concentrations of HABs in adjacent waters will affect the air quality and the level of toxins in the beach and water. Hypoxia can also cause a distasteful odor that would reduce the beach-going experience and the level of toxins in the sand and adjacent waters will directly affect the likelihood of contracting a health problem during a visit.

Air Quality

The air quality is desirable for both tourists and residents of the Florida Keys who desire to enjoy the outdoors. The two primary causes of poor air quality are HABS and hypoxia. The hypoxia concern is particularly unpleasant in manmade canals that turnover during high winds causing a hydrogen sulfide smell to be released.

Manatee, Turtle & Dolphin health

One of the many reasons tourists and residents enjoy the FKDT is for the charismatic megafauna that inhabit the ecosystem. These range from reptiles, such as turtles to fish such as marlins to marine mammals, such as manatees and dolphins. These animals are most sensitive to toxins from chemicals that tend to bioaccumulate up the food chain. Dolphins have been found to have high PCB levels in nearby embayments (Litz et al. 2007) and Florida Bay can have high mercury levels in the top fish species (Evans and Crumley 2005). These species are also dependent upon the seagrass for habitat and in the case of manatees and turtles food, as well as the abundance of their desired prey species.

Seafood Safety

The safe consumption of seafood from the Florida Keys is necessary to maintain the economic health of the fisheries. HABS can cause shellfish, including oysters to be unsafe for consumption and leave humans susceptible to paralytic shellfish poisoning (Kirkpatrick et al. 2004) and toxin loading in the form of mercury can endanger the consumption of higher trophic level fish species (Plessi et al. 2001). This attribute is equally important for residents and tourists of the FKDT, but also for anyone who prefers consuming seafood from this area.

Aesthetics/Uniqueness

One of the appealing features of the Florida Keys is the impressive color mosaics one can view when riding down the overseas highway or sailing along in their boat. This is pleasing to residents and tourists alike, as well as those who enjoy nature documentaries about the region. This feature is a product of the light attenuation along with the suspended sediment composition and differing benthic habitat communities. All of these rely upon good water quality to maintain this feature of the ecosystem.

Water Clarity

The diving and spearfishing industries rely upon good water clarity to ensure business remains optimal. Water clarity is already lower in the Florida Keys than in other Caribbean locations and further degradation should be prevented (Palandro et al. 2004). The clarity of the water is a direct product of the light attenuation and thus dependent upon the concentrations of CDOM, phytoplankton and suspended sediment.

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Appendix – Fish and Shellfish Sub-model

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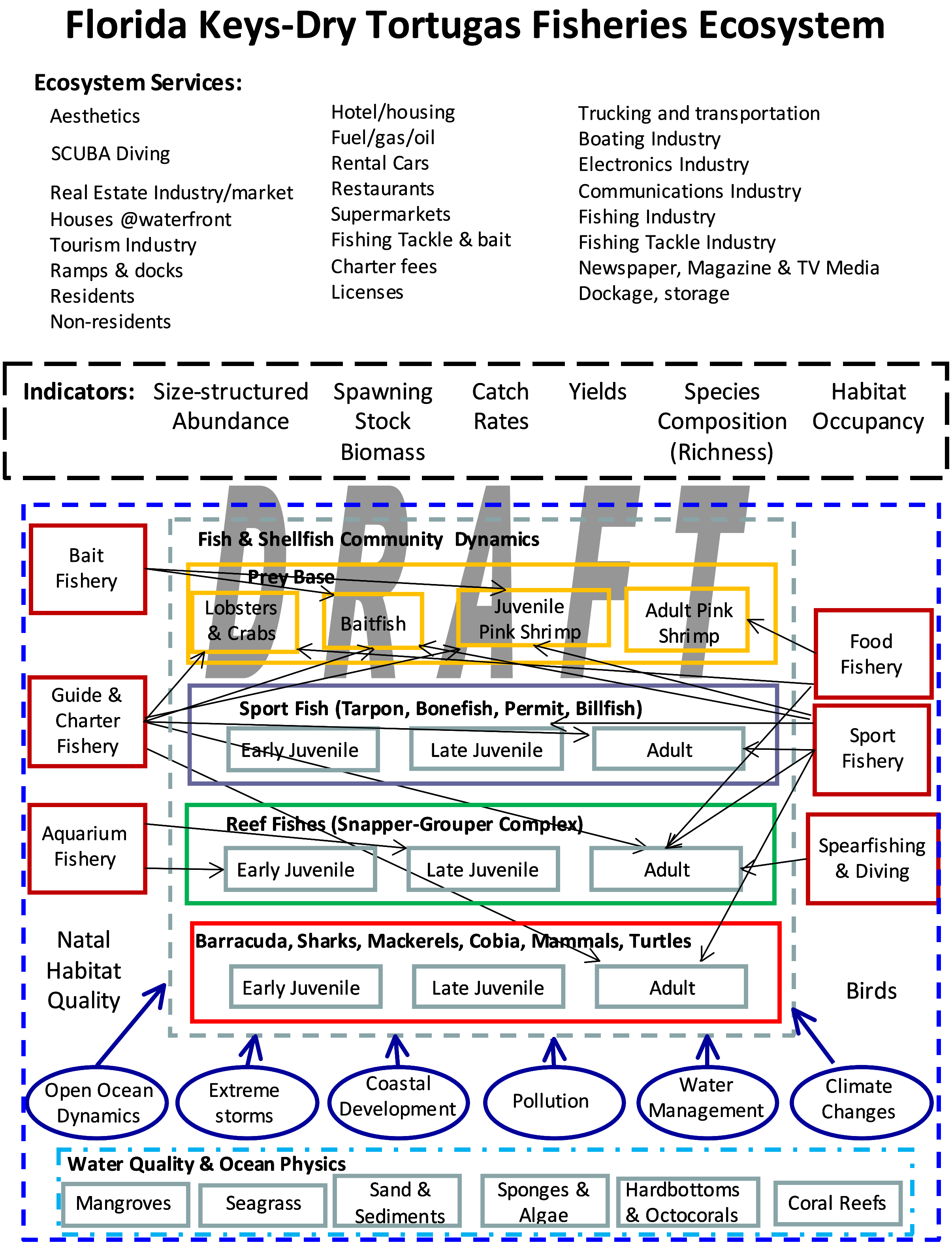

Florida Keys-Dry Tortugas Fisheries Ecosystem

Ecosystem Services:

Aesthetics

SCUBA Diving

Real Estate Industry/market
Houses @waterfront
Tourism Industry
Ramps & docks
Residents
Non-residents

Hotel/housing
Fuel/gas/oil
Rental Cars
Restaurants
Supermarkets
Fishing Tackle & bait
Charter fees
Licenses

Trucking and transportation
Boating Industry
Electronics Industry
Communications Industry
Fishing Industry
Fishing Tackle Industry
Newspaper, Magazine & TV Media
Dockage, storage

Indicators: Size-structured Abundance; Spawning Stock Biomass; Catch Rates; Yields; Species Composition (Richness); Habitat Occupancy

Florida Keys-Dry Tortugas Fisheries Ecosystem Conceptual Model Description

ECOSYSTEM SERVICES

Coral reefs in southeastern Florida and the Florida Keys provide the ecological foundation for vital fisheries and a tourism-based economy that generated an estimated 71,000 jobs and US$6 billion of economic activity in 2001 (Johns et al., 2001). They also contributed to the designation of Florida as the "fishing capital of the world" by the state legislature (FWC, 2003). Coral reef ecosystem goods and services, however, extend beyond fishing to include a range of educational, scientific, aesthetic, and other recreational uses, such as snorkeling, SCUBA diving, and tourism.

Aesthetics
Fishing & Diving
Tourism & Real Estate
Supporting Marine Industries

These ecosystem goods and services, however, are threatened by increased exploitation and environmental changes from a rapidly growing regional human population.

The sustainability of multispecies coral reef fisheries is a key conservation concern given their economic and ecological importance, the significant dependence of subsistence and artisanal fishers on reef fisheries for their livelihoods, and the considerable and growing threats to coral reef habitats (i.e. coral bleaching and disease, pollution and climate change). Sustainability refers to the ability of an exploited stock to produce goods and services, including yields at suitable levels in the short term, while maintaining sufficient stock reproductive capacity to continue providing these goods and services into the indefinite future (Walters & Martell 2004). Intensive exploitation and overfishing is perhaps the major threat to these ecosystems (Russ 1991; Haedrich & Barnes 1997; Ault *et al.* 1998, 2005*a*, 2008).

However, the Florida Keys reef ecosystem is considered one of the nation's most significant, yet most stressed marine resources (U.S. Department of Commerce, 1996) and is managed by Florida, the National Oceanic and Atmospheric Administration (NOAA), and the National Park Service.

PRESSURES

Coral reefs in the Florida Keys-Dry Tortugas are impacted by fishing and indirectly by habitat degradation from other human activities including coastal development, altered freshwater flow, and changes in water quality from pollution, sedimentation, and excess nutrients (CERP 1999; Cowie-Haskell and Delaney, 2003). Human impacts have grown as a result of Florida's tenfold population growth from 1.5 million people in 1930 to 16 million in 2000. In 2000, over 5 million residents, nearly a third of Florida's population, lived in the five southern counties adjacent to coral reefs (Palm Beach, Broward, Miami-Dade, Monroe, and Collier). In addition, over three million tourists visit the Keys annually (Leeworthy and Vanasse, 1999).

The principal factors influencing the dynamics and sustainability of snapper-grouper and other reef fish populations include: (1) fishery removal of key prey (e.g., shrimps, baitfish) and predators (e.g., barracuda, sharks), (2) alterations to benthic habitats (e.g., loss of mangroves and seagrasses to shoreline development, channel dredging, and ship groundings), and (3) alterations to water quality (e.g., pollution, nutrification, and turbidity), quantity, and timing of freshwater inflows. Other environmental issues facing the Keys include coral declines from diseases and bleaching, invasion of exotic species, shifts to algal dominance, and damage from contact by anchors, grounded vessels, divers, snorkelers, and fishing gear. In addition, hurricanes have a 16% annual probability of striking the Keys (Neumann, 1987) and damaging habitat. Looking at the full spectrum of impacts suggests that achieving sustainable reef fisheries will likely entail substantially more analysis of inter-related factors than simply assessing fishing mortality rates for a few snapper and grouper species (Bohnsack and Ault 1996; Ault et al., 1999b; Lindeman et al., 2000).

Fisheries (bait fishery, guide & charter fishery, aquarium fishery, food fishery, sport fishery, spearfishing and diving)

Precise data on coral reef fishing effort trends do not exist, but are reflected by state-wide fishing statistics and numbers of registered boats. In 2001, for example, an estimated 6.7 million recreational fishers took 28.9 million marine fishing trips in Florida and caught 171.6 million fish, of which 89.5 million (52%) were released or discarded (U.S. Department of Commerce, 2002). From 1964–2002 the number of registered recreational boats in southern Florida grew by more than 500%, while the number of commercial vessels grew at a much lower rate, about 150%. Many of these vessels are used for fishing and for non-extractive activities, such as sailing, sightseeing, transportation, snorkeling, and SCUBA diving. Increased fishing fleet size has been accompanied by a number of technological advances that have been estimated to have quadrupled average fishing power (Mace, 1997), i.e., the proportion of stock removed per unit of fishing effort (Gulland, 1983). These advances include improvements in fishing tackle, hydroacoustics (depth sounders and fish finders), navigation (charts and global positioning systems), communication, and inexpensive, efficient, and more reliable vessel and propulsion unit designs (Bohnsack and Ault, 1996; Ault et al., 1997, 1998). These fishing trends have thus become an obvious concern to the fishery sustainability and persistence of the coral reef ecosystem.

Fisheries in southern Florida are complex (Bannerot, 1990; Chiappone and Sluka, 1996). Adult reef fishes are caught for food and sport around bridges and on offshore patch and barrier reefs. Commercial and sport fisheries also target spiny lobster, marine aquarium fishes and invertebrates, inshore and offshore. Pink shrimp, a principal prey item of the snapper-grouper complex, are intensively exploited. Offshore, a substantial commercial food fishery targets adult pink shrimp inhabiting softbottoms near coral reefs. In coastal bays and near barrier islands, juvenile pink shrimp are commercially targeted as live bait for the recreational fishery. Both food and sport fisheries target pre-spawning subadult pink shrimp as they emigrate from coastal bay nursery grounds to offshore spawning grounds. Inshore, sport fisheries pursue highly prized game fishes, including spotted seatrout, sheepshead, black and red drum, snook, tarpon, bonefish, and permit, while commercial fisheries primarily target sponges and crabs. Offshore of the deep margin of the barrier reef, commercial and sport fisheries capture an assortment of species including amberjack, king and spanish mackerel, barracuda, sharks and small bait fishes (e.g., Exocoetidae, Mullidae, Carangidae, Clupeidae, and Engraulidae). Farther offshore (seaward of the 40 m isobath), commercial and sport fisheries catch dolphinfish, tunas, and swordfish, and sport fishers target sailfish, wahoo, and white and blue marlin.

Reef fisheries target the “snapper-grouper complex,” which consists of 73 species of mostly groupers and snappers, but also grunts, jacks, porgies, and hogfish. The fishery has been intensively exploited over the past 75 yrs, during which the local human population has grown exponentially and generated concerns over sustainable fishery productivity. Many reef species are extremely sensitive to exploitation (Coleman et al., 2000; Musick et al., 2000), and coastal development subjects coral reefs to a suite of other stressors that can cumulatively impact reef fish populations by degrading water quality and damaging nursery and adult habitats (Bohnsack and Ault, 1996; Lindeman et al., 2000; Jackson et al., 2001; Porter and Porter, 2001).

Birds
Open Ocean Dynamics
Extreme Storms
Coastal Development
Pollution
Water Management
Climate Changes

STATE

Fish & Shellfish Community Dynamics

The Florida Keys have more than 500 fish species, including 389 that are reef-associated (Stark, 1968), and thousands of invertebrates, including corals, sponges, shrimps, crabs, and lobsters. Species in the snapper-grouper complex utilize a mosaic of cross-shelf habitats and oceanographic features over their life spans (Ault and Luo, 1998; Lindeman et al., 2000). Most adults spawn on the barrier reefs and sometimes form large spawning aggregations (Domeier and Colin, 1997). The Dry Tortugas region, in particular, contains numerous known spawning aggregation sites (Schmidt et al., 1999). Pelagic eggs and developing larvae are transported from spawning sites along the barrier reef tract by a combination of seasonal wind-driven currents and unique animal behaviors to eventually settle as early juveniles in a variety of inshore benthic habitats (Lee et al., 1994; Ault et al., 1999b). Some of the most important nursery habitats are located in the coastal bays and near barrier islands (Lindeman et al., 2000; Ault et al., 2001). As individuals develop from juveniles to adults, ontogenetic habitat utilization patterns generally shift from coastal bays to offshore reef environments.

- Prey Base
- Sport Fishes
- Reef Fishes
- Barracuda, Sharks, Mackerels, Mammals, Turtles

Water Quality

Another important aspect focuses on the potential effects of habitat alteration on reef fishery sustainability resulting from planned Everglades restoration activities. From the late 1940–1960s, the Army Corps of Engineers and the South Florida Water Management District constructed an elaborate network of canals that drained wetlands for agriculture and human habitation, reduced seasonal flooding in urban areas, and provided freshwater for human use. This water management system was a major factor in promoting regional human population growth. The canal network also detrimentally impacted the Everglades and coastal marine ecosystems by altering the distribution of freshwater within the watershed and the quantity, quality, timing, and spatial locations of freshwater discharges to coastal bays. The Comprehensive Everglades Restoration Plan (CERP, 1999) is a 30-yr project aimed at correcting some of these adverse environmental effects and restoring the terrestrial everglades ecosystem while meeting the anticipated human water needs for the next 50 yrs.

Ocean Physics & Regional Ocean Dynamics

Unique topographic and oceanographic conditions help sustain the highly productive Florida Keys coral reef ecosystem. The coastal marine environment exhibits relatively little topographic variation, although the sea floor abruptly plummets to depths of 1500 m or more several kilometers seaward of the barrier reef tract. Oceanographic dynamics are influenced by the Loop Current in the southeastern Gulf of Mexico which merges with the Florida Current near the Dry Tortugas and then flows parallel to the barrier reef through the Straits of Florida towards Miami. This unique geophysical setting promotes dynamic oceanographic conditions comprised of intricate recirculating gyres and surface currents with some of the highest current speeds in the world (Stommel, 1976; Olson, 2001, 2002). The seaward edge of the barrier reef tract is usually subjected to open tidal exchange from the Florida Straits with its warm, clear, low nutrient waters conducive to coral reef development. These conditions are periodically interspersed with pulses of nutrient-rich waters from locally intense upwelling events along certain deep reef margins where some of the most luxuriant coral habitats are found (e.g., Miller et al., 2001; Olson, 2001, 2002; Ault et al., 2002).

The Florida Keys have a subtropical maritime climate with moderate temperatures and two seasons: the summer wet season (May–October), marked by numerous convective thunderstorms, and the winter dry season (November–April) which features infrequent, fast-moving, dry cold fronts. Water circulation in coastal bays is primarily influenced by tides and wind (Wang et al., 2003). During the wet season, fairly sharp salinity gradients exist in coastal bays in which near-freshwater conditions found along the coastal shoreline progressively change to near-oceanic conditions at the barrier islands.

Habitats

Benthic habitats exhibit a distinct cross-shelf pattern. Fringing mangrove habitats occur on the land-sea edge of coastal bays and around barrier islands. Coastal bays have three main benthic habitat types: seagrass beds, bare unconsolidated substrates, and oolitic limestone hardbottoms populated with sponges and octocorals. Seaward of the barrier islands, benthic habitat types include stony coral patch reefs and barrier reefs, sponge-gorgonian covered hardbottoms, seagrass beds, and carbonate sands.

- Mangroves
- Seagrass

- Sand & Sediments
- Sponges & Algae
- Hardbottoms & Octocorals
- Coral Reefs

ECOLOGICAL AND FISHERY INDICATORS

In principle, sustainable exploited populations need sufficient reproductive capacity in terms of the biomass of spawning adults to replenish themselves into the indefinite future. The FSS framework has two “primary” elements, the coral reef ecosystem and the interacting human-fishery sector, and three “derived” elements: data acquisition, model building, and resource risk assessment. Data acquired from biotic and abiotic components of the coral reef ecosystem and the human-fishery sector are used to construct mathematical and statistical models that reflect the complexity and uncertainty of real ecosystem processes and their interactions with the human-fishery sector. Models of perceived reality are then employed to assess the risks to fish stock sustainability under current and anticipated future conditions of fishing intensity, water management practices, and other environmental conditions. Knowledge and insights gained are provided to managers and policymakers, who in turn implement regulations to modulate human impacts on the ecosystem to ensure fishery sustainability.

The elements of the analysis framework (data acquisition, modeling, and risk assessment) are ubiquitous to most real-life fishery science applications. The centerpiece of the analysis process is an integrated suite of mathematical models that couple ecosystem dynamics and human impacts (Ault et al., 1998, 1999b, 2003a, 2005; Wang et al., 2003).

Size-structured abundance
Spawning stock biomass
Catch rates
Yields
Species composition (richness)
Habitat occupancy

Fishing impacts are normally evaluated as tradeoffs between yields (in biomass) extracted by the fishery relative to the biomass of spawners remaining in the sea that are required to ensure sustained production. This concept is illustrated using two widely used fishery management benchmarks: yield-per-recruit (YPR) and spawning potential ratio (SPR). YPR is the expected lifetime yield of a cohort scaled to annual recruitment of newborns for a given combination of fishing mortality rate and minimum capture age or size. SPR is the expected lifetime spawning biomass of a cohort for a given combination of fishing mortality and age of capture scaled to the unexploited lifetime spawning biomass. In the U.S. south Atlantic, the federal minimum standard is 40% SPR for Goliath grouper, *Epinephelus itajara* (Lichtenstein, 1822), and 30% SPR for other reef fish stocks (NOAA Fisheries, 2002). These values are derived from density-dependent stock-recruitment theory where the number of recruits to a population is expected to be approximately the same at or above the minimum SPR threshold. The maximum YPR value at which SPR is at or above the 30% threshold denotes the level of exploitation expected to produce “maximum sustainable yield” (MSY).

Sustainability analyses involved comparison of various population metrics at current levels of fishing mortality against standard fishery management sustainability benchmarks. Typically, simulation models are configured to assess several reference points to address several sustainability risks, including fishery yields, spawning potential ratio (SPR; Clark 1991) and precautionary control rules (for example Restrepo & Powers 1999). Estimated SPRs are compared to USA Federal standards which define 30% SPR as the threshold below which a stock

is no longer sustainable at current exploitation levels (see Gabriel *et al.* 1989; Restrepo *et al*. 1998). Evaluation of control rules involved determination of Fmsy (F generating maximum sustainable yield, MSY) and Bmsy (population biomass at MSY). We defined F =M as a proxy for Fmsy (Quinn & Deriso 1999; Restrepo & Powers 1999).

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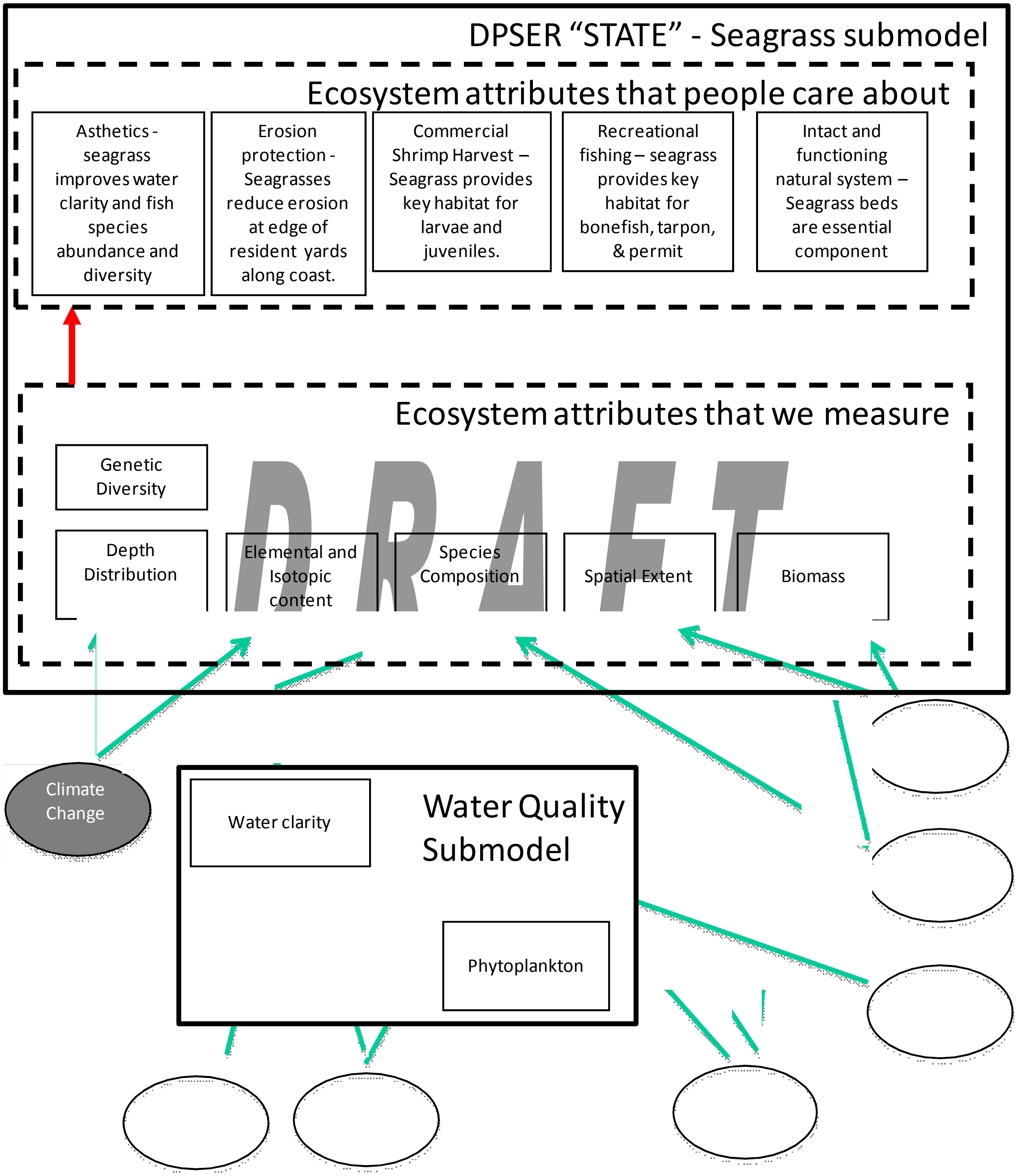
Appendix – Seagrass Sub-model

James Fourqurean, Florida International University



Appendix – Mangrove Sub-model

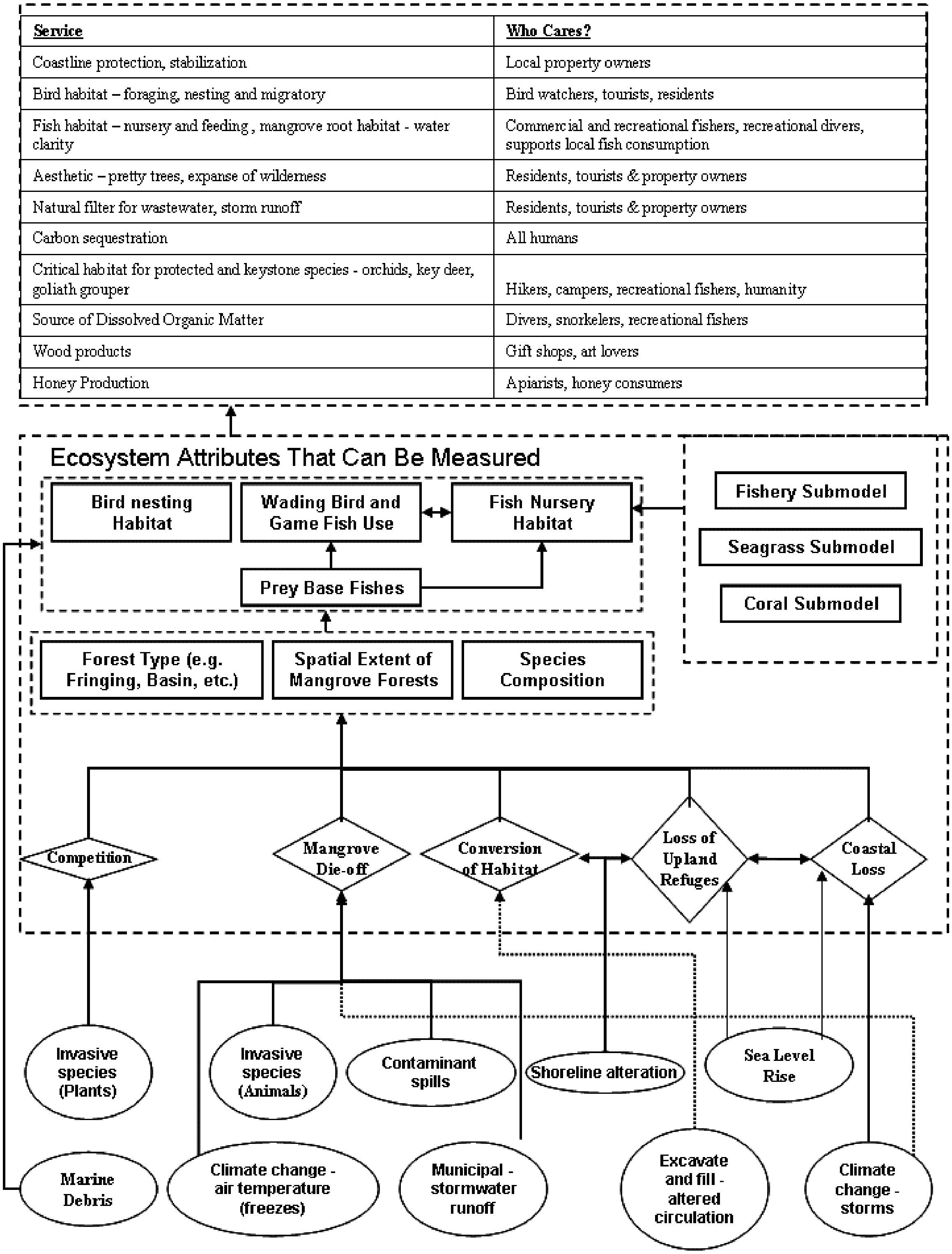
Jerry Lorenz, Audubon Society

INTRODUCTION

Prior to urbanization, there were 95,000 ha of mangrove forests in the Florida Keys/Dry Tortugas (FKDT) (Coastal Coordinating Council 1974). Ecosystem services provided by these mangrove forests include nursery habitat for numerous fishery species of economic importance and critical foraging habitat for adults of some of these same species (Odum et al. 1982, Lewis et al. 1985, Faunce and Serafy 2006). They provide foraging and nesting habitat for South Florida's ubiquitous fish eating birds (Odum et al. 1982) as well as nesting and stopover habitat for resident and migratory passerine bird species (Odum et al. 1982). They are highly effective at sequestering carbon dioxide, nutrients and protect shorelines from erosion and storm surges (Odum and McIvor 1990). Local, regional and global stressors, both natural and anthropogenic may result in loss of this habitat in the FKDT domain.

There are three species of mangroves in the Florida Keys: red (*Rhizophora mangle*) black (*Avicennia germanans*) and white (*Laguncularia recemosa*) mangroves. Buttonwood (*Conocarpus erectus*), a mangrove associate, is also common in mangrove forests in southern Florida. Tidal forces, climatic conditions and soil type result in these species forming six different forest types: overwash, fringe, riverine, basin, hammock and scrub forests (Lugo and Snedaker 1974). The arrangement of the species within forest type determines the biota that occur within the mangrove forests (Lugo and Snedaker 1974). Epiphytes and sessile invertebrates frequently grow on specialized root adaptations of mangroves (prop roots and pneumatephores) and these, plus the mangrove leaf litter are the basis of mangrove food webs (Odum and Heald 1975). Odum et al (1982) reported 220 species of fish, 21 reptiles, 3 amphibians, 18 mammals and 181 birds utilize the mangroves of southern Florida.

Figure xx: Mangrove Sub-model



Service	Who Cares?
Coastline protection, stabilization	Local property owners
Bird habitat – foraging, nesting and migratory	Bird watchers, tourists, residents
Fish habitat – nursery and feeding , mangrove root habitat - water clarity	Commercial and recreational fishers, recreational divers, supports local fish consumption
Aesthetic – pretty trees, expanse of wilderness	Residents, tourists & property owners
Natural filter for wastewater, storm runoff	Residents, tourists & property owners
Carbon sequestration	All humans
Critical habitat for protected and keystone species - orchids, key deer, goliath grouper	Hikers, campers, recreational fishers, humanity
Source of Dissolved Organic Matter	Divers, snorkelers, recreational fishers
Wood products	Gift shops, art lovers
Honey Production	Apiarists, honey consumers

ICEM COMPONENTS

Pressures
1) Municipal - Stormwater runoff
2) Contaminant spills
3) Sea Level Rise
4) Climate Change – storms
5) Excavate and fill – Altered circulation
6) Shoreline Alteration
7) Invasive species
8) Climate change –air temperature
9) Marine Debris

State
1) Mangrove forest spatial extent, forest type and tree species composition
2) Prey base production
3) Wading bird and game fish use
4) Fish nursery capacity
5) Changes in bird nesting habitat

Attributes that people Care About
1) Coastline protection and stabilization
2) Bird habitat – foraging, nesting and migratory
3) Fish habitat – nursery and feeding
4) Aesthetics
5) Natural Filter for wastewater, storm runoff
6) Carbon sequestration
7) Habitat for protected and keystone species
8) Source of DOM
9) Wood products
10) Honey production

PRESSURES

Contaminant spills and Municipal - Stormwater runoff

Mangroves are well adapted to thrive in anaerobic soils (Walsh 1974). These adaptations include a shallow root system and root specialization that allow the portion of the root just above the waters surface to take in oxygen and distribute it to the roots in the anaerobic environment (Walsh 1974). If these root adaptation become clogged, such as being coated by oil, the root systems fail and the plant dies (Odum et al. 1982). Studies performed after two oil spills near the Panama Canal documented the immediate loss of mangroves that were coated by the spill (Jackson et al. 1989, Duke et al. 1997) and that the damage was persistent for years after the spills (Duke et al. 1997). The presence of oil tankers off shore near the FKDT could result in an oil spill that reaches and destroys these mangroves. Another threat is Gulf of Mexico oil exploration and extraction. The Gulf's Loop Current has the capacity to convey water from the northern Gulf (where the significant drilling occurs) to the FKDT (Sturges et al. 2005). An oil rig blow-out in the northern Gulf could contaminate the FKDT mangroves with oil, as is potentially the case with the recent Deepwater Horizon/BP oil rig explosion. There is also a political push to open Florida's coastal water to oil exploration which could result in a more immediate impact should a drilling accident occur closer to the FKDT. Stormwater runoff may contain petroleum products or other contaminants that may also be injurious to mangrove trees in urbanized areas of the FKDT.

Sea Level Rise

Wanles et al. (1994) estimated sea level rise in the FKDT to be 20-40 cm per century and that mangroves could accrete soils up to 30 cm per century. The IPCC (2007) predicts that future sea level rise will be between 20 and 60 cm per century. These estimates suggest that at the low end mangrove accretion could keep pace with sea level rise but the higher estimates would out pace their capacity by a good margin. If the specialized root systems become flooded, the roots would not be able to respire and the tree would drown (Walsh 1974). The end result would be spatial loss of mangroves if the higher estimates take place. This would be the direct impact of sea level rise alone, however, the interaction of sea level rise with other pressures (specifically Climate change – storms and Shoreline alteration) can have synergistic impacts (discussed below).

Climate Change – storms

The effect of global climate change on the frequency of hurricanes in the north Atlantic is, admittedly, not well understood but increased sea surface temperatures have been demonstrated to increase the number and intensity of hurricanes since the 1970's (IPCC 2007). The IPCC (2007) predicted a global decrease in cyclone formation but an increase in their number and intensity will likely increase in the north Atlantic, based on their prediction of higher sea surface temperatures in that basin. This increase would result in greater frequency and intensity of strikes in the FKDT. As was demonstrated from Hurricane Andrew in 1990, intense storms can destroy entire mangrove forests (Pimm et al. 1994). Furthermore, Wanless et al. (1994) demonstrated that intense storms in 1935 and 1960, removed not only mangrove forests but washed away much of the soils as well. Up until the storms hit, mangroves were able to accrete soils to keep up with sea level rise, but when these soils were washed away, along with the trees, the resulting habitat was too deep for mangrove propagules to establish themselves leaving open mud flats where dense forest once stood (Wanless et al. 1994). In this way both hurricanes and the combination of hurricanes and sea level rise can result in the permanent loss of mangrove habitats.

Excavate and fill – Altered circulation

Impounding of mangrove forests can result in sudden mangrove mortality if water levels behind the impoundment result in flooding of the upper root zone, thereby drowning the trees (Odum et al. 1982). If the effect of the impoundment is to make the mangrove forest dryer, than mangrove will gradually be replaced by more upland species through successional changes (Odum et al. 1982). Both of these have occurred in the FKDT in the past (Odum et al. 1982) and, although now regulated, permits can be acquired to create such impoundments (e.g., the recent expansion of the Key West International Airport; pers. obs). Another possible means for altering circulation patterns that could alter mangrove habitats is proposals to remove some of the dredge and fill causeways created by the Flagler East Coast Railroad and the US-1 road bed (e.g., the Florida Keys Feasibility Study and Florida Keys Tidal Channel Demonstration Project which are both part of the Comprehensive Everglades Restoration Plan; U.S. Army Corps of Engineers 1999). These projects are designed to restore more natural circulation patterns between the Keys, thereby presumably undoing damage caused to both the coral reef and Florida Bay caused by the lack of circulation (U.S. Army Corps of Engineers 1999). These causeways increased the spatial habitat of mangroves by reducing flow rates and allowing the establishment of propagules on many mud flats adjacent to the roadway. Restoring the flow may result in the direct destruction of these forests or their inability to re-establish after a catastrophic event (e.g., hurricanes, freezes).

Shoreline Alteration

Urbanization of both mangrove and upland habitats has been extensive in the FKDT on islands that are connected by roadways (Strong and Bancroft 1994). Strong and Bancroft (1994) documented the destruction of 44%, 50%, 65% and 39% of mangrove forests on southern Key Largo, Plantation Key, Upper and Lower Matecumbe Keys respectively, principally due to conversion to dredge and fill subdivisions prior to 1991. Loss of upland habitat in the FKDT can also affect mangroves in combination with sea level rise. In places like Everglades National Park, mangroves are expected to remain the same or increase in size with an expansion inland and concomitant loss shoreward (Pearlstein et al. 2009). In the FKDT, much of the inland habitats have also be destroyed through urbanization removing inland sea level rise refuges for mangroves as in Everglades National Park. Strong and Bancroft (1994) estimated the loss of upland hammock forest at 64%, 70%, 76% and 69% for southern Key Largo, Plantation Key, Upper and Lower Matecumbe Keys respectively. Although current and future losses of both mangrove and upland habitat in the FKDT are well regulated, losses still continue through permitted and illegal clearing of the habitats in urbanized areas (pers. obs.)

Invasive species

At least two species of Indo-Pacific mangroves have been established in southern Florida and are expanding their ranges and displacing native mangroves (Fourqurean et al. In Press). Invasive upland species, such as Brazilian pepper (*Schinus terebinthifolius*; Lass and Prather, 2004) and Australian pines (*Casuarina equisetifolia*; pers. obs.) have also displaced mangroves in areas of low salinity and higher elevations. Introduced animals can also have a direct impact on mangrove forests. For example, mangroves have been found susceptible to damage from native foliovores (Imbert et al., 1999) and wood boring organisms (Rehm and Humm 1973). It is conceivable that the introduction of more noxious species of such organisms may result extensive damage to mangrove forests. Introduced vertebrates can also cause extensive damage as demonstrated by the nearly complete destruction of the mangrove forest of Lois Key in the lower Florida Keys by a food-subsidized colony of free roaming rhesus monkeys (pers. obs., also see http://www.cnn.com/TECH/science/9807/10/monkey.island/). Introduced animals can also have a direct impact on the community structure within mangrove forests by out competing or preying upon native species (e.g. Trexler et al. 2000, Barbour et al. 2010).

Climate change –air temperature

Although the greatest threat of global climate change is the steady increase in mean temperatures, most models indicate that there will be greater variance in temperatures as well

(IPCC 2007). This suggests that, although the mean temperature in the FKDT will likely increase, there will also be greater variability around that mean including, possibly, more frequent and severe cold events. Mangroves are susceptible to cold stress that takes the form of defoliation and death (Stevens et al. 2006). For example, in December 1989, overnight temperatures dropped to approximately freezing for two consecutive nights along the lower east coast of Florida (NOAA 1990). This resulted in the defoliation of hundreds of square kilometers of dwarf red mangrove forest along the extreme south eastern coast (pers. obs.). If global climate change does result in lower extreme temperatures in the FKDT, such impacts may become more common and more severe.

Marine Debris

Because of the specialized root adaptations of mangroves, mangroves tend to trap and hold marine debris. Although this debris may have little or no impact on the trees themselves, it can have lethal effects on the animals that populate the mangrove forest. These impacts can range from invertebrates becoming trapped in discarded bottles to fish and birds becoming entangled in plastic or monofilament fishing line (pers. obs.). This mortality is localized but it could have a cumulative effect across the scale of the FKDT.

STATE

State of mangrove forest: spatial extent, species composition, and forest type

The pressures listed above, with the exception of marine debris, can result in changes in forest type, tree species composition or the loss of mangrove forests entirely. Invasive plants, through competition with mangrove trees, can not only change the species composition but can also change the type of forest as well or simply displace mangroves entirely. Invasive animals, contaminant spills, freezes and hurricanes can result in mangrove kills. After the trees are killed, they can be replaced by different species (Craighead 1971), different forest type (Odum et al. 1982) or replaced by non-mangrove habitat (Craighead 1971, Wanless et al. 1994) resulting in overall loss of mangrove forest spatial extent. Shoreline alterations, such as dredge-and-fill construction projects, have, and will continue, to dramatically reduce the spatial extent of mangrove forests permanently. The combination of upland urban development and sea level rise will cause mangroves to die at lower elevations and not have the ability to expand there range to higher elevations resulting in the loss of mangrove forest spatial extent. Impoundments can change the type of forest (eg. from overwash to basin forest: Rey et al. 1990) and in the process change the species composition of the forest or impoundments can permanently change the habitat itself resulting in the loss of mangrove spatial extent (Odum et al 1982). Sea level rise alone (Gilman et al. 2007), or in combination with climate change induced tropical storms (Wanless et al. 1994), can cause the inundation of forests to the point that they drown thereby permanently resulting in the loss of coastline and the permanent loss of mangrove forest spatial extent.

State of fish and bird use of mangrove forest

A decrease in the spatial extent of mangrove forests in the FKDT will eliminate highly productive habitats for the small demersal resident fishes that make up the prey base for both predatory fish and piscivorous birds (e.g. Lorenz 1999, Lorenz and Serafy 2006), thereby eliminating important foraging grounds for these species. Forest declines will also eliminate critical nesting habitat for myriad bird species (Odum et al. 1982). Studies of fishes in the mangrove forests of southern Florida show that fish species composition is highly variable depending on the forest type and the tree species composition of those forests (western Florida Bay: Thayer et al. 1987; northeastern Florida Bay: Ley et al. 1999, Lorenz 1999, Lorenz and Serafy 2006; Biscayne Bay: Serafy et al. 2003; and the southeastern Everglades: Faunce et al. 2004). Therefore changes in forest type or tree species composition will alter the type of fish community that utilizes these habitats. Increased structural complexity of mangrove root systems have been demonstrated to decrease predator efficiency (Primavera 1997) so forest type and tree species composition would determine the use of habitats as nursery grounds for juvenile game fish species as well as the forest use for piscivorous fish and birds. Changes in mangrove forest type and species composition also determine the suitability for nesting habitat for many bird species. For example, White Crown Pigeons require dense canopy while several species of wading birds nest in more open canopy. Changes in forest structure and type may change the suitability of the forest as nesting habitat for specific bird species.

ECOSYSTEM ATTRIBUTES PEOPLE CARE ABOUT

Coastline protection and stabilization

Property owners in the FKDT region benefit from the protection that mangrove shoreline provide during tropical storms. These forests buffer wind speeds and attenuate storm surges thereby reducing the effects of these forces on developed properties. Mangrove lined creeks also provide safe anchorages to boats during storms.

Bird habitat

Bird watching is one of the fastest growing past times in the United States (Carver 2009) and advertisements in “birding” literature are used by the Monroe County Tourist Development Council to attract bird watches to the Keys for vacations (pers. obs.). The presence of a diverse community of birds, including those that are dependant on mangrove forests, provides high levels of satisfaction of vacationing bird watches as well as the hoteliers and restaurateurs that cater to this generally affluent group of tourists (Carver 2009). Furthermore, even tourists who have no inclination toward bird watching have their visits enhanced by seeing such common species as brown pelicans, osprey, eagles, herons, ibis and spoonbills, thereby leading to higher satisfaction with visiting the Keys.

Fish habitat

As stated above, mangrove root habitat provides both nursery habitat for economically valuable juvenile fish and shellfish as well as providing foraging habitat for game species. Harding (2005) estimated that, in 2005, retail sales associated with saltwater recreational fishing in Monroe and Dade counties totaled $408.7 million and supported more than 7200 jobs. Backcountry fishers target game species such as mangrove snapper, seatrout, redfish, tarpon, and snook from among the mangrove prop roots and adjacent waters while offshore fishermen target adult grouper and snapper species that spent part of their early life cycle in the mangrove forest (Lewis et al. 1985). Commercial fishers also benefit from mangroves as the three species with the largest dock landing in the FKDT (pink shrimp, spiny lobster and stone crabs) also spend portions of their juvenile life stages in mangrove forests (Lewis et al. 1985)

Aesthetic value
Leeworthy and Wiley (1996) surveyed residents and visitors of the FKDT and determined that wildlife viewing/nature study was a top activity. The aesthetic value of myriad mangrove islands and meandering mangrove lined creeks certainly adds to the value of these activities.

Waste water/storm water filtration
Mangrove forests act as sinks for both nitrogen and phosphorous taking in these nutrients as water flows through the forest (Odum et al. 1982). Waste water and storm water are rich in these nutrients and these nutrients can be damaging to coral reefs and other ecosystems (see water quality sub- model and coral reef and hard bottom sub-model). The presence of mangroves adjacent to developed areas of the Keys would reduce the amount of nutrients reaching the reefs by filtering runoff through the forests. Furthermore, mangroves have been demonstrated to remove and sequester heavy metals (Foroughbakhch et al. 2008) that are a component of storm water runoff and can be damaging if they enter the various food webs of the FKDT.

Carbon sequestration
Mangrove forests store massive amounts of carbon (Howe, et al. 2009). The loss of mangrove forests not only releases the stored carbon but also prevents further sequestration of carbon. By removing CO_2 from the atmosphere through photosynthesis and thus sequestering this recognized greenhouse gas, mangroves provide a valuable service to human society.

Critical Habitat for protected species
Manatee, small-toothed sawfish, goliath grouper, bottlenose dolphin, white-crowned pigeon, reddish egret, lower keys striped mud turtle, key deer, American crocodile, bald eagle, osprey, brown pelican, and mangrove cuckoo are examples of protected species that rely on or frequent mangrove habitats in the Florida Keys. Losing more mangrove habitat could further endanger these species, lowering biodiversity and also making the Keys less attractive as a place for people to observe rare species of animal. In particular, many snorkelers will visit mangrove habitats in search of charismatic megafauna such as manatee and sharks.

Export of organic material to other ecosystems
Although mangroves are a net sink for carbon, they do export organic mater to other marine systems (Odum et al. 1982). Granek et al. (2009) demonstrated that filter feeders such as sponges, bivalves and corals consume and assimilate mangrove based organic mater when in proximity to mangrove forests.

Wood Products
Mangroves are harvested in many parts of the world to be used in wood products (Odum et al. 1982). Historically, in southern Florida (including the FKDT) buttonwood was harvested for use in charcoal production and red mangrove bark was harvested to manufacture tannic acid (Tebeau 1968). Today, there is no commercial harvesting of mangroves in southern Florida but there are artisanal uses of mangroves for wood working, art works, and cooking wood (pers. obs.).

Honey production

The Florida Agriculture Statistics Service reports that Florida was the fourth largest honey producing state in the U.S. in 2008 with an estimated value of $15.4 million. Black mangrove honey is of a very high quality such that the tree is sometimes referred to as the "honey mangrove" (Florida Fish and Wildlife Research Institute, 2006). Apiarists in the Florida Keys target blossoming black mangrove stands to house their hives and market black mangrove honey (pers. obs.).

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Appendix – Coral and Hardbottom Sub-model

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CORAL REEFS AND HARDBOTTOM COMMUNITIES

INTRODUCTION

The reef communities of the Florida Reef Tract represent the only living tropical coral reef system in the continental U.S. and several interacting factors have contributed to the consideration of this ecologically, economically, and aesthetically unique system as an “ecosystem at risk” (Bryant et al., 1998). The location of Florida reefs adjacent to large and rapidly growing urban centers makes this system vulnerable to anthropogenic disturbances like eutrophication, sedimentation, and pollution commonly associated with coastal development and industrial and agricultural activities (Glynn et al., 1989; Lapointe and Clark, 1992; Lipp et al., 2002). Similarly, the Florida Reef Tract and adjoining coastal lagoons (i.e., Biscayne Bay, Florida Bay) support recreational and commercial fishing and harvesting activities that provide a multi-billion dollar income to the local economy (Johns et al., 2001), but these activities have resulted in significant overfishing and depletion of most harvested stocks as well as direct physical damage to coral reefs from boating activities (Ault et al., 1998; Lirman et al., 2010).

Reefs of the Florida Keys, from Key West to Key Biscayne, are commonly divided into two main types, offshore shelf-margin bank reefs and lagoonal patch reefs. Offshore bank reefs with spur and groove habitats are generally oriented perpendicular to the shelf and are found on the seaward face of the shelf-margin (Marszalek et al., 1977). Patch reefs are high-relief features (up to 9 m of vertical relief) located within the inner lagoon between the Florida Keys and the shelf-margin reefs. Patch reefs are commonly dome- or linear-shaped, and range in diameter from a few meters to up to 700 m (Marszalek et al., 1977; Jaap, 1984; Lirman and Fong, 2007).

In addition to hermatypic, accreting reefs, low-relief hardbottom communities are a key component of coastal habitats of South Florida. Hardbottom habitats in the Florida Keys can be found adjacent to the mainland and islands at depths from < 1m to > 20 m. Hardbottom communities are characterized by of a limestone platform covered by a thin layer of sediments and consist of a sparse mixture of stony corals, soft corals, macroalgae, and sponges. Many of these communities are found on remnant, low-profile habitats lacking significant zonation and topographical development (<1 m of vertical relief) in areas where sediment accumulation is < 5 cm (Lirman et al., 2003). These habitats, which can be important nursery habitats for lobsters, are characterized by low coral cover and small coral colony size (Blair and Flynn, 1989; Chiappone and Sullivan, 1994; Butler et al., 1995).

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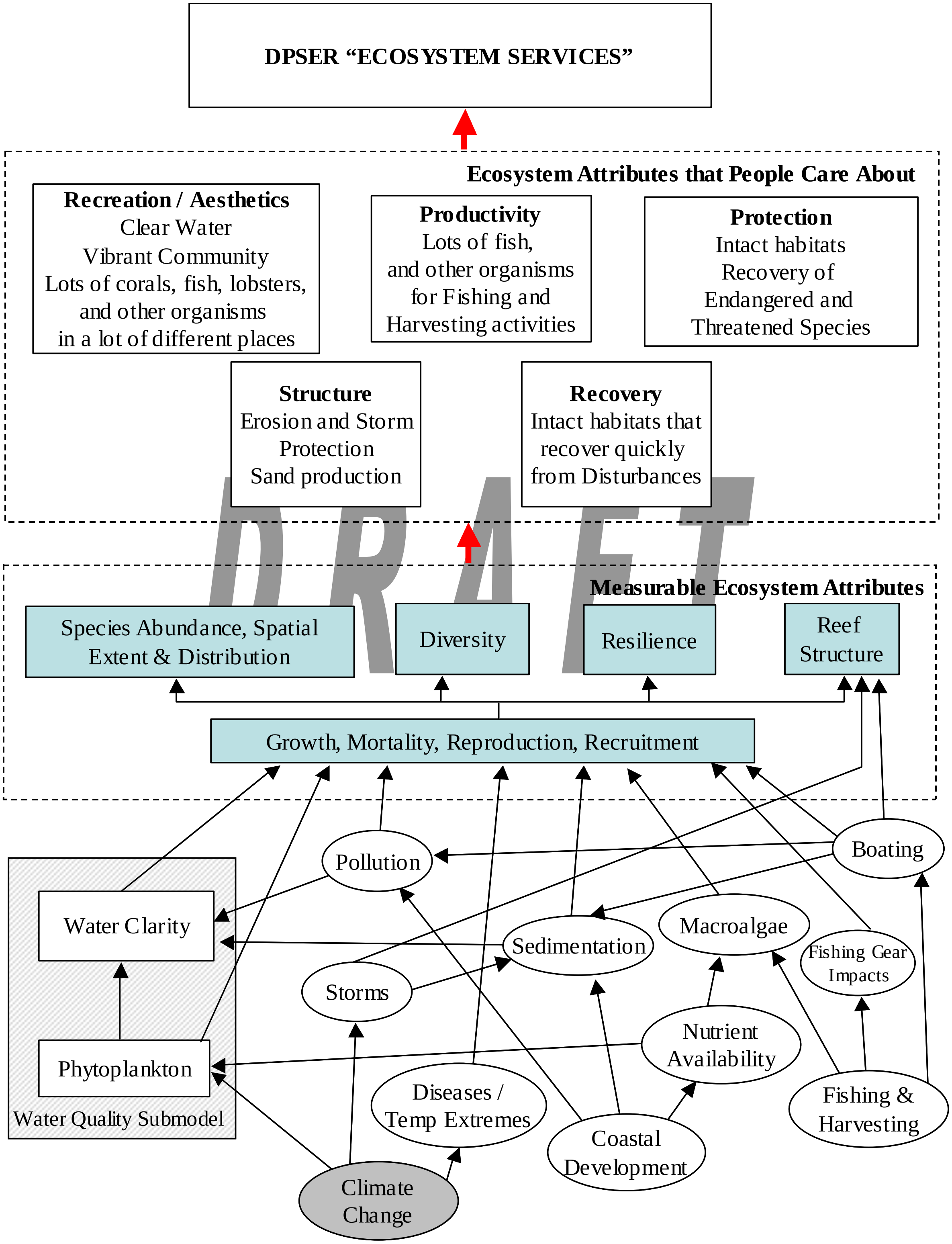

CORAL REEF AND HARDBOTTOM SUB-MODEL

Pressures

8) *Climate Change*
9) *Diseases*
10) *Temperature Extremes*
11) *Storms*
12) *Coastal Development (Nutrient Availability, Sedimentation, Pollution)*
13) *Fishing and Harvesting (Macroalgae, Fishing gear impacts)*
14) *Boating*

State

10) *Water Clarity (link to Water Quality Model)*
11) *Species abundance, spatial extent and distribution*
12) *Species Diversity*
13) *Resilience*
14) *Reef structure*

Attributes That People Care About

7) *Structure*
    a. *Erosion Control*
    b. *Storm Protection*
    c. *Sand Production*
8) *Recovery Potential*
9) *Recreation and Aesthetics*
    a. *Clear Water*
    b. *Vibrant Natural Community*
    c. *Lots of organisms (corals, fish, lobsters, etc)*

    d. *Variety of habitats in many different places*

10) Productivity

    a. *Lots of fish and other organisms for fishing and harvesting activities*

11) Protection

    a. *Intact Habitats for sustainability of existing organisms*
    b. *Intact Habitats for the recovery of protected species*

PRESSURES

Global Climate Change (GCC) and the stressors associated with this phenomenon are a major source of concern for coral reef and hardbottom organisms (CR&HB) in South Florida that commonly live near thresholds for environmental factors predicted to be affected by GCC. The GCC-related factors that can influence the abundance, distribution, and diversity of CR&HB organisms include: (1) increased sea surface temperatures that can result in severe coral bleaching (Glynn, 1993; Van Oppen and Lough, 2009), (2) ocean acidification caused by increases in atmospheric CO^2 can result in reduced calcification and even skeletal dissolution (Kleypas et al., 1999; Andersson et al., 2005; Cohen and Holcomb, 2009), (3) increases in storm frequency can result in enhanced physical damage; and (4) sea-level rise can modify the depth distribution of organisms based on their light requirements.

Diseases have been implicated as one of the main causal factors in the drastic declines in the abundance and distribution of corals recorded over the past three decades in Florida and elsewhere (Aronson and Precht, 2001; Kim and Harvell, 2002; Richardson and Voss, 2005). Many (if not most) of the epizootic agents and transmission pathways that affect soft and hard corals and sponges have not been fully described. Nevertheless, studies have found that increased temperatures are related to disease prevalence (especially after bleaching events, Brandt and McManus, 2009), human pathogens may cause disease in nearshore corals (Sutherland and Ritchie, 2004), and that the predatory and territorial activities of snails, polychaete worms, and fish may be a mechanism for inter-colony transmission of diseases vectors (Williams and Miller, 2005).

Temperature extremes, both high (> 30) and low (< 15 C) have been shown to cause coral bleaching (i.e., expulsion of symbiotic dinoflagellates) and, if prolonged, significant mortality to corals and other benthic organisms (Van Oppen and Lough, 2009). Coral bleaching and mortality in the Florida Reef Tract have been recorded during the 1998 and 2005 bleaching events. Cold-water mortality of corals and other organisms was observed historically (Davis, 1982; Jaap and Sargent, 1994) and, more recently, in the winter of 2010 (Lirman, personal observation).

The physical impacts of **hurricanes and tropical storms** have been well documented in South Florida. Impacts of hurricanes range from minor colony fragmentation and scouring to the severe fragmentation of reef framework (Lirman and Fong, 1997; Gardner et al., 2005, Gleason et al., 2007). Storms can cause direct physical damage in the form of colony fragmentation, dislodgement and overturning, burial, sediment scouring, as well as secondary damage through light reduction, impairment of filter feeding activities, and the reduction in salinity due to rainfall and increased runoff (Goreau, 1964). Beneficial impacts of storms include the removal of macroalgae and the reduction in seawater temperature that may mitigate bleaching (Manzello et al., 2007).

Coastal Development activities were recently identified by reef scientists and resource managers as one of the main sources of disturbance to coastal habitats (Kleypas and Eakin, 2007). The stressors associated with coastal and urban development (as well as commercial and recreational activities) include: nutrient availability, sedimentation, pollution.

Nutrient loading to coastal habitats can be both natural and anthropogenic. For the purpose of this modeling exercise, nutrient loading from human activities is considered on top of the nutrients derived from natural sources. Increased nutrients can have both direct and indirect impacts on benthic organisms (Szmant, 2002). Direct impacts include the impairment of calcification and growth in stony corals under high nutrient conditions (Koop et al., 2001). Indirect effects include the disruption of the coral-zooxanthellae symbiosis and a reduction in the translocation of C to the host (Fabricius, 2005), increased phytoplankton in the water column leading to reduced light penetration and even toxicity (Brand and Compton, 2007; Butler et al., 2005; Boyer et al., 2009), and enhanced growth of macroalgae, a key space competitor in coral reefs and hardbottom habitats (Lapointe and Clark, 1992; Lapointe et al., 2002, 2004).

Macroalgae overgrowth of corals under high nutrient and low grazing conditions has been implicated in the phase shift from coral-dominated to algal-dominated communities throughout the world (Hughes, 1994; McCook, 1999; Hughes et al., 2007). Human activities can result in the release of: (1) top-down control of macroalgae by modifying the trophic structure of CR&HB habitats by reducing the abundance of key herbivores (e.g., parrotfishes), and (2) bottom-up control of macroalgae by increasing nutrient availability. The rapid growth of macroalgae under these scenarios can result in coral mortality through shading, sediment accumulation, smothering, and allelopathy, as well as reduced recruitment and survivorship of coral larvae (Lirman, 2001; McCook et al., 2001; Nugues and Roberts, 2003).

Sedimentation is recognized as an increasing source of disturbance to CR&HB habitats around the globe experiencing rapid population expansion, watershed modification, and coastal construction (Wilkinson, 2002, 2008). Sedimentation can impact coral reef and hardbottom organisms through light reduction, smothering and burial, and toxicity (Bastidas et al., 1999; Fabricius, 2005). Reductions in coral growth, photosynthesis, reproductive output, lesion regeneration, feeding activities, and recruitment have all been documented for corals under high sediment loading (Rogers, 1983, 1990; Riegl, 1995, Babcock and Smith, 2000; Lirman et al., 2003; Philipp and Fabricius, 2003).

Pollution impacts caused by human activities on CR&HB habitats have been associated with oil spills (Jackson et al., 1989), urban and agricultural stormwater and overland runoff (Glynn et al., 1989; Jones, 2005; Fauth et al., 2006), as well as physical impacts caused by solid waste disposal and others (Peters et al., 1997). The impacts of oil spills may include tissue and larval mortality as well as sublethal impacts on photosynthesis and reproduction (reviewed by Haapkylä et al., 2007).

Fishing and Harvesting activities, both recreational and commercial, are key components of the economy of South Florida (Johns et al., 2001). The removal and collection of marine organisms has both direct and indirect impacts on CR&HB habitats. Direct impacts include the targeted removal of organisms such as fish, sponges, lobsters, shrimp, anemonae, live rock, and others. Indirect impacts include physical disturbance associated with harvesting activities, fishing and collecting gear, and boating, and modifications to the trophic structure and removal of key organisms that can have cascading impacts on benthic communities. Fishing gear impacts have been documented for both coral reefs and hardbottom communities. These impacts include the removal of sponges and soft corals by drag nets (Ault et al., 1997), as well as trap and line impacts on reef organisms (Chiappone et al., 2005). While the removal of grazers (parrotfishes, surgeonfishes, sea urchins) is not a problem in South Florida where fishing activities are highly regulated, overfishing of grazers has resulted in increases in macroalgae in other areas in the Caribbean (Hughes, 1994). The removal of predatory fish, though, may result in an increase in the abundance of damselfish that can, through their territorial activities that include killing coral tissue to grow macroalgae, result in increased coral mortality (Kaufman, 1977). Another cascading effect of predator removal, in this case lobsters, may be the increase in the abundance of corallivorous gastropods (*Coralliophila abbreviata*) that cause significant tissue mortality on colonies of reef-building corals and are known prey items for this once abundant taxon (Johnston and Miller, 2007).

Boating activities, both recreation and commercial, are a major source of physical impacts to CR&HB habitats (Precht, 2006 and references therein). The physical damage caused by vessel groundings is a major source of disturbance to shallow habitats found within and adjacent to busy shipping lanes. In Florida, impacts by large and small vessels to coral reefs are a significant source of coral mortality and reef-framework modification (Lutz, 2006; Lirman et al., 2010).

Physical damage to benthic organisms and habitats can be caused directly by the impact of vessels' hulls, keels, propellers, and anchors, or indirectly through the movement of dislodged coral colonies and the shifting of sediments and rubble created during the initial impact. Damage to coral reefs can range from superficial, where only the living surfaces of corals are damaged, to structural where the geomorphologic reef matrix is fractured and exposed (Lirman et al., 2010). Indirect impacts of boating activities also include chemical pollution through the disposal of gas and oil into marinas and coastal habitats.

STATE: MEASURABLE ECOSYSTEM ATTRIBUTES

The impacts of the pressures and stressors identified in this conceptual model translate into measurable structural and functional ecosystem attributes through their impacts on vital processes of CR&HB organisms such as mortality/survivorship, growth, calcification, reproduction, recruitment, and regeneration. These lethal and sublethal impacts scale up to ultimately influence the abundance, diversity, spatial distribution, morphological structure and resilience that characterize CR&HB habitats and organisms.

Coral reefs are among the most diverse ecosystems in the world and their **diversity** has been always considered a metric of condition (Connell, 1978). Diverse communities (both at the species/taxa and genetic level) are believed to be more resistant and resilience to disturbances and are clear management goals for CR&HB habitats.

The **abundance** (most commonly estimated as percent cover) of stony corals is the most commonly used metric of coral reef status. Over the past three decades, declining patterns in coral cover have been used to highlight the status and trends within these habitats (Gardner et al., 2003).

In coral reefs, structure and function are tightly coupled. Reef-building corals provide the **topographical structure** that is synonymous with healthy, thriving coral reefs and serves as essential habitat for hundreds of thousands of associated reef species (Bell and Galzin, 1984). With the loss of live coral cover, bioerosional forces can exceed reef accretion and a flattening of the reef structure can ensue, diminishing the reef value as habitat (Alvarez-Filip et al., 2009) and affecting the capability of reefs to catch up with sea-level rise.

Resilience, or the ability of systems to absorb, resist or recover from disturbances or to adapt to change while continuing to maintain essential functions and processes, is increasingly recognized as a desirable ecosystem attribute in scenarios where multiple acute and chronic disturbances are common occurrences (Holling, 1973; Nyström and Folke, 2001). The Nature Conservancy's Reef Resilience Program (http://www.reefresilience.org/index.html) has identified four main components or elements of reef resilience that need to be considered: (1) *representation and replication* (and risk-spreading) to help increase likelihood of habitat survival; (2) designation and protection of *critical areas* vital to survival and sustainability of marine habitats that constitute high-priority conservation targets, such as fish spawning aggregations and nursery habitats; (3) preserving *connectivity* among reefs and associated habitats to ensure replenishment of coral communities and fish stocks; and (4) *effective management* to meet conservation and restoration goals and objectives, and, ultimately keep reefs vibrant and healthy.

Other measurable ecosystems attributes tightly linked to CR&HB habitats, namely **Water Quality, Seagrass**, and **Fish and Shellfish** components, are described in detail in other sections of this report.

ECOSYSTEM ATTRIBUTES THAT PEOPLE CARE ABOUT

The three-dimensional **Structure** provided by coral reefs provides protection from the impacts of storm waves and surge, tides, protecting both natural shorelines and property from physical damage. Both living and fossil coral reefs have also been important sources of construction materials (sand, rock, tiles) in South Florida. Lastly, coral reefs provide much needed protection for beaches and natural shorelines from erosion.

The health of CR&HB habitats is closely tied to the value of the **recreational, commercial, aesthetic, and educational services** they provide. Healthy, growing reefs with high topographical complexity provide high levels of productivity that translates into abundant fish and shellfish stocks that can be harvested by locals and visitors. Diverse, productive and healthy CR&HB habitats provide maximum enjoyment for snorkelers, and divers, and a wide variety of different habitat types widely distributed provide a large number of diverse enjoyment opportunities for repeat visitors (as well as spread the impacts of excessive use over a wider area). Lastly, an intact habitat with an intact trophic structure: (1) maximizes the long-term sustainability of the system, (2) increases the likelihood of recovery of threatened species like the staghorn and elkhorn corals, and (3) increases the resilience potential of the system so that the unique Florida Keys experience can be enjoyed by both present and future generations!

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Appendix – Valuing Ecosystem Services

(Right now, this section contains text left over from editing "Ecosystem Services" in the body of the report.)

Table 2.5: Methods for Evaluating Ecosystem Services – DRAFT 06-22-10

Ecosystem Service	Value of Service	Methods to Estimate Value
Recreational fishing	Use Value – willingness to pay to maintain or improve fishing conditions	Survey-based research such as contingent valuation focused on fishing success by species or travel cost modeling
	Economic Contribution – income, employment, tax revenues generated as visitors and residents spent money to fish in the FK/DT.	Survey-based research focused on resident and visitor recreational fishers in the FK/DT.
SCUBA diving, snorkeling and glass bottom boating	Use Value – willingness to pay to maintain or improve coral reef conditions	Survey-based research such as contingent valuation focused on management measures to protect or improve coral reefs or travel cost modeling
	Economic Contribution – income, employment, tax revenues generated as visitors and residents spent money to SCUBA and snorkel in the FK/DT.	Survey-based research focused on residents and visitors who SCUBA and snorkel in the FK/DT.
Beautiful, unique environment including viewing nature, bird watching, swimming, etc.	Use Value – willingness to pay to maintain or improve populations of orchids, birds, and key deer, shoreline water quality, air quality/odor, mangrove acreages and quality, seagrass acreages and any plant or animal that contributes to the beautiful, unique environment	Survey-based research focused on all residents and visitors of the FK/DT.
Intact habitat – corals, mangroves, seagrass, birds, fish	Non-Use Value – willingness of all adults in Florida (and in U.S. perhaps) to pay for management measures focused on protecting habitat in the FK/DT. Includes Existence, Bequest and Option values.	Survey-based research such as contingent valuation or choice stated preferences focused on all U.S or Floridians.
Commercial fish / shellfish harvest Maintain food variety and	Consumer and producer surplus by species increases with biomass.	Market value of fish harvested is indicator. Total value would be estimated through consumer demand functions and producer supply functions for fish /

Table 2.5: Methods for Evaluating Ecosystem Services – DRAFT 06-22-10

Ecosystem Service	**Value of Service**	**Methods to Estimate Value**
nutrition		shellfish species.
Reduction of property damages	Avoided cost of reduced storm damage to buildings and boats	Avoided cost estimation / Hedonic price analysis if data is sufficient
Reduced incidence of illness from seafood	Avoided cost of illness	Avoided cost estimation and choice stated preferences with reductions in the probabilities of suffering illness.
Natural filter for human wastes (wastewater and stormwater)	Avoided cost of alternative waste management such as wastewater treatment plants and stormwater systems	Avoided cost estimation, travel cost random utility models relating site choice to water quality, or choice stated preference models relating changes in values to changes in water quality.
Education Value	Non-Use Value – willingness of all adults in Florida (and in U.S. perhaps) to pay for the education / research value of the FK/DT ecosystem in its current and improved states.	Survey-based research such as contingent valuation or choice stated preferences focused on all Floridians.
OTHERS TO BE ADDED		

An example of how use values are estimated using survey-based research is provided in the document prepared for NOAA and the southeast Florida counties titled, "Socioeconomic Study of Reefs in Southeast Florida (Johns, Leeworthy, Bell and Bonn, 2001). The study provides estimates of the following values that represent the time period June 2000 to May 2001:

- Total reef use of residents and visitors in each of the four counties as measured in terms of person-days.
- Economic contribution of the natural and artificial reefs as residents and visitors spend money in each of the four counties to participate in reef-related recreation.
- Willingness of reef users to pay to maintain the natural and artificial reefs of southeast Florida in their existing conditions.
- Willingness of reef users to pay for additional artificial reefs in southeast Florida.
- Socioeconomic characteristics of reef users.

Economic contribution is measured by total sales, income, and employment generated within each county from residents and visitors who use the reefs. In addition, the opinions of residents regarding the existence or establishment of "no-take" zones as a tool to protect existing artificial and natural reefs are presented. This study found that 5.46 million person-days were spent fishing, diving and snorkeling on reefs in the Florida Keys in 2000. These activities provided $140 million in income to Florida Keys residents and supported 10,000 full- and part-time jobs in the local area. These reef users were willing to pay $51.78 million per year to support reef management that protects the reefs in their current condition providing a total asset value of $1.65 billion.

Categories of economic value

Products and resource inputs used by firms. Healthy sea grass beds provide habitat and food sources for fish, shellfish, and crustaceans that are harvested, processed and sold. In addition, healthy sea grass beds maintain water resources for open space aesthetics, recreational fishing, wildlife viewing, diving, and boating allowing firms in the marine recreation industry to offer equipment, access, and tour services to local residents, visitors, and tour groups.

Amenity services provided to households. Healthy sea grass beds maintain water resources for open space aesthetics, recreational fishing, wildlife viewing, diving, and boating providing local residents with a wide range of outdoor recreation opportunities.

Life support services to firms and households. Healthy sea grass beds assimilate wastes and byproducts from firms and households. Healthy intact sea grass beds provide shoreline protection, nutrient cycling, sediment retention, and storm water treatment. The valuable services provided by sea grass beds are an integral part of living and doing businesses in the FKDT.

Categories of economic benefit

Use value is the value that comes from individuals' actual or planned use of the ecosystem service. For example, groups of individuals take day trips to sea grass beds in FKDT to canoe and dive with the manatees. The *use value* includes the value of those trips or the willingness to pay to participate in these activities associated with either the current or improved condition of the ecosystem.

Option value is the amount individuals will pay to assure the ecosystem service will be available for use in the future apart from any planned uses. For example, some individuals may not have plans to travel to sea grass beds in the FKDT but they appreciate manatees in the wild and enjoy knowing that sea grass beds will be there in the future in case they (or others) decide to visit and view the manatees. The *option value* is the value an individual obtains from knowing the species will be available in the future for enjoyment.

Non Use/Passive Economic Use Value is the value individuals place on the assurance that the ecosystem will continue to provide services separate from actual or planned uses. For example, some individuals although they don't travel to the sea grass beds still have an appreciation for manatees in the FKDT and enjoy knowing the species will continue to winter in FKDT in the future. In the economics literature, this type of value has often been categorized according to people's motives, even though people's motives are irrelevant to the legitimacy of the values (economists don't question people's motives for consuming a good or service). The motives are often broken down into *existence value* or the willingness to pay to ensure that something exists in a certain condition and bequeath value or the willingness to pay to ensure future generations have the opportunity to experience the resource in a certain condition. Economists have more recently moved to adopting the terminology of passive economic use value for this category of value because people have to know something about what they are valuing. People learn about the condition of various resources through many media sources (e.g. TV, radio, magazines, newspapers, internet, news letters, etc.) that is they consume these resources passively through learning about them.

Quasi option value is the amount individuals will pay to postpone decisions that will irreversibly diminish or eliminate the ecosystem service.

Techniques for valuing ecosystem services

Travel cost is a method that utilizes visitor trip expenditures to quantify the recreational use value of a site visit. The Random Utility Model (RUM) models site choices based on site characteristics/attributes to allow for estimating how values change with changes in site characteristics/attributes.

Contingent valuation is a stated preferences method that uses survey questions to ascertain individuals' willingness to pay to retain or increase an ecosystem service or willingness to accept a loss or reduction in an ecosystem service.

Hedonic pricing is a method that uses the market price of a traded good to infer the value of a non-traded ecosystem good or service. The method can be used where the quality of the ecosystem good or service is believed to influence the price of the traded good.

Choice modeling is a stated preferences method that uses survey questions to ascertain individuals' tradeoff between levels of an ecosystem service, levels of competing uses of the resource, and cost. This method can integrate the physical/natural sciences in defining the good or service or change in the good or service to be valued, and can be directly tied to management actions. The method also allows for non economic rankings of preferences.