IMPLICATIONS OF SEA LEVEL RISE FOR WETLANDS CREATION AND MANAGEMENT IN FLORIDA

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ABSTRACT

A 60 to 300 centimeter rise in sea level is forecast for the next century due to global warming caused by elevated CO_2 levels from increased energy consumption. Recent sea level has risen at a much slower rate, and wetland effects of the relatively gradual rise can be found along open coastlines, bay shores, and tidal rivers. The impact of a higher sea level depends on the rate of change and its final stand; geomorphic considerations; and biotic responses. Key geomorphic factors are sediment source, subsidence rate and upland slope. Key biotic responses are vertical accretion, dispersal, and salt tolerance. Tidal freshwater wetlands are particularly vulnerable to projected rates of sea level rise because of salt intolerance and limited substratum availability. Overall, wetlands in proximity to developed uplands may be seriously threatened if rates of sea level rise exceed mid-range estimates (about 180 cm per 100 years). Wetland managers need to decide on meaningful time horizons for preservation, conservation and restoration. Consideration of time horizons and various sea level rise scenarios should be a part of routine wetland management practice, especially creation, restoration, and mitigation. Aspects of wetland creation affected by sea level rise include species selection, site selection and preparation, monitoring, and design of compatible upland activities. Dedication of low-lying upland as permanent wetland easements could be an extremely meaningful form of mitigation if mid-range to high rates of sea level rise can be forecast or measured with greater certainty.

INTRODUCTION

The average and extreme levels of the sea affect marine, intertidal and riverine geology, chemistry and biology, as well as a number of economic factors. Sea levels have been studied throughout history and recently by scientists and engineers. An aspect of sea level central to all of these interests has been the rate of sea level rise or fall. This paper reviews data on sea level, the record and effects of sea level rise in Florida, and implications of projected rates for wetland management and science.

Virtually every aspect of Florida's biogeochemistry is the result of past sea level stands. The present distribution and abundance of tidal marshes and mangroves in the state are the consequence of low

tidal range, a subtropical climate, and especially the fact that sea level has been rising at a low rate, relative to earlier times. About 7000 years ago sea level was 4.0 meters below modern sea level; 4000 years ago it was approximately 20 meters lower than present; and for the last 2000 years the sea has risen by about 1.0 meter (Scholl, Craighead, & Stuiver 1963).

Oceanographic measurements made during the past century reveal that sea level continues to rise along most shores. During 1940-1975 the average rate of sea level rise along the coast of the United States was 1.5 mm/yr (Hicks 1978), which is about half the rate measured during a 30-50 year period before 1940 when global temperatures were higher (Donn & Shaw 1967). For the period 1898-1980, sea level along the Florida coast has risen between 1.7-2.4 mm/yr (Hicks, Debaugh, & Hickman 1983), as shown in Table 1.

Table 1. Trends and variability of sea level in Florida, adapted from Hicks, Debaugh, and Hickman (1983).

	Record		Value, mm/yr	
Station	Began	Missing	Trend	± Std. Error
Fernandina Beach	1898	1924-38	1.7	0.4
Mayport	1929	0	2.3	0.3
Miami Beach	1932	1979	2.3	0.2
Key West	1913	0	2.2	0.2
Cedar Key	1915	1926-38	2.0	0.2
Pensacola	1924	0	2.4	0.3

FLORIDA'S TIDAL ENVIRONMENTS

The effect of tides occurs along the entire Florida coastline and includes a larger area than is affected by saltwater. Truly marine areas affected by the tide are those nearshore parts of the Gulf of Mexico and Atlantic Ocean where tidal currents are modified by bathymetry, and where wave climates, water chemistry, or other factors vary on a tidal basis. Sandy beaches are the most common boundary between marine areas and uplands.

Salt marshes and mangrove forests are exposed directly to the Gulf of Mexico along much of the west coast and usually adjoin waters of estuarine salinity. Submerged aquatic vegetation grows in shallow

waters seaward of the marsh or mangrove coast, which also supports subtidal and intertidal oyster reefs, algae beds, or unconsolidated sediments. Coastal wetlands of the Big Bend area are primarily black needlerush (Juncus roemerianus) marshes, whereas the Everglades wetlands open to the sea are comprised mostly of red mangrove (Rhizophora mangle) or black mangrove (Avicennia germinans).

The upland side of coastal marshes and mangroves is vegetated either by freshwater grass marshes or by meadows of succulent halophytes. Large areas behind the Everglades mangrove zone are sawgrass (Cladium jamaicensis), bulrush (Scirpus spp.) or cattail marsh, usually with extensive intermixing by herbaceous freshwater vegetation. Where fringing forests or marshes are backed more closely by uplands, but separated by level ground affected by tides, large areas of cordgrass (Spartina spp.) or meadows of glasswort (Salicornia virginica), saltwort (Batis martima), sea purslane (Sesuvium portulacastrum) and other halophytic ground cover may grow. Salterns develop in the same areas when local conditions allow spring tides to flood poorly drained areas and salt accumulates by evaporation. Marshes and mangrove forests may also be separated from uplands by scarps of low relief, or there may be a rapid transition to upland plant communities where relief is even greater.

Tides (and salinity) affect the mouths and downstream ends of nearly all rivers in Florida, and tides alone affect an even greater reach of most rivers by causing current reversals and tidal cycles of shoreline submergence and exposure. River shorelines exhibit a wide range of physical conditions and vegetation as a result of the strong gradients established by river flow and tidal action. Saltwater marshes (or mangroves in southern areas) grow along the shoreline or as islands in lower to middle river reaches, but are replaced by brackish or freshwater marshes farther upstream if suitable substratum is available. Tidal freshwater marshes occur in Florida rivers but are not extensive. Instead, brackish marshes end abruptly at the downstream side of floodplain forests. Current reversals and shoreline submergence caused by tidal action can occur for several kilometers upriver, through the floodplain forest.

EFFECTS OF RECENT SEA LEVEL RISE ON FLORIDA WETLANDS

The effects of a gradually rising sea level have been read by geologists in the evolution and modern appearance of coastal landforms in the Everglades and marsh-dominated shorelines of the Big Bend region. Studies of comparable depth are presently unavailable for bays and estuaries or tidal rivers of the state.

Peats of mangrove origin occur under modern mangrove forests in the Everglades and below sands in Florida Bay and the Gulf of Mexico. Freshwater muds occur below the peat which indicate that mangrove forests expanded inland as sea level rose during the past several

thousand years. The interface between peat and mud and samples of these materials have been used to date their periods of deposition, which represent the rates of sea level rise, deposition, and lateral movement. In general, submergence rates have equalled the rate of coastal sedimentation, about 3.4 cm/100 years for several centuries (Scholl 1964a).

The near equivalence of these rates does not imply that all forests have survived. First, mangrove peats are buried offshore where no modern forests stand. Second, the thickness of peat deposits thin landward. Third, mangrove peats eroded from other forests have probably settled in depositional environments along the coast. Finally, there is ample evidence today of forest erosion along the open coast; dissection of the forest by channels and intra-forest bays; and inland expansion of forests in tidal brackish and freshwater areas (Scholl 1964b; Spackman, Dolsen, & Riegel 1966). Altogether, the geologic and botanic record depicts "tracking" by mangrove forests of a steadily transgressing sea, with seaward losses and landward gains resulting in a dynamic stability for the wetland system.

A similar pattern of lateral translation by wetlands has been found toward the southern end of the marsh system in the Big Bend region, a sand-starved coastline (Hine & Belknap 1986). Low uplands have been drowned by the sea, isolating hammocks of terrestrial plants over highpoints in the underlying bedrock. The hammocks are surrounded by Juncus marshes growing on autochthonous peats (produced by the marshes). Interior marsh areas are dissected by small creeks aligned with fractures in the underlying limestone. Seaward marshes have larger creeks and more open water and fewer hammocks. The bedrock highs exposed by tidal action provide attachment sites for oysters, which are developed as coalesced reefs aligned perpendicular to east-west tidal currents. As in the Everglades example, the Big Bend marsh system is eroding on its seaward face, expanding inland, and accreting vertically at rates controlled by local conditions. In both the Big Bend and Everglades areas, major sediment redistribution probably occurs during hurricanes, and the extent of their effect is preconditioned by the accumulated action of sea level rise during antecedent periods of calm (Davis 1940; Hine & Belknap 1986).

Far less complete but supportive evidence is available for bays, estuaries, and tidal rivers. Trend analyses of wetland vegetation have been conducted based on aerial photographs, for the period 1950-1980 in the Tampa Bay region (Tampa Bay Regional Planning Council 1986) and for the period 1945-1982 in the Charlotte Harbor region (Harris, Haddad, Steidinger, & Huff 1983). In both cases, examples of inland encroachment of marshes and mangroves were found, especially in Charlotte Harbor. Although marsh expansion was less evident in the Tampa Bay area, it was noted where fringing uplands were low and level. Moreover, there probably has been an overall decrease in saltern area, at least in Hillsborough County, which cannot be attributed to upland development.

Scant data exist at present in Florida for tidal river effects attributable to sea level rise. Wharton (1985) reconstructed wetland vegetation in the tidal portion of the Myakka River (Sarasota & Charlotte Counties) from surveyors' notes in the 1840s and determined that mangroves presently occur some 7.4 river kilometers upstream of their historic location in downstream areas. This difference could be interpreted as a response to rising sea level but may also be attributable to freeze damage, recruitment during droughts, or other natural factors.

PROJECTED RATES OF SEA LEVEL RISE

An increase of carbon dioxide and other "greenhouse gases" has occurred during the past century due to deforestation, industrialization, and population growth. These gases promote atmospheric warming. The National Academy of Sciences (1983) predicted a 1.5-4.5 C warming if greenhouse gases double, a process which is expected with reasonable certainty during the next 100-300 years.

These predictions have stimulated a number of estimates regarding the effect of atmospheric warming and climatic feedbacks on sea level. As part of the NAS report, Revelle (1983) forecasted a 70 cm rise in sea level by 2085, in response to a global warming of 2.7 C. The U.S. Environmental Protection Agency estimated in 1983 that sea level would rise from a low of 56 cm to a high of 368 cm by 2100, and provided several intermediate estimates as well (Hoffman et al. 1983). Following refinement of glacial and other studies, EPA revised their estimate in 1986 to a 57-368 cm range by 2100 (Hoffman et al. 1986). Thomas (1986) also has estimated the 2100 sea level to be 64-230 cm above the present stand of the sea.

These calculations are based on a complex series of measurements, assumptions, and relationships between atmospheric, oceanic, and biologic processes, and are under continuous refinement. For purposes of this paper, however, it is instructive to note:

(a) Sea level has been rising in Florida at 1.7-2.4 mm/yr (Hicks et al. 1983).

(b) Marshes have accumulated sediments at rates one order of magnitude greater (Hatton et al. 1983); upper limits of sedimentation are not known, but 10 mm/yr submergence is considered "catastrophic" (Orson, Pangestou, & Leatherman 1985).

(c) Low estimates for future sea level rise fall between 5-6 mm/yr (Hoffman et al 1986; Thomas 1986).

IMPACTS OF RAPID SEA LEVEL RISE ON FLORIDA WETLANDS

A number of adverse impacts will result if sea level rises more rapidly than Florida wetlands can accumulate sediment. Tidal marshes and possibly mangroves will drown when submerged so often that waterlogging occurs, or when soil chemistry is adversely affected. These effects will be more pronounced along the seaward edge of wetlands and along creeks. Creek widths will increase as dissection of forests or marshes proceed, resulting in an increase in relative water surface area and also in marsh or forest edge (Hine & Belknap 1986).

Other changes will occur as sediment-related processes are affected. A reduction of plant biomass may lead to reduced rates of *in situ* organic accumulation, as well as a reduced ability of marshes or forest root-zones to trap water-borne sediments. Erosion of destabilized wetland borders may occur. On balance, some wetlands could benefit because eroded sediments become available for deposition elsewhere (Orson et al. 1985). Also, scarps may be relocated which could create additional marsh or forest substratum from upland areas and add additional sediments to down-gradient wetlands.

The areal effect of rapid sea level rise is likely to be an accelerated version of existing processes, e.g., heightened erosion of seaward wetlands and increased wetland expansion, landward (where low uplands are available). Species replacement within a particular wetland is probable (Redfield 1972). Where increased tidal access brings saltwater into fresh water marshes or cypress domes, replacement by salt tolerant species can be expected. Tidal freshwater marshes in rivers are likely to be eliminated if *Juncus* or other salt marshes migrate upriver in response to increased salinities because the tidal freshwater marshes will have no suitable, intertidal substratum farther upstream (Estevez 1988), at least not until the lower reaches of floodplain forests are killed and their sediments are redistributed.

The effects of sea level rise on Florida's tidal wetlands will be aggravated by human-caused changes to coastal environments. Chief among these are:

Shoreline Protection

Seawalls, upland fill, or other protective measures on the upland side of coastal wetlands will prevent their migration in response to rising sea level. The result, in light of heightened erosion on the seaward side, will be a net loss of wetlands as they are "pinched out" (Titus, Henderson, & Teal 1984). The current practice of regulatory agencies to permit conversion of salterns to storm water basins--or even uplands--is particularly retrogressive in this respect.

Channelization, Spoiling, and Dikes

These structures accelerate the rate of local subsidence by compressing marsh sediments; starving marshes of water-borne sediment by routing water away from marshes; promoting saltwater intrusion; and changing patterns of tidal inundation (Craig, Turner, & Day 1980). Spoils and dikes, as well as clearing operations on the upland sides of wetlands, promote invasion by exotic species such as Brazilian pepper (*Schinus terebinthifolius*) and Australian pine (*Casuarina equisetifolia*), which crowd out native wetland species.

Diversions of River Flow

The distribution, abundance, and condition of wetlands along the tidal reach of Florida rivers are controlled by the physical and chemical interaction of freshwater discharge and tidal action. River discharges provide nutrients and sediments, affect water levels, and establish salinity gradients in tidal rivers (Mahmud 1985). Flow reductions mimic sea level rise by shifting salinity patterns upstream, dislocating stationary and dynamic estuarine environments. Where flow reductions occur *in addition to* sea level rise, rapid and catastrophic wetland impacts can be expected in the tidal reaches of coastal plain rivers, especially for spring-fed systems.

The special case of seagrasses has not as yet been considered in relation to the sea level rise issue. Flooding, waterlogging, erosion and may other impacts to wetlands are not relevant in the case of these plants, but increased light attenuation by a longer light-path may be significant for seagrasses located near their compensation depths. Sediment redistribution caused by erosion may increase local turbidity, which can also result when the mean depth of lagoons and bays increases to the point that fetch, wave climates, current structure, or other physical features are changed. For example, the loss of offshore bars along "estuarine shelves" (Lewis, Durako, Moffler, & Phillips 1985) could expose inshore grassbeds to higher wave energy and turbidity. Estuarine grassbeds and submerged aquatic vegetation would also be affected as salinity patterns changed in tidal rivers.

IMPLICATIONS FOR WETLAND MANAGEMENT

Florida shares equally with the rest of the nation the task of choosing appropriate responses to the issue of sea level rise, but the state has proportionately more wetlands to lose if responses are inappropriate or are implemented too late. If mid-range to high rates of sea level rise can be forecast with greater certainty, Florida wetland managers should be ready to implement well-reasoned programs, rather than to start their design in a crisis atmosphere. In light of the wetland impacts likely to occur even under historical rates of sea level rise, a few recommendations can already be tendered.

1. Use Relevant Vertical Reference Data

Neither mean sea level of 1929 nor the National Geodetic Vertical Datum are intrinsically meaningful with respect to modern wetland elevations. Sea level has risen in Florida since 1929 and so have its wetlands. The National Ocean Survey redetermined local tidal datum planes in the 1970s, and these data should be consulted when planning tidal wetland projects. Elevations for new projects can also be established by surveying nearby natural marshes.

2. Establish Useful Life as a Design Criterion

When time horizons for wetland projects are discussed at all, the usual sense is that the system will be expected to persist indefinitely. This is a desirable goal even though hurricanes, freezes, and other natural forces set upper limits to the longevity of a specific wetland. It may be useful to intentionally design "utility wetlands" with shorter useful lives than "wilderness wetlands" (Clark 1986). Also, the time lines set for created wetlands may not need to be as long as ones set for restoration or mitigation wetlands.

3. Take Advantage of Upland and Inland Sites

Wetland creation, restoration or mitigation projects in areas where sea level rise impacts will not be felt first include tidal rivers; the upper ends of bays and estuaries; blind ends of lagoons; and creeks and streams flowing to tidal waters. In some cases it may be sufficient to prepare low uplands for natural wetland recruitment, through removal of ditches, spoils, or other barriers (see below).

4. Prevent and Remove Upland Barriers to Wetland Migration

Florida's extensive lowlands near tidal wetlands are important as incipient wetlands. Barriers include roads, fill, seawalls, ditches and buildings. These structures could be removed; removed once depreciated; or never built in order to allow for wetland migration. Whether or not sea level rise accelerates, one meaningful measure would be protection of salterns. These tidal landforms are being converted into uplands, stormwater catchment basins, or other uses which will prevent wetland migration from occurring.

5. Dedicate Low-lying Uplands

Governments and developers of large coastal properties should inventory the actual location and extent of lowlands adjacent to tidal wetlands and consider their long-term preservation as a land-use and planning tool. Property can be conveyed fully as part of site planning

or perpetual easements could be dedicated. Such lowlands (but not salterns) could be used as freshwater wetlands for stormwater management, until they are encroached upon by tidal wetlands.

6. Establish Long-term Monitoring Programs

Sea level *per se* is actively monitored but there is a need for data on current wetland dynamics. Much more information is needed in Florida on elevations of specific wetlands; rates of sediment accumulation and loss; historic trends in unstudied wetlands; effects of exotic species on wetland movement onto lowlands; saltern geomorphology and habitat value; and wetland dynamics in tidal rivers.

CONCLUSION

Sea level is likely to rise at rates which are significantly greater than have occurred in the recent past, but even if coastal wetlands can accumulate sediment at comparable rates, Florida will probably experience net wetland losses due to sea level rise because of the extensive amount of protected shoreline already in place; ditches, channels, and levees created for mosquito control, land-fill and navigation; existing hydrological alterations; and increasing demands by a growing population for flood control and potable water.

The moderate to high rates forecast for sea level rise should be detectable by measurements made during the next twenty years. Two decades would not be an excessive period to wait for more definitive data except that Florida is experiencing tremendous population growth, especially along its coastlines, and large areas of the state near tidal wetlands will be developed in twenty years. Management decisions regarding sea level rise, tipped in favor of wetlands, would only put off more intensive land uses for a few years if predicted rates do not materialize, but would significantly protect wetlands if higher rates do occur.

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