

Appendix I:

Sea Level Rise in Florida: A Bibliographic Essay of Current Science

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Sea Level Rise in Florida: A Bibliographic Essay of Current Science

A project of The University of Florida Conservation Clinic¹

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Introduction

This bibliographic essay compiles the current peer-reviewed science and policy related to sea level rise in Florida. Sea level rise and climate change are global phenomenon. However, spatial and temporal changes in sea level vary on local and regional scales due to differences in ocean density, circulation patterns, climatic events, coastal geomorphology, and topography. Issues of scale are important when considering sea level rise. Many of the considerations in the broader sea level rise literature, such as anthropogenic contributions to climate change and the role of glacial melt in future predictions, are best addressed at a global scale. Conversely, issues of regional and local significance include land loss, habitat migration, vulnerability, and land use planning. This bibliography maintains a regional focus on Florida-specific sea level rise literature.

Sea level rise is an issue of paramount importance for the state of Florida due to its lengthy coastline; low relief; high coastal population density; and ecologically sensitive and economically important beaches, coastal wetlands, estuaries, lagoons, and aquifers. Florida was the last state to emerge from the ocean following the last inter-glacial maximum and has experienced fluctuations in sea level of 120 m in the past 21,000 years (IPCC, 2007).

In the 2,000 years prior to 1850, global sea level was fairly constant. Sea level began to rise at a rate of $\sim 2 \text{ mm y}^{-1}$ from 1850-1950, and increased to a rate of $\sim 3 \text{ mm y}^{-1}$ after 1993 (IPCC, 2007). Approximately half of the rise is attributed to the thermal expansion of the ocean, and half to the translocation of land water and ice to the oceans. In general, relative sea level rise in Florida has mimicked the rate of global sea level rise, with some local variability even within the state.

Understanding sea level change in Florida requires both a historical perspective and the ability to use predictive sciences to forecast future conditions using numeric and physical models. The historic record is rooted in geologic sciences, but also includes archeology, anthropology, and the use of biological indicators of past circumstances. Relying on this historic record, predictions of future sea level impacts and inundation maps can be constructed using scenarios, probability, and physical elevation data. Predictive models are only as accurate as the historic data used to construct them. Therefore, as our understanding of the past increases, and as the present becomes the past, our predictions become

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increasingly accurate. Sea level rise science is continually evolving and has increasingly caught the attention of the social sciences (economics, law, and planning) interested in how sea level rise will impact the human condition.

Presented as an annotated bibliography, this summary of research is intended to serve as a 'one-stop-shop' for existing peer-reviewed literature (through January, 2012) related to sea level rise in Florida. We have excluded the large body of gray literature, with varying levels of scientific rigor, available from government agencies, universities, and conservation organizations. Instead, we have focused exclusively on peer reviewed literature, or publications in journals accepted by their discipline as the basis for scholarship (e.g. law journals). This literature was compiled by an interdisciplinary team of scientists and attorneys using a number of search engines, databases, and internal references, including but not limited to Google Scholar, Web of Knowledge, Westlaw, author and key word searches. Fifty-three publications are summarized and grouped into three broad categories: physical, biological, and social sciences. We have made every effort to briefly, objectively, and accurately summarize each publication, notwithstanding that we do not pretend to grasp the disciplinary subtleties and complexities that all subject matter embraced. Any errors or omissions are the responsibility of the authors of this bibliography.

A second goal of this research is to provide a general analysis of the types of topics covered in the current sea level rise literature and a discussion of topics and areas of study that we feel are under-represented in the literature. We did this through a meta-analysis of keywords common to sea level rise literature. The results of the meta-analysis are presented in the conclusion of this document. Gaps in this body of literature are also discussed.

Physical Science

Adams, P. N., N. D. Opdyke, and J. M. Jaeger. 2010. "Isostatic Uplift Driven By Karstification and Sea Level Oscillation: Modeling Landscape Evolution In North Florida" *Geology* 38(6) 531-534.

Keywords: modeling, historic sea level rise, karst

The limestone and dolostone that forms Florida's platform is dissolved by freshwater at, and below, ground level. This process, called karstification, decreases the density and weight of the rock. As a result, isostatic uplift occurs, a process in which the lithosphere rises to reach gravitational equilibrium. This paper presents a numerical model that accounts for changes in sea level, karstification, precipitation, and isostatic uplift in order to age geologic features. The model also shows that the rate of uplift due to karstification is approximately $1/20 \text{ mm y}^{-1}$, indicating that the Florida platform is not completely stable relative to sea level.

Chu-Agor, M.L., R. Muñoz-Carpena, G.A. Kiker, A. Emanuelsson, and I. Linkov. 2011. "Exploring sea level rise vulnerability of coastal habitats through global sensitivity and uncertainty analysis." *Environmental Modelling Software* 26(5) 593-604.

Keywords: modeling, wetlands, habitat migration, inundation, panhandle, threatened and endangered species, barrier islands

This work uses the Sea Level Affecting Marshes Model (SLAMM) to simulate changes in inundation and wetland migration associated with sea level rise at Eglin Airforce Base's barrier islands in the Florida Panhandle. Sensitivity analysis was used to show that the most important variables in driving model behavior are the vertical error of land elevation maps, historic trend of sea level rise, accretion,

and sedimentation rates. The results also indicate that low-elevation habitats, such as salt marshes and tidal flats, exhibit a mix of gains and losses in overall area due to the ability of these habitats to migrate landward in response to sea level. However, habitats at higher elevations generally show a loss in overall area. These results can assist in determining management strategies for the snowy plover, a threatened shore bird that nests on sandy beaches along the Gulf Coast of Florida.

Doyle, T. W., K. W. Krauss, W. H. Conner, and A. S. From. 2010. "Predicting the Retreat and Migration of Tidal Forests Along the Northern Gulf of Mexico under Sea-Level Rise." *Forest Ecology and Management* 259 770-77.

Keywords: modeling, mangroves, wetlands, forests, habitat migration

Throughout the Gulf of Mexico, mangrove forests are expanding at the expense of tidal freshwater forests. This study uses a mathematical model called SLOPE (Sea Level Over Proportional Elevation) to predict future coastal habitat change in the Gulf of Mexico from Texas to Key West. The model incorporated data on tidal ranges, existing habitat area, land form, and current and predicted sea level rise to predict future coastal habitat types. In south Florida, the model output suggests that mangrove forests will replace freshwater wetlands, minimizing the loss of total wetland habitat, but greatly reducing biodiversity.

Geselbracht L, K. Freeman, E. Kelly, D. R. Gordon, and F. E. Putz. 2011. "Retrospective and prospective model simulations of sea level rise impacts on Gulf of Mexico coastal marshes and forests in Waccasassa Bay, Florida." *Climatic Change* 107(1-2) 35-57.

Keywords: modeling, wetlands, forest, habitat migration, Big Bend

This work applies the Sea Level Affecting Marshes Model (SLAMM) to understand how sea level rise will impact land cover and wetland migration in the Big Bend region of Florida. The study attempts to verify the SLAMM predictions through hindcasting (comparing model results to measured data) using field data collected between 1984 and 2008. The verification showed that the model satisfactorily simulated past land cover patterns, especially the historic losses of coastal forest, transitional saltmarsh, saltmarsh, and inland freshwater marsh. However, hindcasting also showed substantial differences between specific model outputs and past conditions, indicating its predictive limitations. Effects of sea level rise were also projected into the future using scenarios of 0.6, 1.0, and 2.0 m sea level rise by 2100. The sea level rise scenario of 0.6 m by 2100 estimated 97% of the 1973 coastal forest area would transition to saltmarsh or transitional saltmarsh by 2100.

Houston, J. R. and R. G. Dean. 2011. "Sea-level acceleration based on U.S. tide gauges and extensions of previous global-gauge analyses." *Journal of Coastal Research* 27(3) 409-417.

Keywords: sea level rise acceleration, sea level rise prediction, tide gauge

The possible acceleration of sea level rise is investigated using historical tide gauge data throughout the US, including Florida. Data records of 60-156 years were analyzed and projections focused on a subset of gauges with data from 1930-2010. Least squares quadratic analysis of gauge

data was used to forecast rates of sea level rise acceleration. Results indicate a slight decrease in the rate of sea level rise acceleration from 0.0014 to 0.0123 mm y⁻¹ between this time period².

Rahmstorf, S. and M. Vermeer. 2011. Discussion of Houston, J. R. and R. G. Dean. 2011. "Sea-Level Acceleration Based on U.S. Tide Gauges and Extensions of Previous Global-Gauge Analyses." *Journal of Coastal Research* 27(3) 409–417. *Journal of Coastal Research* (27)4 784-787.

Keywords: sea level rise acceleration, sea level rise prediction, tide gauge

This article presents a discussion of Houston and Dean's (2011) work (shown above). Rahmstorf and Vermeer state that there are three basic weaknesses of the Houston and Dean paper. 1) The use of a regional non-weighted approach does not consider global measurements. 2) The arbitrary cutoff of 1930 in the historical records may cause bias in the results and make sea level rise appear to increase linearly rather than accelerating. 3) Rahmstorf and Vermeer expect acceleration to increase with increasing temperatures, but large temperature changes have yet to be seen. This is not accounted for in the Houston and Dean paper.

Houston, J. R. and R. G. Dean. 2011. Rebuttal to Rahmstorf, S. and Vermeer, M., 2011. Discussion of: Houston, J.R. and Dean, R.G., 2011. "Sea-Level Acceleration Based on U.S. Tide Gauges and Extensions of Previous Global-Gauge Analyses." *Journal of Coastal Research* 27(3) 409–417. *Journal of Coastal Research* 27(4) 788-790

Keywords: sea level rise acceleration, sea level rise prediction, tide gauge

This is a rebuttal to the discussion of Houston and Dean (2011) by Rahmstorf and Vermeer (2011) (shown above). Here, Houston and Dean argue that the time-based approach that they used to analyze changes in sea level is a standard and acceptable method. They assert the method is not inferior to the empirical method presented by Rahmstorf and Vermeer, and that Rahmstorf and Vermeer's figure based on empirical methods does not exhibit the good agreement with projected and measured sea level rise acceleration that they claim it does.

Krauss, K. W., A. From, T. W. Doyle, T. J. Doyle, and M. Barry. 2011. "Sea-level rise and landscape change influence mangrove encroachment onto marsh in the Ten Thousand Islands region of Florida, USA." *Journal of Coastal Conservation* 15(4) 629-638.

Keywords: mangroves, habitat migration, Ten Thousand Lakes

This paper maps changes in mangrove land cover between the Gulf of Mexico and the Ten Thousand Lakes area. The study covers a period of 78 years between 1927 and 2005. In 2005 there were 7,281 ha of mangroves, 1,878 ha more than in 1927. This represents a 35% increase in mangrove land cover in the study area. The authors attribute the increase to sea level rise, but also note other

² Note: Inclusion of this article, the discussion, and rebuttal departs from the Florida focus of this bibliography. We included these articles to highlight the current academic discussion concerning acceleration in global sea level rise, the use of tide gauges vs. satellite altimetry, and the role of the predictive sciences in the discussion – all of considerable interest to Florida-focused researchers

anthropogenic impacts. For example, waterway construction has increased tidal influences in the area and possibly enhanced the dispersal of mangrove propagules. Additionally, changes in fresh overland runoff may also be contributing to the change in land cover. The authors state that understanding the mechanisms responsible for mangrove expansion can offer options to managers striving to conserve freshwater marshes.

Muhs, D. R., K. R. Simmons, R. R. Schumann, and R. B. Halley. 2011. "Sea-level history of the past two interglacial periods: new evidence from U-series dating of reef corals from south Florida." *Quaternary Science Reviews* 30(5-6) 570-590.

Keywords: historic sea level rise, Florida Keys

This research provides new data estimating the timing and degree of sea level rise during the Last Interglacial Period in Florida. The Last Interglacial Period (occurring approximately 120,000 yr ago) is considered to be the last time that global temperatures were warmer than the present. Fossil corals from Key Largo Limestone were aged using uranium radio-dating. Results show that for at least 9,000 years, sea level was higher than the present level during the Last Interglacial Period. Samples from fossil reefs in the Florida Keys show ages of approximately 200 thousand years old, indicating sea levels at or above present day levels. Both the Key Largo Limestone and the Miami Limestone measurements indicate that sea level during the Last Interglacial Period was approximately 6.6 - 8.3m higher than present day sea level.

Obeysekera, J., M. Irizarry, J. Park, J. Barnes, and T. Dessalegne. 2011. "Climate change and its implications for water resources management in south Florida." *Stochastic Environmental Research and Risk Assessment* 25(4) 495-516.

Keywords: modeling, storms, historic sea level rise, Everglades

This work looks at historical records and climate change projections to understand the impacts of climate change on the Everglades ecosystem, as well as the drivers that are most important for influencing that system. Analysis shows no trends in long-term (1913-2008) or recent (1950-2007) rainfall and temperature in Florida. However, global climate models (GCMs) do not capture regional characteristics of rainfall and temperature in this area. Data from Key West indicates an increased frequency and variance of extreme sea level events between 1961 and 2008, when compared to 1913-1960. A sensitivity analysis showed that important drivers for the Everglades ecosystem include rainfall, evapotranspiration, sea level rise along the southern tip, and changes in salinity.

Park, J., J. Obeysekera, M. Irizarry, J. Barnes, P. Trimble, and W. Park-Said. 2011. "Storm surge projections and implications for water management in South Florida." *Climatic Change* 107(1-2) 109-128.

Keywords: Storms, tide gauge, Key West, Pensacola, Mayport

This research analyzed long-term tidal records to determine storm surge occurrence in Key West, Pensacola, and Mayport. The nontidally influenced 50-year return period storm surge was found to be 0.5 m high in Key West, and 1.1 m high in Mayport and Pensacola. Using predicted eustatic sea level rise scenarios and the Atlantic Multidecadal Oscillation (AMO) index, future storm surge return periods were predicted. Forecasts show a significant 'condensing' of the return period of storm surges,

such that a 1-in-50-year storm surge could become a 1-in-5-year storm surge. These results are discussed within the context of water management in Florida.

Saha, A.K., S. Saha, J. Sadle, J. Jiang, M. S. Ross, R. M. Price, S.L.O. Sternberg, and K. S. Wendelberger. 2011. "Sea level rise and South Florida coastal forests" *Climatic Change* 107(1-2) 81-108.

Keywords: modeling, forests, mangroves, inundation, Everglades

This paper proposes that sea level rise will negatively impact coastal hardwood hammocks and buttonwood forests within Everglades National Park prior to actual inundation with seawater. These systems are reliant upon precipitation which provides freshwater to the vadose zone of the soil. The vadose zone is expected to be impacted by saltwater intrusion prior to surface water inundation due to a rising water table and drought conditions. The authors used the mangrove-hammock model (MANHAM) to simulate the response of hardwood hammocks and mangroves to sea level rise. Through this work, 21 species in the Everglades National Park are identified as being threatened by sea level rise. Restoring freshwater inflow to the Everglades is one option to mitigate these effects, at least in the short-term.

Titus, J. G., and C. Richman. 2001. "Maps of Lands Vulnerable to Sea Level Rise: Modeled Elevations Along the U.S. Atlantic and Gulf Coasts." *Climate Research* 18(3) 205-228.

Keywords: remote sensing, inundation, Everglades

Mapping predictions of coastal SLR impacts requires both high resolution elevation data of land and water surfaces as well as models of coastal processes (erosion, marsh accretion, sedimentation, etc.). This paper presents large-scale and small-scale maps of coastal land elevation along the U.S. Atlantic coast and Gulf of Mexico using the highest level of accuracy currently available by combining several data sources. Past limitations of coastal maps are discussed. For example, the widely available 7.5-min USGS quadrangle maps use a wide contour interval (1.5 m) and most are benchmarked by the National Geodetic Vertical Datum (NGVD) from 1929. Using this out-dated benchmark creates a 10-20 cm inaccuracy in these maps. LIDAR can increase accuracy but can be cost-prohibitive. By combining coastal data from USGS and NOAA, the authors estimate that the area of land below the 1.5 m contour in S and SW Florida is actually 8,744 km², almost double the area presented in the 1990 EPA report to congress. This is mainly due to the inclusion of additional NOAA shoreline data and higher estimations of open water in the Everglades than previously used. The report estimates that approximately 1/3 of the Everglades is below 1.5 m and half of Everglades National Park is within 0.3-0.6 m of sea level.

Walton, T. L. 2007. "Projected sea level rise in Florida." *Ocean Engineering* 34 1832-1840.

Keywords: modeling, sea level rise acceleration, sea level rise prediction, tide gauge

This paper addresses the rate of sea level rise in Florida using a model based on historic tide gauge data. It discusses scenarios where sea level rises at a constant rate and scenarios where the rate of sea level rise is accelerating. Tide gauge data from five sites in Florida between 1941 and 2005 are used in to fit a statistical model. The model produced projections for future sea level rise until the year 2080. Three models were compared assuming a first order, second order, and exponential relationship. Results indicate that sea level will rise faster than past projections using straight trend lines. These results also show a maximum sea level rise by 2080 of 0.36 m.

Wanless, H. R., R. W. Parkinson, and L. P. Tedesco. 1994. "Sea level control on stability of Everglades wetlands." Pages 199–224 in S. M. Davis and J. C. Ogden, editors. *Everglades: the ecosystem and its restoration*. St. Lucie Press, Delray Beach, Florida, USA.

Keywords: historic sea level rise, habitat migration, wetland, salinity, Everglades

The Everglades formed over the past 3,200 years during a period of relatively slow sea level rise, a rate averaging 4 cm per 100 y. This slow rate allowed sediments and organic matter to accrete vertically. Prior to this period of wetland formation, sea level rise was faster (23-50 cm per 100 y), which was too fast for the development of stable coastal swamp, marl, or sand ecosystems. Current sea level rise in the Everglades is 3-4 mm y⁻¹ (20-40 cm per 100 y). This increased rate is already impacting the Everglades by accelerating erosion along shore margins, causing landward migration of saline wetlands and increasing saltwater intrusion to surface and ground waters. According to the authors, if sea level rise continues at the present pace, or accelerates, these impacts will worsen and be exacerbated by storms.

Zhang, K. Q., B. C. Douglas, and S. P. Leatherman. 2000. "Twentieth-Century Storm Activity Along the US East Coast." *Journal of Climate* 13 1748-61.

Keywords: storms, tide gauges, Mayport

Speculation that climate change is causing increased storm activity along the U.S. Atlantic coast was investigated using water level data from tide gauges and tropical storm tracking data. Several short-comings of past research indicating an increase in storm frequency and intensity are discussed, such as, 1) the lack of long-term data (the most extensive record previously used was only 25 years), 2) the use of coastal damage reports that do not account for increased coastal development over time, 3) the difficulty in separating the contribution of astronomical tides from storm surges, and 4) the importance of distinguishing tropical storms (hurricanes) from extratropical storms (northeasters). Results indicate that Mayport has a greater occurrence of tropical storms than extratropical storms. There is significant inter-decadal variation in storm activity along the entire East Coast, with the period of greatest storm frequency and intensity occurring from the late-1950s to the early-1960s. This study found no "discernible long-term secular trend in storm activity during the twentieth century."

Zhang, K., J. Dittmar, M. S. Ross, and C. Bergh. 2011. "Assessment of sea level rise impacts on human population and real property in the Florida Keys." *Climatic Change* 107(1-2) 129-146

Keywords: remote sensing, sea level rise prediction, inundation, Florida Keys

Remote sensing using LIDAR and digital elevation maps (DEM) were used to estimate the inundation of the Florida Keys in 2100 under current sea level rise predictions. The simulation shows a 0.6 m rise in sea level would inundate 70% of the Key's land area, and a 1.5 m rise in sea level would inundate 91% of the land area. Inundation of populated areas and implications for real estate are discussed. Results indicate the lower Keys are more vulnerable to sea level rise than the upper Keys. Nonlinear behavior of sea level rise inundation and tipping points are highlighted by the authors.

Zhang, K. 2011 "Analysis of non-linear inundation from sea-level rise using LIDAR data: a case study for South Florida." *Climatic Change* 106(4) 537–565.

Keywords: sea level rise prediction, inundation, remote sensing, Everglades, Miami-Dade County, Broward County, Palm Beach County

Remote sensing, using LIDAR digital elevation maps (DEM), was used to estimate the areas of Miami-Dade County, Broward County, Palm Beach County, and Everglades National Park inundated under predicted sea level rise. Sea level rise scenarios of 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 m by 2100 were considered. Results show inundation occurring at a non-linear rate due to regional topography. Thresholds, or tipping points, occur when sea level rise reaches 1.25, 1.5 and 3.0 m in height. The author also compares the predictions of inundation using the two different elevation data sets available. The resolution of USGS DEM data resulted in 1.65 times more land inundation under the 1.5 m scenario than when the LIDAR data was used. Miami-Dade County was shown to be the most vulnerable area to sea level rise, followed by Broward and then Palm Beach Counties. Results indicate catastrophic inundation in Miami-Dade and the Everglades National Park if sea level rises by 1.5 m.

Biological Sciences

Aiello-Lammens, M. E., M. L. Chu-Agor, M. Convertino, R. A. Fischer, I. Linkov, and H. R. Akcakaya. 2011 "The Impact of Sea-Level Rise on Snowy Plovers in Florida: Integrating Geomorphological, Habitat, and Metapopulation Models." *Global Change Biology* 17(12) 3644-54.

Keywords: threatened and endangered species, wildlife habitat, modeling, Gulf of Mexico

The Snowy Plover (*Charadrius alexandrinus*) is a small shorebird that is listed as "Threatened" in Florida. It lives and breeds on sandy beaches, salt flats, and river bars along the Gulf of Mexico. To assess the potential impact of sea level rise on suitable habitat for the Snowy Plover, the authors combined three types of computer models: a geomorphological model called SLAMM (Sea Level Affecting Marshes Model), a habitat model, and a demographic model (which included species-specific factors such as carrying capacity, density-dependence, and dispersion). The model output predicts an increase in the probability of Snowy Plover extinction by 2100 from the current probability estimate of 7%, to a 9 and 11% probability under scenarios of 1 m and 2 m sea level rise, respectively. The model also predicts a decline in the minimum abundance of Snowy Plovers in 2100 from the current estimate of 97 individuals, to 77 individuals with a 1 m rise in sea level, and 70 individuals with a 2 m rise in sea level. This paper demonstrates the applications of using linked models for predicting species vulnerability to sea level rise, but warns the model output includes significant uncertainty about the role of survival rate and fecundity in the predictions.

Chambers, L. G., K. R. Reddy, and T. Z. Osborne. 2001. "Short-Term Response of Carbon Cycling to Salinity Pulses in a Freshwater Wetland." *Soil Science Society of America Journal* 75(5) 2000-2007.

Keywords: wetlands, greenhouse gases, salinity

The wetlands that fringe the coast of Florida are very productive, accumulating large amounts of carbon stored in the organic-rich soils of these ecosystems. As sea level rises, saltwater is encroaching inland and has the potential to change the biology of the wetland soils (especially the microbial populations that live in the soil). A change in soil microbial communities could reduce the stability of the accumulated carbon, subsequently releasing it into the atmosphere and adding to the concentration of

atmospheric carbon dioxide (CO₂), a greenhouse gas. Using organic wetland soils collected near Cape Canaveral, this study shows that the chemical composition of saltwater (especially sulfate, a major ion in seawater) can accelerate the activity of some microbial populations in the soil, increasing the rate at which carbon is released from the soil in the short-term. When looking at the soil microbial community as a whole, the intrusion of low-salinity saltwater could cause the greatest increase in the rate of carbon loss from wetland soils because microbial activity is stimulated while the impact of salt-stress is still minimal.

Coleman F. C. and C. C. Koenig. 2010. "The effects of fishing, climate change, and other anthropogenic disturbances on red grouper and other reef fishes in the Gulf of Mexico." *Integrative and Comparative Biology* 50(2) 201–212.

Keywords: wildlife habitat, water quality, fisheries, habitat migration

This study investigates how anthropogenic disturbances affect three fish species in the Gulf of Mexico: the shallow-water Atlantic goliath grouper (*Epinephelus itajara*), the red grouper (*Epinephelus morio*), and the tilefish (*Lopholatilus chamaeleonticeps*). Each of these species is considered an ecosystem engineer, or foundation species. Disturbances of greatest concern to the fisheries in the Gulf of Mexico are over fishing, red tides, oil and gas extraction/exploration, and climate change. With respect to climate change, sea level rise in particular may alter the biogenic foundation species or the autogenic ecosystem engineers. Because of the accelerated pace of sea level rise relative to historical changes, these foundation species may not be able keep pace with sea level rise by migrating landward. Rising temperatures due to climate change may also cause shifts ocean currents, nutrient availability, or larval success, and subsequently negatively impact these species' recruitment.

Desantis, L. R. G., S. Bhotika, K. Williams, and F. E. Putz. 2007. "Sea-Level Rise and Drought Interactions Accelerate Forest Decline on the Gulf Coast of Florida, USA" *Global Change Biology* 13(11) 2349-2360.

Keywords: forests, biological indicator, habitat migration, salinity, Big Bend

This paper documents the continuation of a 13-year study of declining coastal forest habitat near Waccassasa Bay in the Big Bed region of Florida (also reported on in Williams et al., 1999 and 2003). Sea level rise in this area averaged 2.4 mm y⁻¹ from 1939 to 2005. Increasing tidal flooding and decreasing relative elevation is strongly correlated with a decline in forest species richness. Cabbage palm (*Sabal palmetto*) is the most salt-tolerant tree species in this area, but was unable to survive when flooding frequency met or exceeded 46% of weeks in a given year. Southern red cedar (*Juniperus virginiana*), the second most salt-tolerant species, was eliminated when flooding frequency reached 23% of the weeks in a given year. The drought associated with La Niña (1998-2002) intensified water stress in all tree species, but was especially damaging to those trees already experiencing increased tidal flooding.

Fei, S. L., J. Cox, and A. Whittle. 2011. "A Perfect Storm May Threaten Florida Panther Recovery." *Frontiers in Ecology and the Environment* 9(6) 317-18.

Keywords: threatened and endangered species, wildlife habitat, Southwest Florida

Although habitat loss and fragmentation due to human development remains the leading cause of the decline of the Florida Panther (*Puma concolorcoryi*), sea level rise also poses a risk to the long-term survival of the species. Panther habitat, which is concentrated in southwest Florida, is low-lying and has a maximum elevation of about 12 m above sea level. Under conservative sea level rise estimates (0.6 m by 2100), about 10% of the current Panther habitat would become inundated. Under the 2 m by 2100 scenario, about 33% of Panther habitat would be lost. The author encourages the consideration of sea level rise impacts when developing wildlife corridors and protected areas in SW Florida.

Gaiser, E. E., A. Zafiris, P. L. Ruiz, F. A. C. Tobias, and M. S. Ross. 2006. "Tracking Rates of Ecotone Migration Due to Salt-Water Encroachment Using Fossil Mollusks in Coastal South Florida." *Hydrobiologia* 569(1) 237-257.

Keywords: habitat migration, biological indicator, salinity, wetland, mangroves, historic sea level rise, Biscayne Bay

Saltwater intrusion and changes in the management of freshwater supplies since the 1900s in south Florida have altered the salinity regime of Biscayne Bay's coastal wetlands. Interested in the migration of coastal ecotones (the transition area between two different types of ecosystems or habitats) over the time, this study used mollusk community composition as a biological indicator for paleo-environmental conditions. Two-meter deep sediment cores were collected throughout the coastal wetlands and analyzed for relic mollusk shells, soil characteristics, and the distribution of carbon and lead isotopes (used to date the soil). The study indicates increasing soil depth in the mangrove fringe, compared to the inland freshwater marsh, which is considered to be a result of higher sedimentation and accretion rates in the mangrove habitat. Mollusk species composition was a reliable indicator of historic salinity in the region. The study also concludes that the ecotone between mangroves and freshwater marshes has been migrating landward at a rate of 2 to 4 m per year, 1-2 orders of magnitude faster than the migration rate prior to 1940. This equates to a 450 m westward expansion of the mangrove habitat, at the expense of the freshwater marsh habitat, in the past 60 years. Mangrove habitat in this area appears to be keeping pace with sea level rise through vertical accretion, and is even expanding landward.

Maschinski J, M. S. Ross, H. Liu, J. O'Brien, E. J. von Wettberg, and K. E. Haskins 2011. "Sinking ships: conservation options for endemic taxa threatened by sea level rise." *Climatic Change* 107(1/2) 147–167.

Keywords: threatened and endangered species, wildlife habitat, Florida Keys

This study evaluated options for conserving rare and endemic species in the face of sea level rise using the Florida Keys as a model system. The Florida Keys face a significant risk of inundation with rising sea level and a loss of habitat that is critical for several threatened species. This paper investigates the conservation options for two species of plants: the Big Pine partridge pea (*Chamaecrista lineata*) and sand flax (*Linum arenicola*) as well as two species of animals: the Key deer (*Oedocoileus virginianus clavium*) and the Lower Keys marsh rabbit (*Sylvilagus palustris hefneri*). The authors advocate for a diverse multi-tiered approach to conservation where short-term and long term strategies are implemented.

Pearlstine, L. G., E. V. Pearlstine, and N. G. Aumen. 2010. "A review of the ecological consequences

and management implications of climate change for the Everglades." *Journal of the North American Benthological Society* 29(4) 1510–1526.

Keywords: threatened and endangered species, wildlife habitat, Everglades

Florida's Everglades is home to 36 vertebrate species and 26 plant species that are listed as endangered, threatened, or candidate species on the Federal Endangered Species Act. This paper presents general ecosystem responses to climate change and sea level rise. It describes the vegetation communities of the Everglades National Park. It also discusses peatlands, carbon sequestration, fishes, amphibians, reptiles, birds, evolutionary adaptation, and presents adaptive conservation strategies. Some of these strategies include restoration; reducing anthropogenic stresses; habitat conservation; assisted propagation, breeding, and migration; the utility of captive populations; and accepting change.

Rizkalla CE, and A. Savage. 2011. "Impact of seawalls on loggerhead sea turtle (*Caretta caretta*) nesting and hatching success." *Journal of Coastal Research* 27(1) 166–173.

Keywords: threatened and endangered species, coastal armoring, beaches

This paper investigates the effects of seawalls on loggerhead turtle nesting and hatching success. The impact of armoring structures is relatively well understood with respect to beach ecosystems. However, the impact of sea walls on sea turtle nesting is less clear. To investigate this question, the authors observed sea turtle nesting behavior at a seaward wall and a landward wall in Florida. Nesting patterns indicate that the erosion at seawalls decreases the number of turtles that attempt to nest in that area. Additionally, the nests that are constructed by seawalls are more at risk for washing away in storms. As sea level rise threatens human development along the coast protective measures, such as armoring the shoreline with seawalls, is expected to increase. According to the authors, this will likely decrease the area of suitable nesting habitat for loggerhead turtles, an endangered species.

Ross, M. S., J. F. Meeder, J. P. Sah, P. L. Ruiz, and G. J. Telesnicki. 2000. "The Southeast Saline Everglades Revisited: 50 Years of Coastal Vegetation Change." *Journal of Vegetation Science* 11(1) 101-112.

Keywords: habitat migration, salinity, wetlands, mangroves, biological indicator, Everglades

In the 1940's, a transitional zone of low vegetation productivity (dubbed the 'white zone' due to the exposure of bare soil) was identified in aerial photographs of the southeastern Everglades. Vegetation in this region occurs in belts parallel to the coastline that are defined mainly by the plant species' tolerance to salinity. The lower belt (nearest the coast) is dominated by red mangroves (*Rhizophora mangle*) and rushes (*Eleocharis spp.*), followed by the white zone where mangrove propogules are sparse and bare soil abounds, and finally upper belt, dominated by Sawgrass (*Cladium jamaicense*). Using the white zone as a proxy for the location of the saltwater boundary, this paper compares the location of that boundary in 1940 to the location in the mid-1990s using aerial photographs. Results indicate that the interior boundary of the white zone has migrated landward an average of 1.46 km, correlating with the rate of sea level rise recorded using tide gauges in Key West. This suggests that sea level rise has altered coastal vegetation patterns over the past 50 years, as well as related processes, such as soil accretion. The paper also documents localized differences in the rate of landward migration of the white zone based on local freshwater management activities. For example,

canal systems that limit freshwater delivery increase the rate of landward movement of the white zone.

Roy, Moutusi, J. B. Martin, J. Cherrier, J. E. Cable, and C. G. Smith. 2010. "Influence of sea level rise on iron diagenesis in an east Florida subterranean estuary." *Geochimica et Cosmochimica Acta* 74(19) 5560–5573.

Keywords: water quality, groundwater, salinity, Indian River

Subterranean estuaries are a transition area between hypoxic fresh groundwater and oxic sea water. It is hypothesized in this paper that iron (Fe) reactions will change as a result of sea level rise and the oxic saltwater that it will introduce. Using samples from porewater and sediments in the Indian River lagoon and a site 250 m offshore, concentrations of Fe, sulfur, and dissolved organic carbon were measured. Iron concentrations increased from 0.5 μM to 286 μM between the shoreline and the freshwater/saltwater boundary. In the Indian River lagoon, Fe transformation generally occur at the freshwater/saltwater boundary and may be important for primary productivity. Long-term changes in the location of the boundary (due to sea level rise) may have a significant effect on local geochemistry by increasing the flux of Fe and possibly increasing ecosystem productivity.

Seavey, J. R., W. E. Pine, III, P. Frederick, L. Sturmer, and M. Berrigan. 2011. "Decadal Changes in Oyster Reefs in the Big Bend of Florida's Gulf Coast." *Ecosphere* 2(10):114 1-14.

Keywords: fisheries, salinity, Big Bend

The coastal zone along the Big Bend of Florida supports an established and highly productive area of oyster reefs with great economic and ecological importance. This study uses aerial photographs of the coastal zone from 1982 to 2010 to assess the health and size of oyster reefs in four key areas. Results indicate a significant decline in the size of all the reefs investigated, with offshore reefs (1000 to 2600 m from shore) losing the greatest area (88%), followed by nearshore reefs (140 to 1000 m offshore; 61% decline) and inshore reefs (0 to 140 m offshore; 50% decline). The low density development of the area and harvest regulations enacted in 1987 reduces the likelihood that human damage is the major cause for the observed decline. The authors hypothesize that increased sea level (tide gauges documented a 5 cm rise in the study area over the 28 year period) may have increased salinity, especially on the offshore reefs, encouraging more predation and possibly increasing sedimentation and wave energy, leading to the decline of the oyster reefs.

Willard, D.A. and C. E. Bernhardt. 2011. "Impacts of past climate and sea level change on Everglades wetlands: placing a century of anthropogenic change into a late-Holocene context." *Climatic Change* 107(1-2) 59-80.

Keywords: historic sea level rise, wetlands, biological indicator, habitat migration, Everglades

Historical sea level rise, climate variability, and anthropogenic changes are evaluated in reference to their impacts on hydrology and wetland plant ecology in the Everglades. The Everglades was formed by the accumulation of freshwater peat 6-7 thousand years ago when sea level was 6.2 m below its' present level. By 5,000 years before present the area from Lake Okeechobee to the Florida Keys was covered with peat formed by sawgrass and water lily communities. Three thousand years ago sea level rise slowed, the coastline of south Florida stabilized, and mangroves communities developed along the coast. Evidence from pollen shows that regional droughts occurring 400 to 1,000 years ago

initiated the development of the ridge/slough topography and tree islands that we see today. Recent anthropogenic changes to the Everglades hydrology via flow alterations, wetland compartmentalization, and sea level rise, have resulted in unprecedented rates of change in the ecosystem. Evidence of these changes can be seen in soil oxidation, soil subsidence, and the alteration or loss of specific habitats and vegetation.

Williams, K., K. C. Ewel, R. P. Stumpf, F. E. Putz, and T. W. Workman. 1999. "Sea-Level Rise and Coastal Forest Retreat on the West Coast of Florida, USA." *Ecology* 80(6) 2045-2063.

Keywords: forests, habitat migration, biological indicator, Big Bend

The Big Bend region of Florida consists of a low-lying carbonate coast with minimal human disturbance. Since the 1930s, changes in the composition and coverage of coastal forest communities have been documented, including shrinking tree islands within the coastal marshes and the landward retreat of the coastal forest edge. This study tested the hypothesis that forest community changes are a result of sea level rise and the differential flooding and salt tolerance of local plant species. Results indicate a negative correlation between tidal flooding frequency, tree species richness, and tree recruitment success. Coastal forests are developing a zonation pattern based on the salt tolerance of seedlings, with mature trees remaining viable long after regeneration has ceased in some stands. This is because older plants are able to tolerate more salt and flooding stress than seedlings. According to the authors, the rate of forest retreat in this area is generally consistent with the rate of local sea level rise.

Williams, K., M. MacDonald, and L. D. L. Sternberg. 2003. "Interactions of Storm, Drought, and Sea-Level Rise on Coastal Forest: A Case Study." *Journal of Coastal Research* 19(4) 1116-21.

Keywords: forests, storms, Big Bend

Conducted at the same sites along the Big Bend coastline as the Williams et al. (1999) study, this paper addresses the impact of storms and severe droughts on coastal forest mortality. A 1993 storm, which was accompanied by a 2-3 m storm surge and high winds, was shown to be more damaging to southern red cedar (*Juniperus virginiana*) populations than to the co-dominant cabbage palm (*Sabal palmetto*). The storm-related increase in mortality of *Juniperus* lasted for 2 years following the storm. The storm up-rooted trees, deposited ~2 mm of sandy silt, left piles of wrack, and caused the erosion of loose soil. The drought also appeared to target *Juniperus*, causing increased mortality, especially in areas of previously documented decline due to sea level rise.

Social Sciences

Bloetscher F., D. E. Meeroff, B. N. Heimlich, A. R. Brown, D. Bayler and M. Loucraft. 2010. "Improving resilience against the effects of climate change." *Journal American Water Works Association* 102(11) 36-46.

Keywords: utilities, groundwater, Miami-Dade County, Broward County

This paper summarizes a history of freshwater supply challenges in southeast Florida. Despite receiving a high 60 inches of rain per year, 70% of that rain occurs during only 4 months of the year (June-Sept.). Water storage is made difficult by the low topography (over 50% of the urban areas of Miami-Dade and Broward counties are > 5ft above mean sea level), a high water table, and competing

demands- a population of 5 million people and the Everglades, which require significant freshwater flow to remain healthy. The development of SE Florida was made possible by reducing groundwater levels through the construction of extensive canals, pumping stations, and water control structures. Increasing sea level rise in this highly porous geology will be accompanied by a higher groundwater table, leading to more extensive flooding during rain events and a higher risk of seawater contaminating the Biscayne Aquifer, the freshwater source for the urban residents. The authors outline several ideas of how water utilities (portable water supply, wastewater, and stormwater) in SE Florida may be able to adapt to sea level rise while still meeting the demands of urban residents and natural areas. The concepts discussed focus on minimizing saltwater intrusion and maintaining adequate freshwater supply. Ideas are presented as an “adaptation toolbox” and include stormwater pumping stations, increased funding for water conservation program, armoring the sewer system to prevent saltwater inflow and relocating high risk wellfields.

Bloetscher, F., D. E. Meeroff, B. N. Heimlich, A. R. Brown, F. Bayler, G. Tim, N. Wood, and B. Yarnal. 2010. “Stakeholder perspectives on land-use strategies for adapting to climate-change-enhanced coastal hazards: Sarasota, Florida.” *Applied Geography* 30(4) 506-517.

Keywords: land use planning, citizen involvement, storms, Sarasota

Sustainable land use planning must account for a number of stressors, including population growth, extreme climatic events, and sea level rise. This research investigates land use planning considerations through the implementation of a community workshop in Sarasota County. Participants in the workshop represented a broad spectrum of stakeholders, including individuals from business, environmental interests, emergency management, government, and planning. Citizens were divided into focus groups where they conducted mapping exercises using the county’s current 2050 comprehensive land use plan. Present and projected storm surge hazard areas based on various sea level rise scenarios were discussed. Common agreement was reached on the need to increase resilience to storm surge hazards and explore alternatives for dealing with future projections of storm surge hazard zones.

Choate, J. F. 2011. “Sea Level Rise Planning for Florida’s Nuclear Energy Infrastructure: A Wait and “Sea” Approach?” *Sea Grant Law and Policy Journal* (4)1, 28-49.

Keywords: inundation, utilities

This paper investigates the risks associated with sea level rise on existing and proposed nuclear power plants in Florida. Federal, state, and local permitting processes for nuclear power plants in Florida are discussed. The locations of current and planned nuclear power plants are described and the inclusion of sea level rise considerations in those plans is investigated. Existing tools and strategies for responding to sea level rise are also reviewed. According to the author, state agencies are discussing moving sites for nuclear power plants inland in preparation for sea level rise. On the other hand, the Federal Nuclear Regulatory Commission was found lacking in its planning for sea level rise and the author asserts that the sea level rise scenarios used by the commission may be too conservative.

Christie, D.R. 2009. “Of Beaches, Boundaries, and SOBs.” *Journal of Land Use Planning and Environmental Law* 25(19) 58-59.

Keywords: legislation, beaches, beach renourishment, private property rights

Florida's Beach and Shore Preservation Act (BSPA) is discussed in detail, including the rationale behind the act, the rights of the state, and the rights of private property owners. The provisions of the Act are similar to common law in terms of the protection of coastal property rights and access to water, but the Act also strives to establish a fixed boundary between private lands and public lands. The Act allows the state government to restore and renourish beaches. This change was prompted by constant beach erosion, which highlighted for policy makers the vulnerability of coastal populations and the state's beach-based economy. The article highlights that setting a fixed boundary on restored beaches between private and sovereign land would serve to unequivocally establish areas for public beach access. The author recognizes that private land ownership fosters a sense of stewardship, but argues that local governments must take responsibility for regulating and managing the use and access of beaches before conflicts occur.

Christie, D. R. 2011. "Sea Level Rise and Gulf Beaches: The Specter of Judicial Takings." *Journal of Land Use Planning and Environmental Law* 26(2) 313-325.

Keywords: legislation, beaches, beach renourishment, private property rights

The question of whether the Beach and Shore Preservation Act's (BSPA) authorization of government-run beach renourishment projects constitutes a regulatory taking of common law property rights is discussed in this article. When the Florida Supreme Court upheld the BSPA's abrogation of the common law right of accretion to private property, it did so on the grounds that accretions are a future contingent right not implicated by the Act's renourishment provisions. It also asserted that the common law right of access to the water is explicitly preserved under the BSPA. The case was then taken to the U.S. Supreme Court in *Stop the Beach Renourishment, Inc. v. Florida Department of Environmental Protection*. The U.S. Supreme Court also upheld the validity of the Act, but Justice Scalia raised the issue that there should be no distinction under the Fifth and Fourteenth Amendment Takings Clauses between what constitutes a traditional taking, and what constitutes a regulatory taking by act of government regulation. With the regulatory takings test in favor of government regulation, Justice Scalia's suggests that the Supreme Court may adopt a less favorable regulatory takings test in the future, which would impose a massive financial burden on the states.

Fischman, A. 2012. "Preserving Legal Avenues for Climate Justice in Florida Post-American Electric Power." *Florida Law Review* 64 295-304.

Keywords: legislation, vulnerability, greenhouse gases

In *American Electric Power Co. v. Connecticut*, the U.S. Supreme Court ruled that the Clean Air Act and EPA regulations preempted any federal common law right to force coal-burning power plants to reduce carbon dioxide emissions that are directly related to global warming and sea level rise. The Court did not, however, address state common law causes of action. Populations in Florida are particularly susceptible to sea level rise and may be interested in legal pathways to force mitigation of climate change. This could include participating in the administrative rulemaking process to limit carbon emissions. However the ruling currently does not address higher magnitude harm that climate-vulnerable populations are likely to face under increasing sea level rise. According to the author, Florida courts may be able to facilitate compensation and relocation for climate-vulnerable populations by upholding claims under state common law nuisance principles.

Frazier, T.G., N. Wood, B. Yarnal and D.H. Bauer. 2010. "Influence of potential sea level rise on societal vulnerability to hurricane storm-surge hazards, Sarasota County, Florida." *Applied Geography* 30 490-505.

Keywords: vulnerability, storms, land use planning, utilities, Sarasota

Current research is split on whether recently observed hurricane frequency is related to climate change or simply multi-decad variations. Regardless, sea level rise is predicted to increase the land area and population in the hazard-zone for storm surges. This paper investigated how the current storm-surge hazard zones in Sarasota County would need to be changed to account for a 120 cm increase in sea level. The authors found that a 120 cm increase in sea level will double the size of the population and number of municipal utilities at risk from a storm surge. Additionally, the current hazard zone for each category of hurricane could roughly be applied to the category beneath it under future sea level conditions (e.g., the zone delineated as hazardous for a category 2 hurricane will be at risk for a category 1 hurricane under predicted sea level rise).

Jancaitis, K. M. 2008. "Florida on the Coast of Climate Change: Responding to Rising Seas." *Environs: Environmental Law and Policy Journal* 31 157-194.

Keywords: land use planning, vulnerability, greenhouse gases

Florida's vulnerability to sea level rise through the loss of land, infrastructure, coastal ecosystems, natural buffers, agriculture, and tourist revenue are discussed in this article. The author suggests the need for a combination of coping methods including prevention, mitigation, and adaptation to adequately address the problem of sea level rise in Florida effectively and efficiently. The paper also asserts the need to prevent future sea level rise by reducing greenhouse gas emissions through the creation of a carbon tax, developing alternative energy resources, and increasing energy efficiency. The use of forests and wetlands as carbon sinks could also be help to reduce atmospheric greenhouse gas concentrations. According to the author, advanced planning is essential, including infrastructure protection, the creation of coastal wetland buffer zones, and decreasing coastal development practices. Utilizing alternative land management practices will allow for adaptations to sea level rise, but complete abandonment of high-risk property may also be necessary.

Martin, J., P. Fackler, J. Nichols, B. Lubow, M. Eaton, M. Runge, B. Stith, and C. Langtimm. 2011. "Structured decision making as a proactive approach to dealing with sea level rise in Florida." *Climatic Change* 107(1) 185-202.

Keywords: land use planning, modeling, threatened and endangered species

This research applies structured decision making (SDM) to the management and conservation challenges facing Florida due to sea level rise. SDM presents a decision analytical framework that allows a rigorous format for natural resources management. SDM's goal is to identify optimal decisions given current knowledge and management objectives. Whereas most applications of SDM are to stationary systems, this research acknowledges the non-stationary reality of the sea level rise problem. As such, management objectives may change and uncertainty exacerbated. This particular application of SDM provides a quantitative model for species management focusing on the Florida manatee. In this model a wetland provides both water for agriculture and habitat for the manatee. The objectives of the model

are to maximize the outflow for agricultural purposes and at the same time provide a minimum area of habitat.

Marshal, A., L. Robinson and M. A. Owens. 2011. "Coastal construction trends in response to coastal erosion: an opportunity for adaptation." *Journal of Coastal Conservation*, (15)1 61-72.

Keywords: beaches, private property rights, beach renourishment, Apalachicola

Half of the sandy beaches in coastal Florida are classified as critical erosion areas. This article investigates how trends in coastal development have responded to the designation of these critical erosion areas. Coastal construction permitting trends between 1987 and 2007 were analyzed spatially and temporally. Three counties: Frank, Gulf, and Bay were selected for study based on their proximity to the Apalachicola National Estuarine Research Reserve. The study concludes that clusters of coastal development have not been reduced or redirected based on a designation as a critical erosion area. The practice of beach nourishment in Florida requires that the beach to be nourished lies within a critical erosion designation. According to the author, this implies that the designation may be subject to external pressures from property owners and governments.

Nolan, J. R. and Bacher, J. 2007. "Zoning and Land Use Planning." *Real Estate Law Journal* 38 211-238.

Keywords: land use planning, citizen involvement

This paper describes the benefits of developing a local citizen-based task force to assist in addressing land use and zoning consideration in communities facing climate change impacts. According to the authors, the task force should be composed of representatives from all stakeholders in the community, and should allow for public participation. Examples of such task forces include: 1) the Miami-Dade Climate Change Advisory Task Force (est. 2006), which advises and provides technical assistance to Board of County Commissioners on issues such as county management, zoning, infrastructure, and planning and 2) the Governor's Action Team on Energy and Climate Change (est. 2007), which reports on adaptation strategies to climate change that minimize adverse impacts on society, public health, the economy, and the natural environment. The authors recommend that all local governments in Florida consider sea level rise in any land use changes occurring at an elevation < 10 ft above sea level, that high resolution topographic maps be created with detailed 1-ft intervals, and that long-term implications of planning strategies be considered instead of the usual 10 to 20 year time frame.

Noss, R. F. 2011. "Between the devil and the deep blue sea: Florida's unenviable position with respect to sea level rise." *Climatic Change* 107(1-2) 1-16.

Keywords: citizen involvement, vulnerability

This paper introduces a special edition of the Journal, "Climatic Change" that includes a series of articles on the impacts of sea level rise on Florida. The special edition is largely the results of a symposium held in 2010 held at the Archbold Biological Station sponsored by the Florida Institute for Conservation Science. Symposium participants concluded that planning for sea level rise should incorporate both anthropogenic and natural issues in concert. The author states that to date, literature has largely focused on rising temperatures and decreasing moisture rather than sea level rise. The author goes on to conclude that the main lesson to be learned from the research in this special edition is

that sea level rise, population growth, development in coastal areas, and habitat fragmentation all make human and natural systems very vulnerable in the state of Florida.

Pace, N.L. 2011. "Wetlands or Seawalls? Adapting Shoreline Regulation to Address Sea Level Rise and Wetland Preservation In the Gulf of Mexico." *Journal of Land Use Planning and Environmental Law* 26(2) 328-29.

Keywords: legislation, beaches, beach renourishment, private property rights, coastal armoring, wetlands

This report summarizes the ongoing debate in Florida between private property owners and the government regarding beach-front development, shoreline protections, and public access. Private property owners are increasingly installing hard coastal armament (seawalls, bulkheads, etc.) to protect their land against erosion and storms, but the state is beginning to limit permits for such armoring in favor of protecting wetlands and natural lands. The author asserts that hard structures will have immense long-term ecological effects along the Gulf of Mexico by accelerating the loss of wetlands and estuarine habitats that provide critical ecosystem services. The paper discusses the current approach to shoreline protection (hard structures) and introduces an alternative, called "living shorelines," as a method of protecting the coast using natural systems. The paper discusses some of the legislation pertaining to this issue, such as Florida's Coastal Construction Control Line, an effort to regulate buildings on coastal properties, and the *Stop the Beach Renourishment, Inc. v. Dep't of Env'tl. Prot.*, 130 S. Ct. 2592 (2010) case, in which the U.S. Supreme Court denied beachfront property owners an injunction against the state for beach renourishment of submerged land. The author asserts that disputes involving Florida shoreline regulation are likely to increase as the effects of sea level rise become more serious.

Parkinson, R. and T. McCue. 2011. "Assessing municipal vulnerability to predicted sea level rise: City of Satellite Beach, Florida." *Climatic Change* (107)1 203-223.

Keywords: vulnerability, citizen involvement, utilities, inundation, Satellite Beach

The City of Satellite Beach authorized a study in 2009 to assess municipal vulnerability to sea level rise and potential adaptations. This paper describes the methods used by the City to assess its vulnerability. One year after the study, an adaptation strategy was presented to the City Council. A public outreach campaign was undertaken during the project that targeted decision makers and local stakeholders. A project team was formed, public forums held, a sea level rise sub-committee established, and the media involved. Municipal vulnerability was investigated through an inundation model and mapping critical assets and infrastructure. Results suggest that a tipping point exists when sea level rise reaches 0.6 above the present level. In response to these findings, it is recommended that the City's Comprehensive Management Plan be updated to account for sea level rise projections.

Peloso, M. E. and M. R. Caldwell. 2011. "Dynamic Property Rights: The Public Trust Doctrine and Takings in a Changing Climate." *Stanford Environmental Law Journal* 30(1) 51-120.

Keywords: legislation, beaches, private property rights, coastal armoring, beach renourishment

Several court cases have recently been filed along the Gulf of Mexico that highlight the current struggle between coastal property owners and the public trust in determining how to best protect

eroding shorelines. The state, as the holder of the public trust, has the right to limit coastal development, but must also use care to avoid the liability of a regulatory takings suit. This paper describes the current legislation protecting both parties. In Florida, the public trust doctrine is codified in Article X, Section 11 of the Florida Constitution. It declares that the state has sovereignty over submerged lands and coastal land up to the mean high water line. The doctrine also recognizes the public right to navigation, bathing, fishing, and reasonable access to the beach. On the opposite side, coastal property owners have the right to unrestricted water access, unobstructed water views, and any land added by accretion or water recession. The friction between the two sides arises when the state takes action to preserve the shoreline through beach renourishment activities or by restricting the construction of coastal armament on private property. Under the Beach and Shore Preservation Act, beach renourishment projects can potentially diminish the rights of coastal property owners by setting new property lines for erosion control. The authors argue for the need of adaptive management techniques to balance the rights of the state with the rights of private property owners in future conflicts that are expected to arise with increasing sea level and storm activity.

Ruppert, T. 2011. "Reasonable Investment-Backed Expectations: Should Notice of Rising Seas Lead to Decreased Expectations for Coastal Property Owners?" *Journal of Land Use Planning and Environmental Law* 26(2) 239-276.

Keywords: land use planning, private property rights, legislation

The balance between the rights of property owners and the responsibility of state and local governments to promote the health, safety, and welfare of the community is a matter of great importance in Florida in light of coastal hazards and sea level rise. Regulations intended to safeguard coastal communities by restricting the use of private property may require compensation to property owners, thereby stifling attempts to adapt to sea level rise. In part, the current legal standard for invoking a regulatory takings claim is whether the regulation conforms to the property owner's reasonable investment-backed expectations at the time of purchase. Factors in determining reasonable investment-backed expectations are dynamic, but generally revolve around whether the property owner should have anticipated the regulation in light of the regulatory atmosphere at the time of purchase, and whether the owner knew of the problem that the regulation seeks to redress. Mandatory notice to property purchasers of the risks involved in purchasing coastal property, including regulatory regimes in place and hazards unique to coastal properties may be able to shape the reasonable investment-backed expectations of coastal property owners. The author contends that if the notice is sufficient, mandatory, and enforceable, regulatory takings claims can be diminished.

Titus, J.G., D. E. Hudgens, D. L. Trescott, M. Craghan, W. H. Nuckols, C. H. Hershner, J. M. Kassakian, C. J. Linn, P. G. Merritt, T. M. McCue, J. F. O'Connell, J. Tanski and J. Wang. 2009. "State and local governments plan for development of most land vulnerable to rising sea level along the US Atlantic coast." *Environmental Research Letters* 4 1-7.

Keywords: coastal armoring, habitat migration

According to the authors, the two general responses to sea level rise are shoreline protection and retreat. Since most property owners and land use planners along the U.S. Atlantic coast have yet to decide how they will respond to sea level rise, this paper uses existing land use maps, land use plans, regulations, and policies to develop a baseline scenario of how coastal development will proceed with a "business as usual" model. The specific goal was to estimate the quantity and location of coastal land

we can expect to follow the “protection” response by adding coastal armoring to protect against sea level rise. Collecting information from 131 jurisdictions from Massachusetts to Florida, coastal land was placed in one of 4 categories depending on their likeliness of coastal protection/armoring. These categories were: developed land (most likely), intermediate (likely), undeveloped (unlikely), and conservation (least likely). Along Florida’s Atlantic coast, 65% of land was developed, 10% intermediately developed, 12% undeveloped, and 13% in conservation. The authors further argue that the importance of changing the policies of the Clean Water Act to recognize that shoreline protection does cause a significant ‘cumulative environmental impact’ by preventing the landward migration of aquatic habitats. Using their assumptions for coastal armoring and the existing laws, the authors assert that we can expect 75% of the Florida Atlantic coast to follow the shoreline protection response to sea level rise.

Wilkins, J. 2011. “Is Sea Level Rise “Foreseeable”? Does It Matter?” *Journal of Land Use Planning and Environmental Law* 26(2) 437-501

Keywords: legislation, land use planning, private property rights, inundation, utilities

Florida’s waiver of sovereign immunity in certain circumstances has allowed private citizens to sue the State for flood damage caused by state action. Several cases are discussed in this paper in which the courts judged the State as liable or not liable for the flooding of private property. Factors considered in these decisions included: 1) whether the State owns the facilities that caused the flood private property (e.g., stormwater drainage systems), 2) whether the flooding has caused a substantial deprivation of beneficial use of the property, 3) whether sovereign immunity has been waived or reserved, and 4) whether the flooding was caused by planning decisions or ministerial functions. Florida’s Local Government Comprehensive Planning and Land Development Regulation Act contains policies applicable to land use planning in coastal areas, including how to limit development in high-hazard areas and safeguard human life from natural disasters. In spite of this, development persists in hazardous areas. The author asserts that if sea level rise and other coastal hazards are not taken into account in local land use planning decisions, it is possible that the decision could be challenged as being inconsistent with the Act, giving rise to liability for the foreseeable impacts of sea level rise.

Wyman, J. B. 2010. “In States We Trust: The Importance of the Preservation of the Public Trust Doctrine in the Wake of Climate Change.” *Vermont Law Review* 35 507-514

Keywords: legislation, beaches, private property rights, beach renourishment, Walton County

According to this article, every state and local jurisdiction owes its citizens the responsibility of preserving its coastline as an important natural resource, when it is threatened by sea level rise, erosion, and storms of increasing intensity. In Florida, submerged lands up to the mean high water line are held in trust for the public’s use and benefit. Florida’s Beach and Shore Preservation Act granted the state’s environmental agency the ability to protect the public trust by authorizing state-sponsored beach renourishment projects. The Act was challenged by several private property owners in Walton County, who argued that beach renourishment deprived them of the common law right to accretion (the extension of private property rights to sediment deposited by the ocean) and the right of contact with the water. Both the Florida and the U.S. Supreme Courts rejected these arguments. The author contends that the victory of the agency in both the Florida and U.S. Supreme Court in *Stop the Beach Renourishment, Inc. v. Florida Department of Environmental Protection* was a victory for the public, and for all states that wish to meet their responsibility of preserving the nation’s shoreline for the public

benefit.

Zhang, K. and S. Leatherman. 2011. "Barrier Island Population along the U.S. Atlantic and Gulf Coasts." *Journal of Coastal Research* 27(2) 356-363.

Keywords: land use planning, barrier islands, vulnerability

The vulnerability of human populations living on barrier islands along the Atlantic and Gulf Coasts to sea level rise was investigated using geographic and census data. Length and areas of barrier islands were quantified. Population densities were also calculated based on 2000 census data. Results showed that one third of the barrier islands in the study site occur in Florida and half of the 1.4 million people living on barrier islands are in Florida. Additionally, population densities on barrier islands are much higher than densities on the mainland in these coastal states. A population increase of 14% was also seen on these barrier islands between 1990 and 2010. This rate of increase is approximately equal to the population increase seen throughout the coastal states.

Conclusions³

In addition to summarizing the literature, this work also identified keywords relating to sea level rise for each article. These keywords are not the same keywords that were assigned by the individual authors for each paper at the time of publication. Instead, they were assigned only for the purposes of this bibliographic summary. An investigation of these keywords was conducted to enable a gap analysis of the literature. Based on this analysis, the most discussed topics were habitat migration, modeling, inundation, land use planning, legislation, and private property rights (Table 1). Gaps in the literature will be discussed below through analysis of the places and habitat types studied as well as gaps in the broad categories of physical, biological, and social sciences.

Table 1. Frequency of occurrence of general keywords.

General Keyword	Freq.	General Keyword	Freq.
beach renourishment	6	modeling	9
biological indicator	5	private property rights	8
citizen involvement	4	remote sensing	3
coastal armoring	4	salinity	7
fisheries	2	sea level rise acceleration	4
greenhouse gases	3	sea level rise prediction	6
groundwater	2	storms	6
habitat migration	12	threatened & endangered species	7
historic sea level rise	6	tide gauge	5
inundation	8	utilities	5
karst	1	vulnerability	6
land use planning	8	water quality	3
legislation	8	wildlife habitat	5

³ These conclusions reflect the body of literature reviewed here. As stated in the introduction, there is a vast body of literature prepared by governmental agencies, conservation groups, and academics that is not reviewed in this bibliography. We do not imply that these topics are not covered in the larger body of literature.

An analysis of ‘place based’ keywords was conducted to assess the frequency of studies occurring in specific areas within Florida (Table 2). The most discussed locations included the Everglades, the Big Bend Region, and the Florida Keys. The most populous coastal cities including Miami, Tampa, and Jacksonville were given little to no attention in the literature. This suggests a general trend of peer-review research toward unpopulated areas.

Table 2. Frequency of occurrence of places within the keywords

Place Keyword	Freq.	Place Keyword	Freq.
Big Bend	5	Palm Beach County	1
Biscayne Bay	1	Panhandle	1
Broward County	2	Pensacola	1
Everglades	8	Sarasota	2
Florida Keys	4	Satellite Beach	1
Indian River	1	Ten Thousand Lakes	1
Mayport	2	Walton County	1
Miami-Dade County	2		

An analysis of the frequency of occurrence of habitat types was also conducted (Table 3). This analysis shows that wetlands, beaches, and forests are the most frequently studied habitat types. Though mangroves are a type of wetland habitat they were included as their own keyword because of the high frequency of occurrence. Barrier islands did not get nearly the same level of attention as the aforementioned habitat types. Additionally, lacking in the literature were studies on aquatic (non-emergent wetland) habitats such as sea grass meadows, and hardbottom (including coral reefs).

Table 3. Frequency of occurrence of habitat types within the keywords.

Habitat Type Keyword	Freq.
barrier islands	2
beaches	7
forests	6
mangroves	5
wetlands	9

Physical Sciences

The current physical science literature is represented by 17 papers containing a combination of historical data (e.g. tide gauges, historic sea level rise, habitat migration) and predictive sciences (modeling). Modeling, a keyword for 7 of the papers, is the most common theme in the physical science literature. This research uses mathematical models (e.g., SLAMM, SLOPE, and GCMs) to predict the probability of local land area inundation or habitat migration under various sea level rise scenarios (that are based on other research). Other common themes include: sea level rise prediction (6 occurrences each) and tide gauges, habitat migration, and inundation (5 occurrences each).

There appears to be a lack of literature pertaining to near-shore currents and sedimentation patterns in Florida that may be affected by sea level change. Data such as sediment deposition, beach dynamics, and barrier island movement could represent crucial parameters for predictive modeling as changes in sedimentation patterns could significantly increase or decrease local sea level rise vulnerability. We did not find any peer reviewed physical science publications regarding saltwater intrusion or groundwater modeling as it relates to sea level rise. Finally, while there were numerous papers highlighting tide gauge data from Florida, we did not find Florida specific references to satellite

altimetry to estimate sea level, a form of measurement that has only been available for the past 20+ years.

Biological Sciences

The biological science literature reviewed in this bibliography includes 15 papers. The most popular theme of these papers is habitat migration and salinity (6 occurrences), followed by biological indicators, threatened and endangered species, and wildlife habitat (5 occurrences). There are several studies that utilize the movement of organisms (e.g., vegetation, mollusks, and oysters) with known salinity thresholds as a proxy for sea level rise. Other literature focus on specific species of interest and uses models to predict the potential loss of habitat due to sea level rise.

Some topics that were not found in the biological science literature include aquatic non-wetland habitats, especially seagrasses and hard bottom habitats such as coral reefs. There is also limited coverage of intangible ecosystem services provided by coastal environments, such as nutrient cycling, pollution removal, storm abatement, and shoreline protection.

Social Sciences

The current social science literature is represented by 20 papers that analyze legal developments, governmental policies, infrastructure vulnerability, and adaptation methods. Private property rights (a keyword in 8 of the papers) is a common theme in the social science literature, especially in reference to conflicts between private property rights and beach preservation. Land use planning (also a keyword in 8 of the papers) emphasizes vulnerability assessments and citizen involvement in planning for sea level rise. Other topics include legislation, governmental responsibility for relocating vulnerable citizens, governmental liability for failing to plan for sea level rise, and beach renourishment.

Social science topics that were not explored for this bibliography include estimations of the economic impacts of sea level rise public perceptions of sea level rise, and legal liability for contributing to or exacerbating sea level rise.

References

IPCC. 2007. Climate Change 2007: Synthesis Report; Pachauri, R. K. and Reisinger, A., Eds.; IPCC: Geneva, Switzerland