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A CONCEPTUAL MODEL OF ECOLOGICAL INTERACTIONS IN THE MANGROVE ESTUARIES OF THE FLORIDA EVERGLADES

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Abstract: A brackish water ecotone of coastal bays and lakes, mangrove forests, salt marshes, tidal creeks, and upland hammocks separates Florida Bay, Biscayne Bay, and the Gulf of Mexico from the freshwater Everglades. The Everglades mangrove estuaries are characterized by salinity gradients that vary spatially with topography and vary seasonally and inter-annually with rainfall, tide, and freshwater flow from the Everglades. Because of their location at the lower end of the Everglades drainage basin, Everglades mangrove estuaries have been affected by upstream water management practices that have altered the freshwater heads and flows and that affect salinity gradients. Additionally, interannual variation in precipitation patterns, particularly those caused to El Niño events, control freshwater inputs and salinity dynamics in these estuaries. Two major external drivers on this system are water management activities and global climate change. These drivers lead to two major ecosystem stressors: reduced freshwater flow volume and duration, and sea-level rise. Major ecological attributes include mangrove forest production, soil accretion, and resilience; coastal lake submerged aquatic vegetation; resident mangrove fish populations; wood stork (*Mycteria americana*) and roseate spoonbill (*Platelea ajaja*) nesting colonies; and estuarine crocodilian populations. Causal linkages between stressors and attributes include coastal transgression, hydroperiods, salinity gradients, and the ''white zone'' freshwater/estuarine interface. The functional estuary and its ecological attributes, as influenced by sea level and freshwater flow, must be viewed as spatially dynamic, with a possible near-term balancing of transgression but ultimately a long-term continuation of inland movement. Regardless of the spatio-temporal timing of this transgression, a salinity gradient supportive of ecologically functional Everglades mangrove estuaries will be required to maintain the integrity of the South Florida ecosystem.

Key Words: Everglades, South Florida, ecosystem restoration, conceptual ecological model, mangrove forest, tidal creeks, estuaries, salinity gradients, water management, sea-level rise, estuarine geomorphology, fish communities, wood stork, roseate spoonbill, American crocodile

BACKGROUND

A brackish water ecotone of coastal bays and lakes, mangrove and buttonwood forests, salt marshes, tidal creeks, and upland hammocks separates Florida Bay, southern Biscayne Bay, and the Gulf of Mexico from the freshwater Everglades. The model boundary from Turkey Point west to Lostman's River delineates the interface of Biscayne and Florida Bays and the Gulf of Mexico that is affected by freshwater flows from the Everglades (Figure 1). The Everglades mangrove estuaries are characterized by salinity gradients that vary spatially with topography and seasonally and inter-annually with rainfall, tide, and freshwater flow from the Everglades. Because of their location at the lower end of the Everglades drainage basin, Everglades mangrove estuaries are particularly vulnerable to changes in sea level and freshwater flow.

Everglades mangrove estuaries and their ecological attributes, as influenced by sea-level rise and increased freshwater flow (in both volume and duration), must be viewed as spatially dynamic, with a possible near-term balancing of transgression but ultimately a long-term continuation of inland movement. Regardless of the spatio-temporal timing of this transgression, a salinity gradient supportive of ecologically functional Everglades mangrove estuaries will be required to maintain the integrity of the South Florida ecosystem.

EXTERNAL DRIVERS AND ECOLOGICAL STRESSORS

All ecological processes and attributes in the mangrove coastline of the southern Everglades are hydrologically controlled by sheet flow from the freshwater wetlands to the north interacting with sea level in the Gulf of Mexico and Florida Bay (Figure 2). Responses to changes in freshwater flow from the implementation of CERP are relatively short term in comparison to the longer-term, progressively increasing changes resulting from relative sea-level rise.

Freshwater Flow

Construction and operation of South Florida's water management system during the Twentieth Century has depleted freshwater flow to the Everglades mangrove estuaries and has altered its timing and distribution (McIvor et al. 1994, VanZee 1999). There are numerous examples of how ecological patterns and processes in the mangrove estuaries are closely linked to patterns of hydrology, salinity, and supply of marine-derived phosphorus, all of which have been altered by reduced freshwater flow (Chen and Twilley 1999, Ross et al. 2000). Because the upstream freshwater Everglades system is so oligotrophic and phosphorus-limited (Noe et al. 2001), the ocean is the source of the limiting nutrient to these estuaries. This ''upside-down'' characteristic of Everglades estuaries is a defining feature and plays a strong role in the interaction of geomorphology and productivity (Childers et al. 2005).

Additionally, Childers et al. (2005) suggested that water residence time, particularly during the dry months, plays a key role in phosphorus cycling in Everglades mangrove estuaries. Along west coast systems, such as Shark River, low freshwater inflows at this time allow salinity incursions up-estuary, extending the influence of the marine phosphorus source to the oligohaline ecotone. In the Florida Bay mangrove zone, though, the loss of freshwater inflow effectively eliminates flushing, and water residence times are long. During this time, Childers et al. (2005) hypothesized that internal recycling of phosphorus (primarily via subtidal and open water processes) and nitrogen (primarily mediated by the mangrove wetlands) dominate dry season dynamics.

Sea-Level Rise

The rate of relative sea-level rise for South Florida increased above recent decadal rates beginning about 1930. Since that time, South Florida has had a relative sea-level rise of about 23 cm (Wanless et al. 1994). This is a rate of 30 cm per century. Anticipated response to global warming is projected to result in a global increase in sea level of about 60 cm in the coming century. Sea-level rise may massively reconfigure geomorphology, circulation patterns, salinity patterns, and ecological processes during the Twenty-First Century (Wanless et al. 1994).

Non-Native Plants and Fishes

The introduction and spread of non-native plants and fishes are additional drivers and stressors on the Everglades mangrove estuaries, although they are not included in this model because of the overwhelming influences of sea level and hydrology. The Mayan cichlid presently dominates the fish community in mangrove wetlands east of Taylor Slough (Trexler et al. 2001), and the non-native plants Brazilian pepper (*Schinus terebinthifolius* Raddi) and common colubrine (*Colubrina asiatica* (L.) Brongn) have invaded mangrove forests. Although less pervasive than sea level and freshwater flow, potential impacts from the spread of non-native plants and fishes merit a better understanding of their ecological roles and potentials for control.

ECOLOGICAL ATTRIBUTES

Mangrove Forest Production, Soil Accretion, and Resilience

Mangrove forests (red mangroves [*Rhizophora mangle* Linnaeus], black mangroves [*Avicennia germinans* (L.) Linnaeus], white mangroves [*Laguncularia racemosa* (L.) Gaertn.f.)], and buttonwood [*Conocarpus erectus*]) dominate primary productivity and soil accretion within the Everglades mangrove estuaries

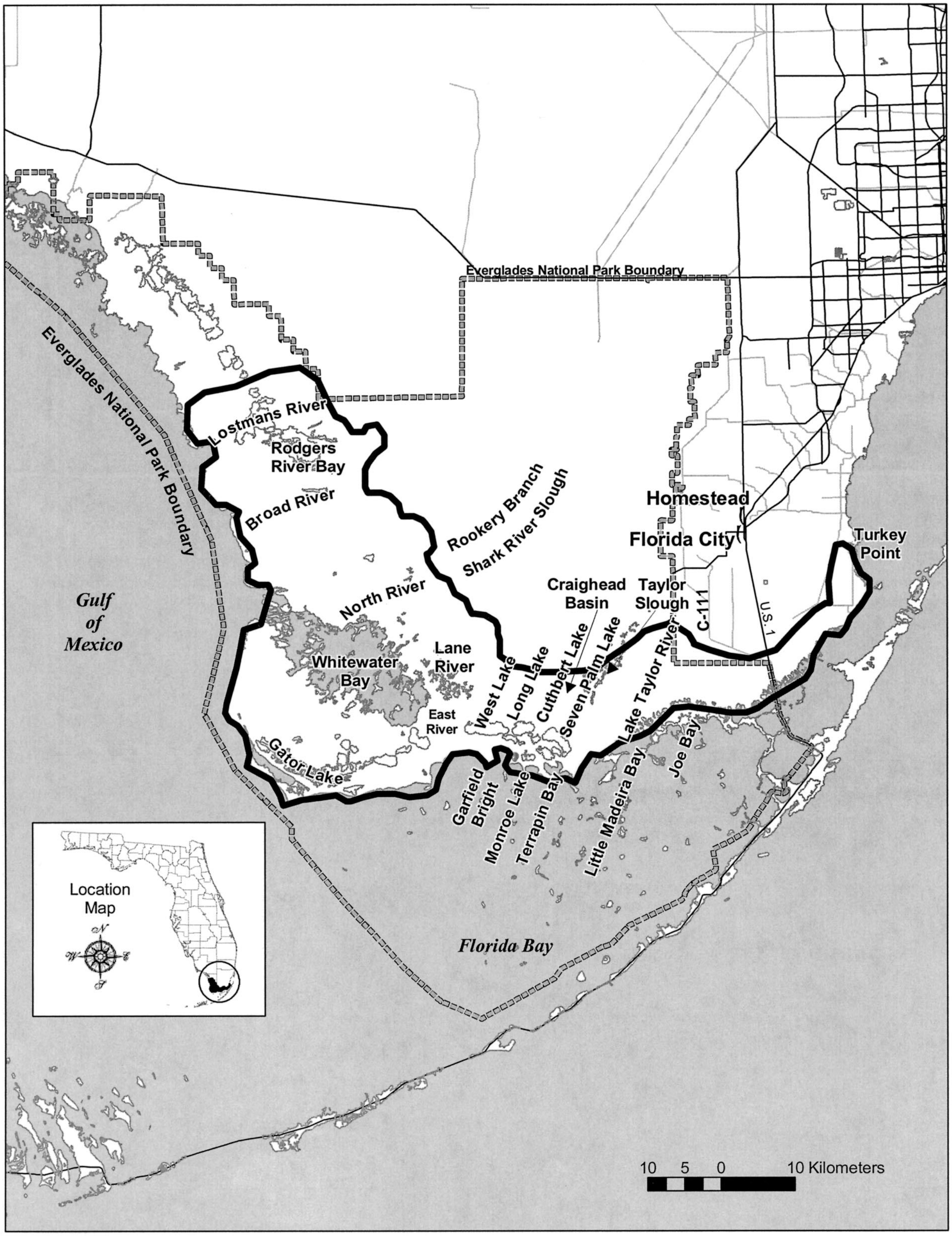

Figure 1. Boundary of the Everglades Mangrove Estuaries Conceptual Ecological Model.

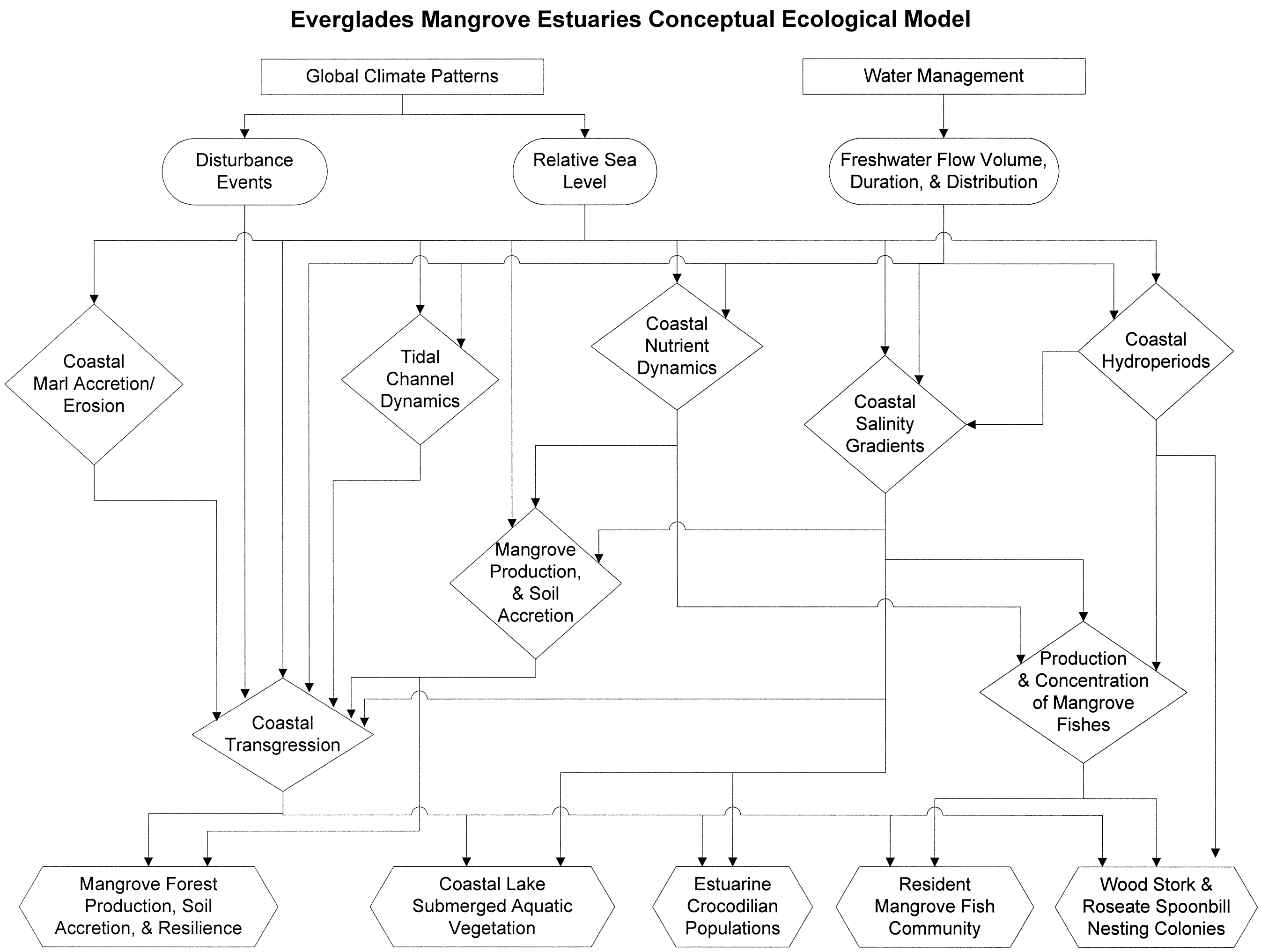

Figure 2. Everglades Mangrove Estuaries Conceptual Ecological Model diagram.

(Twilley 1998, Chen and Twilley 1999, Childers et al. 1999, Davis et al. 2004). That productivity appears to reflect the nutrient status of the estuarine interface, which is related to mixing of phosphorus-poor water from the freshwater Everglades with relatively phosphorus-rich water from the Gulf of Mexico (Davis et al. 2001 a, b, Davis et al. 2003, Childers et al. 2005).

Aboveground biomass and production in the mangrove forests of Shark River Slough and other Gulf estuaries increase from the ecotone toward the Gulf of Mexico, reflecting the direct connection of these systems to the marine phosphorus source (Chen and Twilley 1999, Rudnick et al. 1999, Childers et al. 2005). Trees in the forests near the Gulf are able to allocate more biomass to aboveground growth. The dwarf mangrove forests along the northern margin of Florida Bay reflect suppressed levels of aboveground productivity and seedling development, as influenced by minimal P supply from either the oligotrophic marshes of the southern Everglades or Florida Bay (Koch 1997, Koch and Snedaker 1997, Satula et al. 2003, Childers et al 2005). High belowground production rates in the dwarf mangrove forests appear to be a biomass allocation phenomenon in which mangroves in the oligotrophic southern Everglades are foraging for nutrients (Krauss et al. 2003). The counter-intuitive expectation is that maintenance of oligotrophic conditions in the southern Everglades [by increased freshwater inflows] may promote peat accretion in these mangroves.

Red mangrove forests in South Florida can potentially accrete organic peat substrate at 2–6 mm/year. Disturbances (major hurricanes, fire, freeze, and changing flushing) disrupt that rate and commonly result in phases of substrate subsidence from decay (Smith et al. 1994, Cahoon and Lynch 1997). Nutrient limitation and salinity stress also reduce that rate.

An important feature for maintenance of an existing wetland environment, its recovery following disturbance events such as hurricanes, freezes, fires, or salinity changes, or the successful shift from one wetland type to another is maintenance of good flushing by either fresh or saline waters (Wanless et al. 1995).

Where flow and flushing diminish, wetland communities collapse (Wanless and Vlaswinkel 2005). This is true for long-term maintenance of mangrove communities and for mangrove communities invading former sawgrass wetlands.

Terrestrial communities embedded in the mangrove forests include tropical forest communities and halophytic prairies. Midden forests, thatch palm (*Thrinax* spp.) hammocks, mixed coastal hammocks, and buttonwood hammocks contribute to local and landscape species diversity within the mangrove zone (including providing substrate for epiphytes) and are able to persist because of the presence of elevated substrates like storm berms and human-originated deposits (Craighead and Gilbert 1962, Craighead 1971). Halophytic prairies dominated by *Batis maritima* Linnaeus, *Salicornia* spp., and *Blutaparon vermiculare* (L.) Mears) appear to represent a long-term landscape element that becomes established where tropical storms alter coastal soils in such a way that mangrove and buttonwood forests are killed (Craighead and Gilbert 1962, Craighead 1971, Armentano et al. 1995).

Coastal Lake Submerged Aquatic Vegetation Communities

Coastal lakes such as Seven Palm Lake, Cuthbert Lake, Long Lake, West Lake, Lake Monroe, and the Taylor River ponds support seasonal beds of SAV under oligohaline to mesohaline conditions. Species richness and total and species-specific percent cover of SAV found in the lakes, ponds, and bays that make up this aquatic network vary both seasonally and interannually in patterns that are related to salinity (Morrison and Bean 1997). Salinity ranges for the suite of 10–12 species, including bladderwort (*Utricularia* spp.) and naiads (*Najas* spp.) are well-documented, with an upper limit of approximately 5–8 ppt, muskgrass (*Chara* spp.) under mesohaline salinities of approximately 15–20 ppt, and widgeon grass (*Ruppia maritima* Linnaeus) under mesohaline salinities of 10–25 ppt.

Waterfowl species that once occurred in large numbers in coastal lakes and basins of the mangrove zone (Kushlan et al. 1982) are dependent on SAV as their primary food resource. The local declines of American coot (*Fulica americana* J.F. Gmelin), lesser scaup (*Aythya affinis* Eyton, 1838), American widgeon (*Anas americana* J.F. Gmelin), and white-cheeked pintail (*Anas bahamensis* Linnaeus) correspond to decline in that food resource, despite overall resurgence of populations in other parts of North America. Recent high-rainfall years have witnessed an increase in coot numbers on West Lake to approximately 2,000 during winter 1996–1997 (O.L. Bass, Jr., Everglades National Park, pers. comm.) but not to the population size of approximately 50,000 that over-wintered there until the 1960s (Kushlan et al. 1982).

Resident Mangrove Fish Populations

Oligohaline wetlands of the mangrove estuary support a resident community of small fishes that is functionally important as an intermediate trophic level supporting wading birds and other higher consumers (Lorenz 2000). Density and seasonal concentration of small marsh fishes in the mangrove zone like sheepshead minnows (*Cyprinodon variegatus* Lacepede), sailfin mollies (*Poecilia latipinna* Lesueur), topminnows (*Fundulus chrysotus* Guenther), rainwater killifish (*Lucania parva* Baird and Girard), and sunfish (*Lepomis marginatus* Holbrook) reflect estuarine salinity, nutrient status, hydroperiod, and drying patterns (Lorenz 2000, Trexler and Loftus 2000), all of which are controlled by freshwater flow and sea level.

The resident fish assemblage decreases in density and size distribution when salinity exceeds 5–8 ppt (Lorenz 1997, 1999, 2000). This relationship has been demonstrated for Florida Bay mangrove wetlands, but not for Gulf of Mexico estuaries. Furthermore, salinity is inversely auto-correlated with hydroperiod in Florida Bay mangrove wetlands, and the relative contribution of each of these variables is not known.

Densities of small fishes in Shark River Slough are approximately 50 percent greater at Rookery Branch, near the interface with the Gulf of Mexico, in comparison to more upstream sites (Trexler and Loftus 2000). Greater fish densities at Rookery Branch hypothetically correspond to enhanced nutrient status and productivity in that area (Childers et al. 1999). In contrast, lower fish densities at the estuarine interface of Taylor Slough relative to sites upstream (Lorenz 1999, 2000, Trexler and Loftus 2000) correspond to low nutrient status and productivity there. Receding water levels following an extended annual hydroperiod can concentrate small fishes in Craighead Basin, at the estuarine interface of Taylor Slough, to densities comparable to the estuarine interface of Shark River Slough (Lorenz 2000).

Relationships of fish populations to hydrology in gulf estuaries are unknown. Populations of small marsh fishes in gulf estuaries may respond to hydroperiod and water recession patterns very differently than Everglades marsh fish communities because of more complex topography created by a dendritic pattern of tidal creeks. Tidal creeks may further influence the resident mangrove fish community as corridors for immigration of juveniles of more marine species.

Wood Stork and Roseate Spoonbill Nesting Colonies

Large nesting colonies of wood storks (*Mycteria americana*, Linnaeus) and great egrets (*Ardea alba*, Linnaeus) in the Everglades during the early 1900s were concentrated in Everglades mangrove estuaries (Ogden 1994). East River, Lane River, Rookery Branch, Broad River, and Rodgers River Bay colonies, in the headwaters of the tidal rivers entering the Gulf of Mexico, supported approximately 90 percent of the total nesting population of these and other wading bird species in the Everglades during the period 1931–1946. Additional colonies along the southern mainland of Florida Bay included Gator Lake, Mud Lake, Mud Hole (located east of Gator Lake), Cuthbert Lake, and Madeira Rookery. All of these coastal nesting colonies collapsed during the second half of the Twentieth Century (Ogden 1994). Larger fishes, such as sunfish and topminnows that grow to 10 cm in length, are considered to be particularly important in the diets of wood storks due to their higher vulnerability to capture (Ogden et al. 1978).

A decrease in roseate spoonbill (*Platelea ajaja*, Linnaeus) nesting in northeast Florida Bay and a shift of nesting distribution from eastern to western Florida Bay accompanied the collapse of the wood stork nesting colonies (Powell et al. 1989, Bjork and Powell 1994, Lorenz et al. 2002). Small fishes have been reported to be the primary diet of roseate spoonbills in Florida Bay (Allen 1942, Powell and Bjork 1990, Dumas 2000). Relatively sparse populations of marsh fishes along the estuarine interface of northeast Florida Bay today require very specific wetland drying patterns to concentrate them and make them available in densities adequate to support spoonbill nesting. Lorenz (2000) reported a water-depth threshold of 12 cm, averaged over the 21-day post-hatching period of roseate spoonbills, that is necessary to concentrate the fish prey base in Taylor Slough coastal sites. Water-level recession to 12-cm depth during that period can concentrate normally low fish density in that region to 85 fish per square meter in remaining pockets of water. The 12-cm depth threshold fits well with success or failure of spoonbill nesting in northeast Florida Bay colonies.

Collapse of coastal wood stork and great egret colonies, and of northeast Florida Bay roseate spoonbill colonies, corresponded to construction of the Central and South Florida (C&SF) Project and the resulting reduction of freshwater flow to the estuarine interface compared to Natural Systems Model (NSM) simulations (VanZee 1999).

Estuarine Crocodilian Populations

The American alligator (*Alligator mississippiensis* Daudin) was historically abundant and nested in freshwater mangrove areas of the Everglades (Craighead 1968). Today, nesting is limited, and few juveniles are observed. Salinity is a major factor limiting distribution and abundance of alligators in estuarine habitats (Dunson and Mazzotti 1989, Mazzotti and Dunson 1989). Alligators lose the capacity to we estuarine habitats for feeding, growth, and reproduction when salinity exceeds oligohaline levels (Joanen 1969). When alligators occur in salt water, it is usually to feed, and there is always a freshwater refugium in close proximity (Jacobsen 1983, Tamarack 1988). In a natural experiment in North Carolina, alligators that were exposed to diversion of freshwater flows due to construction of a power plant relocated to the diversion canal to maintain access to fresh water.

Small alligators are especially vulnerable to exposure to salt water. In laboratory experiments, small alligators ceased feeding and should signs of stress when exposed to salinities greater than 10 ppt (Lauren 1985). Alligators do feed and gain mass at 4 ppt (Mazzotti and Dunson 1984). For these reasons, alligators are good indicators of restoring freshwater flows to estuarine systems and the subsequent reestablishment of an extensive freshwater/brackish water zone.

The American crocodile (*Crocodylus acutus* Cuvier) dwells in ponds and creeks of the mangrove estuaries of Florida Bay (Ogden 1976, Mazzotti 1983). American crocodiles are tolerant of a wide salinity range as adults because of their ability to osmoregulate (Mazzotti 1989). Juvenile crocodiles lack this ability (Mazzotti 1989), however, and their growth and survival decrease at salinities exceeding 20 ppt (Mazzotti and Dunson 1984, Mazzotti et al. 1988, Moler 1991). Juvenile crocodiles tend to seek freshwater pockets, such as black mangrove stands, when those choices are available.

ECOLOGICAL EFFECTS: LINKAGES BETWEEN STRESSORS AND ATTRIBUTES

Coastal Transgression

The stability/instability of the shoreline and coastal wetlands in the southern Everglades is manifest through the dynamic interaction of freshwater outflows, sea-level rise, and saline water inflow, the rate of import/export of sediment, and the capability of the sedimentary environment or bio-sedimentary substrate level to respond to changes in water level. In this time of rapidly rising sea level (Wanless et al. 1997), most mangrove communities are presently losing area of coverage (Wanless et al. 2000). In the coming century, the coastal mangrove community can be expected to become increasingly dissected. Sustained rates of accretion of coastal marl shorelines of Florida Bay probably are also incapable of keeping up with predicted rates of sea-level rise, and over-topping and breaching of embankments during storm events are likely under future scenarios of rising sea level.

Where rates of peat or marl elevation buildup do not keep up with rates of sea-level rise, shoreline transgression and landward salinity intrusion will lead to mangrove erosion along shorelines and mangrove movement into interior landscapes. Saline intrusion into freshwater wetlands underlain by peat substrate may lead to wetland collapse and transformation to open, saline ponds and estuaries (Wanless and Vlaswinkel 2005). Saline intrusion into marl substrate wetlands results in an advancing zone of diminished productivity (white zone) (Ross et al. 2002). Restoration of freshwater flow volume, timing, and distribution may slow the inland movement but will not change the rate of erosion along the shoreline.

The coastal Everglades have also been re-configured during the past century by filling in of tidal creeks. Siltation and mangrove encroachment of tidal creeks (Craighead 1971, Meeder et al. 1996) has progressed to the extent that open water courses that were described earlier this century are no longer recognizable (G. Simmons, gladesman, pers. comm.). Reduced freshwater flow volume and rising sea level are probable contributing factors.

Coastal Hydroperiods and Salinity Gradients

Pre-drainage hydrologic conditions in the southern Everglades produced prolonged pooling of freshwater just upstream from the mangrove estuaries and prolonged durations of freshwater flow into the estuaries (VanZee 1999). The freshwater pooling and inflow supported wide salinity gradients, including a broad oligohaline zone, in the mangrove estuaries.

A combination of reduced freshwater flow and increased relative sea-level rise has resulted in higher salinities in the formerly oligohaline mangrove zone and significant saline intrusion into former freshwater marshes of the lower Everglades (Ross et al. 2000, Ross et al. 2002). Although surface-water salinities fluctuate laterally through wet and dry seasons, saline ground-water intrusion has moved and remains far inland of the position prior to drainage.

White Zone

At the landward interface of the mangrove estuaries with marl wetlands, a ''white zone'' band of sparse, mixed mangrove and graminoid vegetation that appears white on color infrared or black-and-white aerial photos. As with any upper bound on an oligohaline ectone, this zone integrates the balance between freshwater flow and sea-level rise (Ross et al. 2002). Egler (1952) described the white zone as a band of low, open vegetation separating mangrove swamps adjacent to the southeast saline Everglades coast (Taylor Slough to Turkey Point) from sawgrass marshes of the interior. Its composition included a mixture of sawgrass (*Cladium jamaicense* Crantz), spikerush (*Eleocharis* spp.), and red mangrove. He considered the inner edge to mark the farthest extent of storm tides. Ross et al. (2000) documented changes in extent and plant species composition of the white zone since Eglers work. They found movement toward the interior of less than 1 km up to about 4 km throughout the region over about 50 years. Movement was maximal in areas where virtually all freshwater has been blocked by canals and management (wetlands east of US 1), and minimal in wetlands where water flow was less impacted by canals, levees, and management (wetlands west of US 1 and directly south of the C-111 Canal). These patterns suggest that freshwater inflows [at least] partially counteract transgression driven by sea-level rise. Working along a hydrologically isolated coastal transect south of Turkey Point, Meeder et al. (1996) documented an inland movement of the interior boundary of the white zone of 1.9 km during 1940–1994. This distance equated to a vertical shift of 13 cm during a period in which sea level rose by only 11 cm.

WORKING HYPOTHESES FOR RESTORATION

Coastal Transgression

Sustained buildup of substrate by physical and biological processes in many coastal marl and mangrove environments of South Florida will not be capable of keeping up with rates of sea-level rise during the twenty-first century. Where rates of peat or marl elevation do not keep up with rates of sea-level rise, shoreline transgression and landward salinity intrusion into mangrove and freshwater wetlands will occur.

White Zone

If sea level continues to rise at its current rate or faster, the leading edge of the white zone will continue to move toward the interior, except along tidal creeks or major drainages. These changes will be least evident in areas in which freshwater input is augmented and greatest in areas cut off from freshwater flow.

Coastal Tidal Channel Characteristics

The dendritic pattern, channel width and depth, flow volume, and material transport of tidal watercourses through the coastal mangrove estuaries are controlled by sea level interacting with the volume, timing, and distribution of sheet flow and channel flow from the southern Everglades. Many tidal creeks through coastal wetlands of the Everglades have disappeared entirely during the past century because they have been filled in with sediments and with the vegetation of surrounding landscapes. Reduced freshwater flow volume and rising sea level are probable contributing factors. Restored freshwater inflow from the Everglades is expected to help sustain open watercourses through the estuary that will more closely resemble historic patterns, yet sea-level rise is expected to modify the patterns of connectivity through the coastal wetlands and create increased sediment loads.

Coastal Hydroperiod and Depth Patterns

Sheet flow in the southern Everglades prior to drainage produced persistent pooling of fresh water upstream from the mangrove estuaries and prolonged freshwater flow into the mangrove estuaries. Reduced volume and duration of freshwater flow have shortened hydroperiods in the southern Everglades, disrupted in sheet flow, and reduced duration of pooling along the sawgrass/mangrove ecotone. Restoration of pre-drainage volume, distribution, and duration of sheet flow in the southern Evergladeds will prolong pooling of fresh water along the sawgrass/mangrove interface and increase volumes and durations of freshwater flow to the estuaries.

Coastal Salinity Gradients

Prolonged pooling of fresh water upstream of the mangrove estuaries and prolonged patterns of freshwater flow supported a wide salinity gradient, including a broad oligohaline zone, in the mangrove estuary. A combination of historical reduced freshwater flow and increased relative sea-level rise have resulted in higher salinities in the formally estuarine mangrove zone and significant saline intrusion into former freshwater marshes of the lower Everglades. Increasing seasonal freshwater sheet flow to the lower Everglades is expected to provide a broader zone of salinity gradients in the lower Everglades and coastal wetlands and should, in the short term, re-establish an oligohaline zone in the coastal wetlands. Over a long-term period, rising sea level is expected to result in high tides overtopping coastal marl ridges and saline waters penetrating more deeply through tidal channels and mangrove forests, shifting the areas of fresh and lower salinity waters inland.

Production and Organic Soil Accretion of Coastal Mangrove Forests

Production and organic soil accretion in the mangrove forests of the coastal Everglades are controlled by phosphorus availability, with relatively large inputs from marine sources and small inputs from freshwater sources. Increased freshwater sheet flow caused by implementation of CERP projects is expected to maintain low nutrient conditions in the southern Everglades mangrove estuaries and in the oligohaline ecotone forests of the western mangrove estuaries. Low nutrient conditions are expected to enhance belowground productivity by mangroves, which will maintain peat production and soil elevation increases—ultimately enhancing the ability of these low salinity forests to maintain themselves against sea-level rise.

Resilience of Coastal Mangrove Forests

Resilience of the mangrove forests of the coastal Everglades after disturbance is dependent on hydrologic flushing by either fresh or saline water, which is driven by sea level and sheet flow from the Everglades. Resilience also varies with soil fertility. Improved freshwater flow and flushing through the lower Everglades and coastal wetlands (through both channel and sheet flow) are expected to aid in recovery of wetlands from catastrophic setbacks (from hurricanes, fire, freeze, and salinity changes).

Coastal Lake Submerged Aquatic Vegetation and Waterfowl

Prolonged periods of elevated salinity in coastal lakes and basins, resulting from diminished freshwater flow volume and duration, have reduced seasonal duration and cover of communities of SAV along shorelines and in tributaries. SAV communities will persist in larger beds, longer into the dry season, and lower in the estuarine system when oligohaline to mesohaline conditions are restored upon resumption of natural freshwater flow volume and duration.

Resident Mangrove Fish Populations

The wet-season density, size structure, and relative abundance of resident mangrove fish populations are directly related to the time since the last dry-down, the length of time the marsh was dry, and salinity in coastal ecotones. Responses of fishes are non-linear and species-specific. The concentration of resident mangrove fishes into high-density patches where wading birds can feed effectively is controlled by the rate of dry-season water-level recession and local topography/

habitat heterogeneity. Restoration of persistent pools of fresh-to-oligohaline water along the interface where mangrove forests meet the Everglades will support increased densities, size distributions, and seasonal concentrations of resident mangrove fishes due to combined effects of prolonged hydroperiod, enhanced drying patterns, and extended periods of freshwater to oligohaline salinity.

Wood Stork and Roseate Spoonbill Nesting Colonies

The collapse of coastal wood stork and great egret nesting colonies in the tributary headwaters and southern mainland of the Everglades mangrove estuary, and the abandonment of roseate spoonbill nesting colonies in islands of northeast Florida Bay, are attributed to declines in population densities and seasonal concentrations of marsh fishes and other wading bird prey in the southern Everglades. Restoration of densities and seasonal concentrations of resident mangrove fishes in persistent pools of fresh-to-oligohaline water immediately upstream from the mangrove forests will provide the necessary prey base in juxtaposition to nesting habitats to re-establish coastal nesting colonies of wood stork and great egret and northeast Florida Bay nesting colonies of roseate spoonbill.

American Alligator

American alligator distribution, abundance, reproduction, and body condition in the Everglades mangrove estuaries are controlled by salinity. Reduced freshwater flow into the mangrove estuaries of the southern Everglades has resulted in succession of former freshwater mangrove areas to saltwater systems, reducing American alligator populations in tidal rivers and tributaries. With the resumption of natural patterns of volume, timing, and distribution of flow to the Everglades, the American alligator is expected to repopulate and resume nesting in the freshwater reaches of tidal rivers in the mangrove estuaries.

American Crocodile

American crocodile relative density and juvenile growth, survival, and condition increase when salinity fluctuates below 20 ppt in shoreline, pond, and creek habitats in Everglades mangrove estuaries. Alteration of location and quantity of freshwater flow to the mangrove estuaries has lowered the relative density of crocodiles in areas where freshwater has been diverted and decreased growth and survival of juvenile crocodiles throughout the estuary in areas of higher salinities. Restoration of Volume, timing, and distribution of freshwater flow will result in an increase in relative density of crocodiles in areas of restored flow, such as Taylor Slough/Taylor River drainage. Reestablishing the salinity gradient in the estuary will increase growth and survival of juvenile crocodiles throughout the estuary.

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