

# Benthic Habitat: Mangroves

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## In a nutshell:

- The mangrove forests of the Florida Keys and Dry Tortugas provide critical nursery and foraging habitat for numerous marine species of economic value; sequester carbon, as well as export organic materials that support coral reef and seagrass food webs; and are critical nesting and foraging habitat for marine water birds.
- People care about mangroves because they provide excellent fishing habitat; stabilize shorelines and provide a buffer against storm surges; are critical habitat to protected and charismatic species; and provide aesthetic, recreational, and tourism value.
- Mangrove habitat in the Florida Keys has been destroyed largely by urbanization of the Keys from the late 1950s through the 1980s. The large-scale loss of mangroves has all but ceased in the Keys due to laws protecting wetlands; however, these laws are continuously under threat of being relaxed. Other localized threats are contaminant spills and invasive species.
- Climate change is the largest global threat to mangroves of the Florida Keys and Dry Tortugas. Sea-level rise, increased frequency of tropical storms, and increased variability in temperature can result in large-scale changes in spatial extent and community structure of these forests.

## Description of Resource

Prior to urbanization, there were 95,000 hectares of mangrove forests in the FK/DT (Figure 1, 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 and nutrients, and they protect shorelines from erosion and storm surges (Odum and McIvor, 1990). Local, regional, and global stressors, both natural and anthropogenic, may result in the loss of this habitat in the Florida Keys. The processes by which these losses occur and why they should be minimized are defined in the ICEM (Figure 2).

There are three species of mangroves in the Florida Keys: red (*Rhizophora mangle*), black (*Avicennia germanans*), and white (*Laguncularia recemosa*). 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 pneumatophores) and these, plus the mangrove leaf litter, are the basis of mangrove food webs (Odum and Heald, 1975). Odum *et al.* (1982) reported that 220 species of fish, 21 reptiles, three amphibians, 18 mammals, and 181 birds utilize the mangroves of southern Florida.



Figure 1. Mangrove forests in the Florida Keys and Dry Tortugas.

## Role of the Mangroves in the Ecosystem

Mangrove forests can sequester nutrients and act as a wastewater filter (Ewel *et al.*, 1998), thereby playing a role in water quality, and they are sources for the export of organic material into coastal waters (Lugo and Snedaker, 1974; Odum and Heald, 1975; Twilley, 1985, 1988; Nixon, 1980). In

addition, these wetlands enhance the fish biomass on nearby seagrass beds (Manson *et al.*, 2005; Thayer and Chester, 1989) and corals, and other reef-building invertebrates have been found to assimilate mangrove organic material (Granek *et al.*, 2009). The mangroves of the Florida Keys/Dry Tortugas are highly productive in small demersal fishes and invertebrates (Heald *et al.*, 1984; Lorenz, 1999) that, during relatively low water periods, become highly concentrated and exploited by water bird species (Lorenz *et al.*, 2002; Odum *et al.*, 1982; Ogden, 1994; Powell, 1987) and game fish (Odum *et al.*, 1982; Odum and Heald, 1975). These wetlands also provide critical nesting habitat for water birds (Kushlan and Frohring, 1985; Ogden, 1994) and nursery habitat for fishery species (Ashton and Eggleston, 2008; Comp and Seaman, 1985; Lewis *et al.*, 1985; Manson *et al.*, 2005).

## Attributes People Care About

The mangroves of the FK/DT provide critical *Ecosystem Services* to the entire southwest coastal ecosystem including:

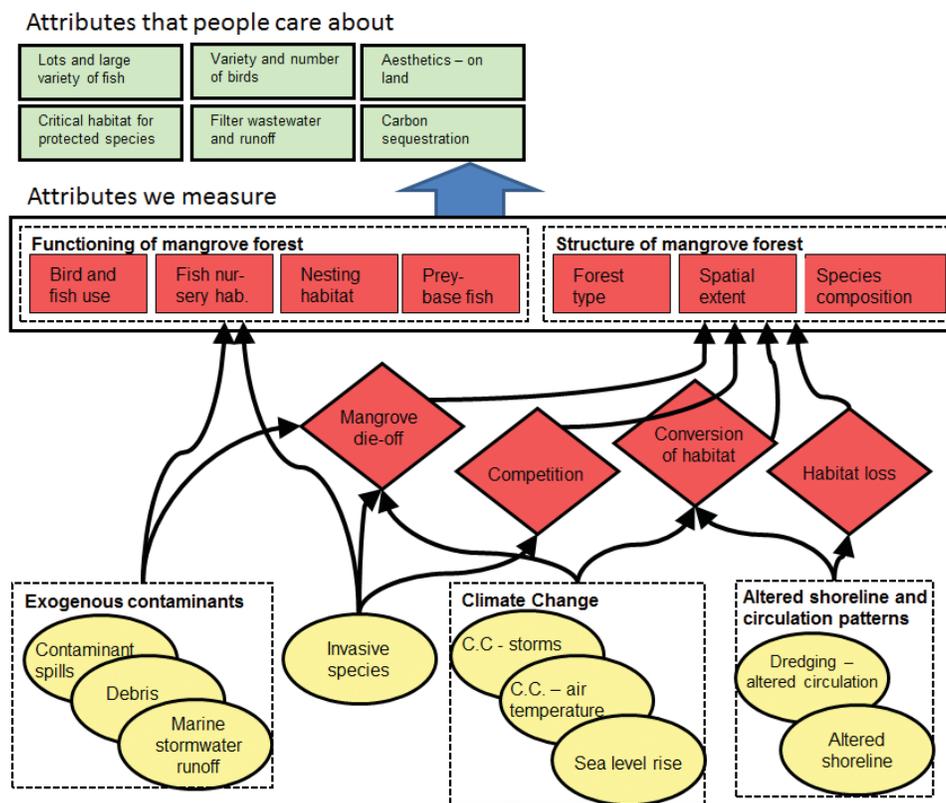


Figure 2. Mangroves submodel diagram for the Florida Keys and Dry Tortugas.

- Coastline protection and stabilization
- Bird habitat—foraging, nesting, and migratory
- Fish habitat—nursery and feeding
- Aesthetics
- Natural filter for wastewater and storm runoff
- Carbon sequestration
- Habitat for protected and keystone species
- Source of dissolved organic matter
- Wood products
- Honey production

### Coastline Protection and Stabilization

Property owners in the Florida Keys benefit from the protection that mangrove shorelines provide during tropical storms. These forests buffer wind speeds and attenuate storm surges, thereby reducing the effects of these forces on developed properties (Barbier *et al.*, 2011; Ewel *et al.*, 1998). Mangrove-lined creeks also provide safe anchorages for boats during storms.

### Bird Habitat

Bird watching is one of the fastest growing past times in the U.S. (Carver, 2009), and advertisements in “birding” literature are used by the Monroe County Tourist Development Council to attract bird watchers to the Florida Keys (personal observation). The presence of a diverse community of birds, including those that are dependant on mangrove forests, provides high levels of satisfaction to vacationing bird watchers, 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 visitor satisfaction.

### Fish Habitat

As stated previously, mangrove root habitat provides nursery habitat for economically valuable juvenile fish and shellfish and provides foraging habitat for game species. Harding

(2005) estimated that in 2005 retail sales associated with saltwater recreational fishing in Monroe and Miami-Dade counties totaled \$408.7 million and supported more than 7,200 jobs. Back-country fishers target game species such as mangrove snapper, seatrout, redfish, tarpon, and snook from among the mangrove prop roots and adjacent waters, while offshore fishers 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 because the three species with the largest dockside landings value in the Florida Keys (pink shrimp, Caribbean spiny lobster, and stone crabs) also spend portions of their juvenile life stages in mangrove forests (Lewis *et al.*, 1985).

### Aesthetics

Leeworthy and Wiley (1996) surveyed residents and visitors of the Florida Keys 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.

### Natural Filter for Wastewater and Storm Runoff

Mangrove forests act as sinks for both nitrogen and phosphorus, taking in these nutrients as water flows through the forest (Odum *et al.*, 1982). Wastewater and storm water are rich in these nutrients, which can be damaging to coral reefs and other ecosystems (see water quality and coral-hardbottom submodels). The presence of mangroves adjacent to developed areas of the Florida Keys reduces 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 Florida Keys.

### 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<sub>2</sub> from the atmosphere through photosynthesis and thus sequestering this recognized greenhouse gas, mangroves provide a valuable service to human society.

## Critical Habitat for Protected and Keystone Species

Manatee, small-toothed sawfish, goliath grouper, bottlenose dolphin, white-crowned pigeon, reddish egret, the 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 animals. In particular, many snorkelers will visit mangrove habitats in search of charismatic megafauna such as manatees and sharks.

## Source of Organic Material to Other Ecosystems

Although mangroves are a net sink for carbon, they do export organic matter 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 matter when in proximity to mangrove forests.

## Wood Products

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 (personal observation). 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 Florida Keys) buttonwood was harvested for use in charcoal production, and red mangrove bark was harvested to manufacture tannic acid (Tebeau, 1968).

## Honey Production

The Florida Agricultural 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 (personal observation).

## Attributes We Can Measure

To assess the health of the Florida Keys/Dry Tortugas mangrove forests and determine how they are responding to sea-level rise, climate change, and land use pressures, researchers can measure key attributes of the system.

- Mangrove forest spatial extent, forest type, and tree species composition
- Prey base production
- Wading bird and game fish use
- Fish nursery capacity
- Changes in bird nesting habitat

## Mangrove Forest Spatial Extent, Forest Type, and Tree Species Composition

Mangrove forests of the Florida Keys were destroyed in large numbers during the development boom from the late 1950s to the early 1980s (Strong and Bancroft, 1994; Lorenz *et al.*, 2002). Currently, mangrove habitats are protected in the Keys, and loss of spatial extent is largely inconsequential although there is still some loss. It is, however, still important to monitor spatial extent, forest type, and species composition to determine the affects of illegal clearing, tropical storms, invasive species, and climate change. Historically, mangrove spatial extent and forest type were quantified using aerial photographs taken by systematic flights from a fixed-wing aircraft (Egler, 1952). Estimates of cover were then made using transparent grid paper and the percent of habitat estimated (Egler, 1952). In more modern times, the aerial photographs were digitized using computer global information system (GIS) programs (Strong and Bancroft, 1994). Currently, satellite imagery can be directly analyzed using state-of-the-art GIS software to acquire highly-accurate estimates of spatial extent and forest type defined (Sabrato and Kushwaha, 2011; Wu *et al.*, 2006). Species composition is generally monitored using standardized transect surveys (Fourqurean *et al.*, 2010); however, aerial reconnaissance using light detection and ranging (LiDAR) techniques has shown promising results in other forest types (Jones *et al.*, 2010).

## Fish and Bird Use of Mangrove Forest

Faunal studies in the Florida Keys have largely focused on bird and fish use. Faunal surveys of indicator species or species composition can provide vital information regarding the health of mangrove ecosystems (Bortone, 2005). Because animals respond more rapidly to perturbations than trees, these surveys can reveal the affects of perturbation before permanent damage is done (Bortone, 2005).

For example, Bancroft and Bowman (1994) used white-crowned pigeons as an indicator species to demonstrate the importance of mangroves to the spread of seeds in nearby deciduous forests. They performed nest surveys and the number of birds entering and leaving a nesting colony to determine the number and spatial extent of pigeon use of mangroves (Strong *et al.*, 1994). Lott *et al.* (2006) used species composition to determine the importance of forests in the Florida Keys to migrating species by capturing birds in nets and through visual observations. Lorenz *et al.* (2002) made repeated visits to nesting colonies of roseate spoonbills to estimate nesting success.

Fish use of FK/DT mangroves has also been performed to gauge the health of the ecosystem and the importance of mangroves. Lorenz and Serafy (2006) used a fish trapping method of the demersal prey-based fish community to demonstrate the deleterious affects of fluctuating salinity on prey abundance. Mark and recapture techniques, visual censuses, video recordings, and acoustic tagging have also been used to track fish movements from mangrove habitats to nearby seagrass and coral reef habitats, thereby demonstrating the importance of mangroves (Farmer and Ault, 2011; Faunce *et al.*, 2004; Meynecke *et al.*, 2008; Murchie *et al.*, 2010; Russell and McDougall, 2005; Verweij and Nagelkerken, 2007). These studies provide valuable information regarding the health of mangrove forests, as well as the importance of mangroves to what humans desire in the marine environs of the FK/DT.

## Drivers of Change in Florida Keys/Dry Tortugas Mangrove Forests

The coastal transition zone represents a region where sustainability is dependent upon a balance of forces,

including climate, tidal fluctuation, runoff of freshwater and terrestrial nutrients, substrate, and wave energy (Odum and McIvor, 1990). The primary driver of change that will affect the Florida Keys mangroves in the coming decades and centuries is global climate change (Davis *et al.*, 2005); however, contaminant spills, invasive species, and urbanization all pose significant threats (Figure 2). These pressures, 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 change the species composition and the type of forest or can 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 types (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. The pressures listed previously, with the exception of marine debris, can result in changes in forest type, tree species composition, or the loss of mangrove forests entirely.

## Description of Pressures

### Exogenous Contaminants

Petroleum oil spills are of particular concern for mangrove ecosystems since the oil can spread over a wide area, resulting in the loss of entire forests (Duke *et al.*, 1997). The Straights of Florida and the Gulf Stream are major shipping lanes, and an oil spill from a large tanker could destroy large areas of mangrove forests (Jackson *et al.*, 1989; Duke *et al.*, 1997). A drilling accident close to the Florida Keys, as might occur with the advent of oil exploration in Cuban territorial waters (Gold, 2011) or if Florida's coastal waters are open to oil exploration and extraction, could result in the same. Oil extraction as far away as the northern Gulf of Mexico can also result in damage to the Florida Keys if the oil is entrained in the Gulf's Loop Current and carried south to the Straights of Florida (Sturges *et al.*, 2005). Such was the fear in the 2010 Deepwater Horizon/British Petroleum oil rig explosion (Thibodeaux *et al.*, 2011). Storm water runoff may contain petroleum products or other contaminants that may also be injurious to mangrove trees in urbanized areas of the Florida Keys. Discarded human refuse (e.g., litter, discarded fishing gear) can become trapped by mangrove root specialization

and cause damage by capturing and killing animals and by reducing the aesthetic value for humans.

### Global Climate Change

Wanless *et al.* (1994) estimated sea-level rise in the Florida Keys to be 20-40 cm per century and that mangroves could accrete soils up to 30 cm per century. The IPCC (2007) predicted that future sea-level rise will be between 20-60 cm per century. These estimates suggest that mangrove accretion may not keep pace with sea-level rise. In the Everglades, it is believed that mangroves will simply colonize wetlands further inshore as sea levels rise (Davis *et al.*, 2005). This may not be possible in the Keys, as much of the upland habitat inshore of the mangrove forests has been lost to urbanization (discussed below).

The effect of global climate change on the frequency of hurricanes in the North Atlantic is not well understood, but increased sea surface temperatures have been demonstrated to increase the number and intensity of hurricanes since the 1970s (IPCC, 2007). The IPCC (2007) predicted a global decrease in cyclone formation and an increase in their number and intensity in the North Atlantic based on their prediction of higher sea surface temperatures in that basin. This increase would result in a greater frequency and intensity of strikes in the Florida Keys. As was demonstrated from Hurricane Andrew in 1992, intense storms can destroy entire mangrove forests (Pimm *et al.*, 1994). The interaction of increased hurricane activity and sea-level rise can have synergistic impacts.

Although the greatest threat posed by global climate change is the steady increase in mean temperature, most models indicate that there will be greater variance in temperature as well (IPCC, 2007). This suggests that, although the mean temperature in the Florida Keys will likely increase, there will also be greater variability around that mean including, possibly, more frequent and severe cold events. In January of 2010 and 2011, significantly low temperatures occurred that resulted in large fish kills in the marine environment of the Florida Keys (personal observation). Although there was little damage to mangrove trees, the events in consecutive years may be a harbinger of more frequent and severe cold stresses.

### Altered Shoreline and Circulation Patterns

Barbier *et al.* (2011) reviewed the loss of estuarine and coastal ecosystems worldwide due to anthropogenic stressors. They indicate that 35 percent of the world's mangrove habitat has been destroyed. Both mangrove and upland habitats have been extensively destroyed in the Florida Keys on islands that are connected by roadways, largely due to urbanization (Strong and Bancroft, 1994).

The impoundment 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, the mangrove will gradually be replaced by more upland species through successional changes (Odum *et al.*, 1982).

A possible means for altering circulation patterns that could alter mangrove habitats are proposals to remove some of the dredge and fill causeways created by the Flagler East Coast Railroad and the U.S. 1 Highway roadbed (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 Florida Keys, thereby presumably undoing damage caused to both the coral reefs and Florida Bay due to the lack of circulation (U.S. Army Corps of Engineers, 1999). Although necessary to accomplish true habitat restoration, these projects will likely result in the loss of mangrove spatial extent (U.S. Army Corps of Engineers, 1999).

### Invasive Species

Globalization of markets has resulted in unprecedented alterations in the distribution of the earth's biota (Mack *et al.*, 2000). Mack *et al.* (2000) indicate that animal invaders can alter their adopted habitats through predation and competition with native species, as well as through grazing and habitat alteration. Plant invaders change their adopted habitat through changes in fire regime, nutrient cycling, hydrology, and energy budgets, thereby changing the habitat at its most basic level (Mack *et al.*, 2000). Numerous exotic species have successfully invaded South Florida and the Florida Keys (Engeman *et al.*, 2011; Gordon, 1998; Trexler

*et al.*, 2000), possibly due to the tropical environment and relatively low diversity of flora and fauna generally associated with tropical and subtropical environments (Mack *et al.*, 2000).

## Mechanisms of Change: Description of Ecological Processes

### Mangrove Die-off

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 water surface to take in oxygen and distribute it to the roots in the anaerobic environment (Walsh, 1974). If these root specializations become coated or clogged, oxygen is blocked from the roots 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 offshore near the Florida Keys could result in an oil spill that reaches and destroys these mangroves.

If the specialized root systems become flooded, the roots can not respire and the tree will 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 if mangrove sediment production cannot keep pace with sea-level rise (Twilley *et al.*, 2001). Even if sedimentation rates can keep pace with the rising sea, tropical storms can remove both trees and sediments from wetlands, leaving behind a habitat unsuitable for mangrove colonization (Wanless *et al.*, 1994).

Mangroves are susceptible to cold stress that takes the form of defoliation and death (Stevens *et al.*, 2006). Olmstead *et al.* (1993) documented the extensive damage to mangroves in Everglades National Park due to freezes in 1977, 1981, and 1989. The December 1989 freeze was particularly virulent. Overnight temperatures dropped to approximately freezing for two consecutive nights along the lower east coast of Florida (NOAA, 1989). This resulted in the defoliation of

hundreds of square kilometers of dwarf red mangrove forest along the extreme southeastern coast (personal observation). If global climate change does result in lower extreme temperatures in the Florida Keys, such impacts may become more common and more severe.

### Conversion of Habitat

Strong and Bancroft (1994) documented the destruction of 44 percent, 50 percent, 65 percent, and 39 percent 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. Strong and Bancroft (1994) estimated the loss of upland hammock forest at 64 percent, 70 percent, 76 percent, and 69 percent 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 Florida Keys are well regulated, losses still continue through permitted and illegal clearing of the habitats in urbanized areas (personal observation). Legislation can also be changed to relax restrictions on development in wetlands, in general, and mangroves specifically. Loss of upland habitat in the Florida Keys 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 (Pearlstine *et al.*, 2009). In the Florida Keys, much of the inland habitats have also been destroyed through urbanization, thereby removing inland sea-level rise refuges.

Odum *et al.* (1982) documented that impoundments created on Florida Keys wetlands resulted in the death of trees. Impoundments can kill the enclosed forest due to both over flooding and over drying of the habitat (Odum *et al.* 1982). Impoundments can also change the type of forest (e.g., from overwash to basin forest; Rey *et al.*, 1990) and, in the process, change the species composition of the forest. Nutrient limitation within impoundments can stunt tree growth, resulting in a dwarf mangrove forest type. Impoundments can also stunt the growth of trees through nutrient limitations (Feller *et al.*, 2003). Persistent hypersaline conditions within impoundments have also been shown to kill the impounded forest (Rey *et al.*, 1990).

As stated above, there are plans within the Comprehensive Everglades Restoration Program to remove many of the causeways created by the Flagler Railroad and U.S. 1 Highway (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).

### Coastal Land Loss

Wanless *et al.* (1994) demonstrated that intense storms in 1935 and 1960 removed not only mangrove forests but also washed away much of the soil. Until the storms struck, mangroves were able to accrete soils to keep pace with sea-level rise. 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.

### Ecological Processes that Affect Fish and Birds

A decrease in the spatial extent of mangrove forests in the Florida Keys 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). Changes in forest type or tree species composition will alter the type of fish community that utilizes these habitats. Forest declines will also eliminate critical nesting habitat for myriad bird species (Odum *et al.*, 1982) and eliminate important foraging grounds for these species (Lorenz *et al.*, 2002). 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). The increased structural complexity of mangrove root systems has been demonstrated to decrease predator efficiency (Primavera, 1997); forest

type and tree species composition thus 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 of 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 (Powell, 1987; Strong *et al.*, 1994). Changes in forest structure and type may change the suitability of the forest as a nesting habitat for specific bird species.

### Invasive Species Competition and Predation

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.*, 2010). Invasive upland species, such as Brazilian pepper (*Schinus terebinthifolius*; Lass and Prather, 2004) and Australian pines (*Casuarina equisetifolia*; personal observation), 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 (Saur *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 in 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 (personal observation, 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., Barbour *et al.*, 2010; Trexler *et al.*, 2000).

### Marine Debris

The root adaptations of mangroves capture and hold human-related refuse items (e.g., bottles, cans, marine industry jetsam). Although these items rarely damage the trees, fauna can become trapped or tangled in this refuse. Personal observations in Florida Keys mangroves include birds and manatees that had become ensnared in monofilament fishing line; fish, diving birds, and reptiles

(including an endangered American crocodile) that had become tangled in discarded nets; and fish and invertebrates that had become trapped in discarded bottles.

## References

- Ashton, D.C., and D.B. Eggleston. 2008. Juvenile fish densities in Florida Keys mangroves correlate with landscape characteristics. *Marine Ecology Progress Series*, 362:233-243.
- Bancroft, G.T., and R. Bowman. 1994. Temporal patterns in the diet of nestling white crowned pigeons: Implications for conservation of frugivorous columbids. *Auk*, 8:44-852.
- Barbier, B.B., S.D. Hacker, C. Kennedy, E.W. Koch, A.C. Stier, and B.R. Stillman. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs*, 81:169-193.
- Barbour, A.B., M.L. Meredith, A.A. Adamson, E. Diaz-Ferguson, and B.R. Silliman. 2010. Mangrove use by invasive lionfish *Pterois volitans*. *Marine Ecology Progress Series*, 401:291-294.
- Bortone, S.A. (ed.). 2005. *Estuarine Indicators*. CRC Press, Boca Raton, FL, 560 pp.
- Carver, E. 2009. Birding in the United States: A demographic and economic analysis. Addendum to the 2006 national survey of fishing, hunting, and wildlife-associated recreation. U.S. Fish and Wildlife Service Report 2006-4.
- Coastal Coordinating Council. 1974. Florida coastal zone management atlas. State of Florida, Tallahassee, FL.
- Comp, G.S., and W. Seaman, Jr. 1985. Estuarine habitat and fishery resources of Florida. In *Florida Aquatic Habitat and Fishery Resources*, W. Seaman, Jr. (ed.). Florida Chapter of the American Fisheries Society, Eustis, FL, 337-435.
- Craighead, F.C. 1971. The trees of south Florida. University of Miami Press, Coral Gables, FL, 212 pp.
- Davis, S.M., D.L. Childers, J.J. Lorenz, H.R. Wanless, and T.E. Hopkins. 2005. A conceptual model of ecological interactions in the mangrove estuaries of the Florida Everglades. *Wetlands*, 25(4):832-842.
- Duke, N.C., S. Zulelka, M. Pinzon, and M.C. Prada. 1997. Large scale damage to mangrove forests following two large oil spills in Panama. *Biotropica*, 29(1):2-14.
- Eglar, F.E. 1952. Southeast saline Everglades vegetation, Florida, and its management. *Vegetatio*, 3:213-265.
- Engeman, R., E. Jacobson, M.L. Avery, and W.E. Meshaka. 2011. The aggressive invasion of exotic reptiles in Florida with a focus on prominent species: A review. *Current Zoology*, 57:599-612.
- Ewel, K.C., R.R. Twilley, and J.E. Ong. 1998. Different kinds of mangrove forests provide different goods and services. *Global Ecology and Biogeography Letters*, 7:83-94.
- Farmer, N.A., and J.S. Ault. 2011. Grouper and snapper movements and habitat use in Dry Tortugas, Florida. *Marine Ecology Progress Series*, 433:169-184.
- Faunce, C.H., and J.E. Serafy. 2006. Mangrove as fish habitat: 50 years of field studies. *Marine Ecology Progress Series*, 318:1-18.
- Faunce, C.H., J.E. Serafy, and J.J. Lorenz. 2004. Density habitat relationships of mangrove creek fishes within the southeast saline Everglades (USA) with reference to managed freshwater releases. *Wetlands Ecological Management*, 12:337-394.
- Feller, I., D.F. Whigham, K.L. McKee, and C.E. Lovelock. 2003. Nitrogen limitation of growth and nutrient dynamics in a disturbed forest, Indian River Lagoon, Florida. *Oecologia*, 134:405-414.
- Florida Fish and Wildlife Research Institute. 2006. Mangroves: Florida's walking trees. Florida Fish and Wildlife Conservation Commission, St. Petersburg FL.
- Foroughbakhch, R., A.E. Cespedes-Cabrales, R.K. Maiti, M.A. Alverado-Vazquez, M.L. Cardenas Avila, and J. Hernandez Pinero. 2008. Ecological aspects of mangroves and their potential as phytoremediation in the Gulf of Mexico. *Crop Research (Hisar)*, 35(3):289-294.
- Fourqurean, J.W., T.J. Smith, III, J. Possley, T.M. Collins, D. Lee, and S. Namoff. 2010. Are mangroves in the tropical Atlantic ripe for invasion? Exotic mangrove trees in the forests of south Florida. *Biological Invasions*, 12(8):2509-2522.
- Gold, R. 2011. U.S. will inspect Cuban rig. *The Wall Street Journal*, October 17, 2011.
- Gordon, D.R. 1998. Effects of invasive, non-indigenous plant species on ecosystem process: Lessons from Florida. *Ecological Applications*, 8(4):975-989.
- Granek, E.F., J.E. Compton, and D.L. Phillips. 2009. Mangrove exported nutrient incorporation by sessile coral reef invertebrates. *Ecosystems*, 12(3):462-472.
- Harding, D.B. 2005. The economics of salt water fishing in Florida. Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission, Tallahassee, FL.
- Heald, E.J., W.E. Odum, and D.C. Tabb. 1984. Mangroves in the estuarine food chain. In *Environments of South Florida Present and Past, II*. P.J. Gleason (ed.). Miami Geological Society, Coral Gables, FL, 149-156.
- Howe, A.J., J.F. Rodriguez, and P.M. Saco. 2009. Surface evolution and carbon sequestration in disturbed and undisturbed wetland soils of the Hunter Estuary, southeast Australia. *Estuarine, Coastal and Shelf Science*, 84(1):75-83.
- IPCC (Intergovernmental Panel on Climate Change). 2007. Summary for Policymakers. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4)*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.). Cambridge University Press, Cambridge, UK and New York, NY, 996 pp.

- Jackson, J.B.C., J.D. Cubitt, B.D. Keller, V. Batista, K. Burns, H.M. Caffey, R.L. Caldwell, S.D. Garrity, C.D. Getter, C. Gonzalez, K.W. Kaufmann, A.H. Knap, S.C. Leavings, M.J. Marshall, R. Steger, R.C. Thompson, and W. Weil. 1989. Ecological effects of a major oil spill on Panamanian coastal marine communities. *Science*, 243(4887):37-44.
- Jones, T.G., N.C. Nicholas, and T. Sharma. 2010. Assessing the utility of airborne hyperspectral and LIDAR data for species distribution mapping in the coastal Pacific Northwest, Canada. *Remote Sensing of Environment*, 114:2841-2852.
- Kushlan, J.A., and P.C. Frohring. 1985. Decreases in the brown pelican population in southern Florida. *Colonial Waterbirds*, 8(2):83-95.
- Lass, L.W., and T.S. Prather. 2004. Detecting the locations of Brazilian pepper trees in the Everglades with a hyperspectral sensor. *Weed Technology*, 18(2):437-442.
- Lewis, R.R., R.G. Gilmore, D.W. Crewz, and W.E. Odum. 1985. Mangrove habitat and fishery resources of Florida. In *Florida Aquatic Habitat and Fishery Resources*, W. Seaman (ed.). Florida Chapter of the American Fisheries Society, Kissimmee, FL, 281-336.
- Leeworthy, V.R., and P.C. Wiley. 1996. Linking the economy and environment of Florida Keys/Florida Bay: Visitor profiles: Florida Keys/Key West. NOAA/National Ocean Service, 159 pp. (available at <http://sanctuaries.noaa.gov/science/socioeconomic/floridakeys/pdfs/visprof9596.pdf>).
- Ley, J.A., C.C. McIvor, and C.L. Montague. 1999. Fishes in mangrove prop-root habitats of northeastern Florida Bay: Distinct assemblages across an estuarine gradient. *Estuarine, Coastal and Shelf Science*, 48:701-723.
- Lorenz, J.J. 1999. The response of fishes to physicochemical changes in the mangroves of northeast Florida Bay. *Estuaries*, 22:500-517.
- Lorenz, J.J., and J.E. Serafy. 2006. Changes in the demersal fish community in response to altered salinity patterns in an estuarine coastal wetland: Implications for Everglades and Florida Bay restoration efforts. *Hydrobiologia*, 569:401-422.
- Lorenz, J.J., J.C. Ogden, R.D. Bjork, and G.V.N. Powell. 2002. Nesting patterns of roseate spoonbills in Florida Bay, 1935-1999: Implications of landscape scale anthropogenic impacts. In *The Everglades, Florida Bay and the Coral Reefs of the Florida Keys: An Ecosystem Sourcebook*, J.W. Porter and K.G. Porter (eds.). CRC Press, Boca Raton, FL, 555-598.
- Lott, C.A., B.E. Langan, M.B. Mulrooney, R.T. Grau, and K.E. Miller. 2006. Stopover ecology of nearctic-neotropical migrant songbirds in hardwood hammocks of the Florida Keys. Final Report, Florida Fish and Wildlife Conservation Commission, Tallahassee, FL, 78 pp.
- Lugo, A.E., and S.C. Snedaker. 1974. The ecology of mangroves. *Annual Review Ecological Systematics*, 5:39-63.
- Mack, R., D. Simberloff, W.M. Lonsdale, H. Evans, M. Clout, and F. Bazzaz. 2000. Biotic invasions: Causes, epidemiology, global consequences and control. *Issues in Ecology*, No. 5, 20 pp.
- Manson, F.J., N.R. Loneragen, G.A. Skilleter, and S.R. Phinn. 2005. An evaluation of the evidence for linkages between mangroves and fisheries: A synthesis of the literature and identifications of research directions. *Oceanography and Marine Biology: An Annual Review*, 43:485-515.
- Meynecke, J.O., G.C. Poole, J. Werry, and S.Y. Lee. 2008. Use of PIT tag and underwater video recording assessing estuarine fish movement in a high intertidal mangrove and salt marsh creek. *Estuarine, Coastal and Shelf Science*, 79:168-178.
- Murchie, K.J., E. Schwager, S.J. Cooke, A.J. Danylchuk, S.E. Danylchuk, T.L. Goldberg, C.D. Suski, and D.P. Philipp. 2010. Spatial ecology of juvenile lemon sharks (*Negaprion brevirostris*) in tidal creeks and coastal waters of Eleuthera, The Bahamas. *Environmental Biology of Fishes*, 89:95-104.
- Nixon, S.W. 1980. Between coastal marshes and coastal waters—A review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry. In *Estuarine and Wetland Processes*, P. Hamilton and K. MacDonald (eds.). Plenum Press, NY, 437-525.
- NOAA. 1989. Climatological data, annual summary, Florida 1989. 93(13).
- Odum, W.E., and E.J. Heald. 1975. The detritus-based food web of an estuarine mangrove community. In *Estuarine Research*, L.E. Cronin (ed.). Academic Press, NY, 265-286.
- Odum, W.E., and C.C. McIvor. 1990. Mangroves. In *Ecosystems of Florida*, R.L. Myers and J.J. Ewel (eds.). University of Central Florida Press, Orlando, FL, 517-548.
- Odum, W.E., C.C. McIvor, and T.J. Smith, III. 1982. The ecology of mangroves of South Florida: A community profile. U.S. Fish and Wildlife Service/Office of Biological Services, FWS/OBS-81-24, 144 pp.
- Ogden, J.C. 1994. A comparison of wading bird nesting colony dynamics (1931-1946 and 1974-1989) as an indication of ecosystem condition in the southern Everglades. In *Everglades: The Ecosystem and Its Restoration*, S.M. Davis and J.C. Ogden (eds.). St. Lucie Press, Delray Beach, FL, 533-570.
- Olmstead, I., H. Dunevitz, and W.J. Platt. 1993. Effects of freezes on tropical trees in Everglades National Park Florida, USA. *Tropical Ecology*, 34:17-34.
- Pearlstone, L.G., E.V. Pealstein, J. Sadle, and T. Schmidt. 2009. Potential ecological consequences of climate change in south Florida and the Everglades: 2008 literature synthesis. South Florida Natural Resources Center, Everglades National Park, SFNRC Technical Series 2009:1, 35 pp.
- Pimm, S.L., G.E. Davis, L. Loope, C.T. Roman, T.J. Smith, III, and J.T. Tilmant. 1994. Hurricane Andrew: The 1992 hurricane allowed scientists to assess damage and consider long-term consequences to well-studied ecosystems. *Bioscience*, 44(4):224-229.

- Powell, G.V.N. 1987. Habitat use by wading birds in a subtropical estuary: Implications of hydrography. *Auk*, 104:740-749.
- Primavera, J.H. 1997. Fish predation on mangrove-associated penaeids: The role of structure and substrate. *Journal of Experimental Biology and Ecology*, 215:205-216.
- Rehm, A.E., and H.J. Humm. 1973. *Sphaeroma terebrans*: A threat to the mangroves of southeastern Florida. *Science*, 182:173-174.
- Rey, J.R., R.A. Crossman, and T.R. Kain. 1990. Vegetation dynamics in impounded marshes along the Indian River Lagoon, Florida USA. *Environmental Management*, 14(3):396-410.
- Russell, D.J., and A.J. McDougall. 2005. Movement and juvenile recruitment of mangrove jack, *Lutjanus argentimaculatus* (Forsskal), in northern Australia. *Marine and Freshwater Research*, 56(4):465-475.
- Sabrato, N., and S.P.S. Kushwaha. 2011. Study on the utility of IRS 1D LISS-III data and classification techniques for mapping Sunderban mangroves. *Journal of Coastal Conservation*, 15(1):123-137.
- Saur, E., D. Imbert, J. Etienne, and D. Mian. 1999. Insect herbivory on mangrove leaves in Guadeloupe: Effects on biomass and mineral content. *Hydrobiologia*, 413:89-93.
- Serafy, J.E., C.H. Faunce, and J.J. Lorenz. 2003. Mangrove shoreline fishes of Biscayne Bay, Florida. *Bulletin of Marine Science*, 72:161-180.
- Stevens, P.W., S.L. Fox, and C.L. Montague. 2006. The interplay between mangroves and saltmarshes at the transition between temperate and subtropical climate in Florida. *Wetlands Ecology and Management*, 14(5):435-444.
- Strong, A.M., and G.T. Bancroft. 1994. Patterns of deforestation and fragmentation of mangrove and deciduous seasonal forests in the upper Florida Keys. *Bulletin of Marine Science*, 54:795-804.
- Strong, A.M., R.J. Sawicki, and G.T. Bancroft. 1994. Estimating white crowned pigeon population size from flight line counts. *Journal of Wildlife Management*, 58(1):156-162.
- Sturges, W., A. Lugo-Fernandez, and M.D. Shargel. 2005. Introduction. In *Circulation in the Gulf of Mexico: Observations and Models*, W. Sturges and A. Lugo-Fernandez (eds.). Geophysical Monograph Series, 161:1-11.
- Tebeau, C.W. 1968. *Man in the Everglades: 2000 Years of Human History in the Everglades National Park*. University of Miami Press, Coral Gables, FL, 192 pp.
- Thayer, G.W., and A.J. Chester. 1989. Distribution and abundance of fishes among basin and channel habitats in Florida Bay. *Bulletin of Marine Science*, 44:200-219.
- Thayer, G.W., D.R. Colby, and W.F. Hettler. 1987. Utilization of the red mangrove prop root habitat by fishes in south Florida. *Marine Ecology Progress Series*, 35:25-38.
- Thibodeaux, L.J., K.T. Valsaraj, V.T. John, K.D. Papadopoulos, L.R. Pratt, and N.S. Pesika. 2011. Marine oil fate: Knowledge gaps, basic research, and developmental needs; a perspective based on the Deepwater Horizon spill. *Environmental Engineering Science*, 28:87-93.
- Trexler, J.C., W.F. Loftus, F. Jordan, J.J. Lorenz, J.H. Chick, and R.M. Kobza. 2000. Empirical assessment of fish introductions in a subtropical wetland: An evaluation of contrasting views. *Biological Invasions*, 2(4):265-277.
- Twilley, R.R. 1985. The exchange of organic carbon in basin mangrove forests in a southwest Florida estuary. *Estuarine, Coastal and Shelf Science*, 20:543-557.
- Twilley, R.R. 1988. Coupling of mangroves to the productivity of estuarine and coastal waters. In *Coastal Offshore Ecosystem Interactions*, B.O. Jansson (ed.). Springer-Verlag, Berlin, 155-180.
- Twilley, R.R., E.J. Barron, H.L. Gholz, M.A. Harwell, R.L. Miller, D.J. Reed, J.B. Rose, E.H. Siemann, R.G. Wetzel, and R.J. Zimmerman. 2001. *Confronting Climate Change in the Gulf Coast Region: Prospects for Sustaining Our Ecological Heritage*. Union of Concerned Scientists, Cambridge, MA and Ecological Society of America, Washington, DC., 82 pp.
- U.S. Army Corps of Engineers. 1999. CERP central and southern Florida comprehensive review study. Final integrated feasibility report and programmatic environmental impact statement, Jacksonville District, U.S. Army Corps of Engineers, Jacksonville, FL.
- Verweij, M.C., and I. Nagelkerken. 2007. Short- and long-term movement and site fidelity of juvenile *Haemulidae* in back-reef habitats of a Caribbean embayment. *Hydrobiologia*, 592:257-270.
- Walsh, G.E. 1974. Mangroves: A review. In *Ecology of Halophytes*, R. Reimhold and W. Queen (eds). Academic Press, NY, 51-174.
- Wanless, H.R., R.W. Parkinson, and L.P. Tedesco. 1994. Sea level control on stability of Everglades wetlands. In *Everglades: The Ecosystem and Its Restoration*, S.M. Davis and J.C. Ogden (eds.). St. Lucie Press, Delray Beach, FL, 199-224.
- Wu, Y., K. Rutchey, N. Wang, and J. Godin. 2006. The spatial pattern and dispersion of *Lygodium microphyllum* in the Everglades wetland ecosystem. *Biological Invasions*, 8:1483-1493.