TACCIMO
Template for Assessing Climate Change Impacts and Management Options

TACCIMO Literature Report
Literature Report – Annotated Bibliography Format
Report Date: March 6, 2013

Content Selections:
FACTORS – Coastal Ecosystems
CATEGORIES – Sea Level Rise
REGIONS – National, East, R8: Southern, South Atlantic, South Central

How to cite the information contained within this report

Each source found within the TACICMO literature report should be cited individually. APA 6th edition formatted citations are given for each source. The use of TACCIMO may be recognized using the following acknowledgement:

"*We acknowledge the Template for Assessing Climate Change Impacts and Management Options (TACCIMO) for its role in making available their database of climate change science. Support of this database is provided by the Eastern Forest Environmental Threat Assessment Center, USDA Forest Service.*"

Best available scientific information justification

Content in this Literature report is based on peer reviewed literature available and reviewed as of the date of this report. The inclusion of information in TACCIMO is performed following documented methods and criteria designed to ensure scientific credibility. This information reflects a comprehensive literature review process concentrating on focal resources within the geographic areas of interest.

Suggested next steps

TACCIMO provides information to support the initial phase of a more comprehensive and rigorous evaluation of climate change within a broader science assessment and decision support framework. Possible next steps include:

1. Highlighting key sources and excerpts
2. Reviewing primary sources where needed
3. Consulting with local experts
4. Summarizing excerpts within a broader context

More information can be found in the user guide. The section entitled Content Guidance provides a detailed explanation of the purpose, strengths, limitations, and intended applications of the provided information.

Where this document goes

The TACCIMO literature report may be appropriate as an appendix to the main document or may simply be included in the administrative record.

Brief content methods

Content in the Literature Reports is the product of a rigorous literature review process focused on cataloguing sources describing the effects of climate change on natural resources and adaptive management options to use in the face of climate change. Excerpts are selected from the body of the source papers to capture key points, focusing on the results and discussions sections and those results that are most pertinent to land managers and natural resource planners. Both primary effects (e.g., increasing temperatures and changing precipitation patterns) and secondary effects (e.g., impacts of high temperatures on biological communities) are considered. Guidelines and other background information are documented in the user guide. The section entitled Content Production System fully explains methods and criteria for the inclusion of content in TACCIMO.

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Effects by Source

Wednesday, March 06, 2013

RESOURCE AREA (FACTOR): COASTAL ECOSYSTEMS

SEA LEVEL RISE

NATIONAL

Biasutti, M., Sobel, A. H., Camargo, S. J., & Creyts, T. T. (2011) Projected changes in the physical climate of the Gulf Coast and Caribbean. Climatic Change, early online, 1-27. doi:10.1007/s10584-011-0254-y

New semi-empirical approaches provide an alternative way for climate models to estimate sea level rise. These are based on the idea that the rate of sea level rise is proportional to the amount of global warming—the warmer it gets, the faster ice melts—and they use past sea level and temperature data to quantify this effect. Extrapolating into the future, these models suggest global sea level rises of about one meter by 2100 under the A1B scenario, about three times that projected by IPCC models (a 21–48 cm range for the same scenario; IPCC 2007; Vermeer and Rahmstorf 2009; Horton et al. 2008; Grinsted et al. 2009; Jevrejeva et al. 2010; summarized in Rahmstorf 2010).

The average rate of sea level rise over the 20th century was 1.7 ± 0.3 mm yr−1 from analysis of tide- 1869
gauge data (Church and White 2006). The rate has increased in recent years, however. From 1993 to 2003, the average rate of sea level rise was approximately 3.1 mm yr−1 with approximately half that rate coming from thermal expansion (IPCC 2007, Chapter 5). Sea level is presently rising at a rate of 3.4–3.5 mm yr−1 based on satellite-based sea-surface altimetry, tide gauges, and global gravity measurements (Fig. 16, Cazenave et al. 2009; Prandi et al. 2009). Since 2003, contributions from thermal expansion have reached a plateau and acceleration of sea level rise has increased as water is moved from storage in land ice to the ocean (Cazenave et al. 2009).

Day, J. W., Christian, R. R., Boesch, D. M., Yбcaz-Arancibia, A., Morris, J., Twilley, R. R., … & Stevenson, C. (2008). Consequences of Climate Change on the Ecogeomorphology of Coastal Wetlands. Estuaries and Coasts, 31, 477-491. doi: 10.1007/s12237-008-9047-

Storm surges will impact farther inland and at higher elevations as relative sea level rises, independent of 1359
increases in storm intensity (Najjar et al. 2000).

Enhanced aboveground production of plants from nutrient enrichment and fresh water also acts to promote trapping of sediments (Morris et al. 2002). Thus, a reduction of freshwater input due to climate change reduces, in a variety of ways, the ability of coastal plants to cope with sea level rise.

Ficke, A. D., Myrick, C. A., & Hansen, L. J. (2007). Potential impacts of global climate change on freshwater fisheries. Rev Fish Biol Fisheries, 581-613.

Sea levels rose by 1–2 mm per year during the 20th century, much faster than prehistoric fluctuation rates. Furthermore, sea level is expected to rise between 10 cm and 80 cm by 2100according to IPCC [Intergovernmental Panel on Climate Change] scenarios (IPCC 2001). Though this rise would be partially attributable to the melting of ice, the majority of sea level rise would occur due to the thermal expansion of seawater (ACIA 2004). Rising sea levels could also increase erosion and inundate important habitat in deltaic regions of temperate coastal streams (Wood et al. 2002).

Gilman, E. L., Allison, J., Duke, N., & Field, C. (2008). Threats to mangroves from climate change and adaptation options: A review. Aquatic Botany, 89, 237-250. doi:10.1016/j.aquabot.2007.12.009

The range of projections for global sea-level rise from 1980 to 1999 to the end of the 21st century (2090–2099) is 0.18–0.59 m (Solomon et al., 2007). Recent findings on global acceleration in sea-level rise indicate that upper projections are likely to occur (Church and White, 2006).

Heberger, M., Cooley, H., Herrera, P., Gleick, P. H. & Moore, E. (2009). The impacts of sea-level rise on the California coast. California Energy Commission, PIER Energy-Related Environmental Research Program, CEC-500-2009-024-F, 115 pp.

More recent research by leading climate scientists, which includes more accurate sea-level measurements by satellites, indicates that sea-level rise from 1993–2006 has outpaced the IPCC projections (Rahmstorf et al. 2007). The authors suggest that the climate system, particularly sea levels, may be responding to climate changes more quickly than the models predict. Additionally, most climate models fail to include ice-melt contributions from the Greenland and Antarctic ice sheets and may underestimate the change in volume of the world’s oceans. 3773

Jevrejeva, S., Moore, J. C., & Grinsted, A. (2012). Sea level projections to AD2500 with a new generation of climate change scenarios. Global and Planetary Change, 80-81, 14-20. doi:10.1016/j.gloplacha.2011.09.006

Sea level is insensitive to RCP [Representative Concentration Pathways scenario] forcing until 2050 with a range of about 0.32 -0.38 m above the 1980-2000 reference level. However, by the end of the 21st century there are clear consequences depending on which scenario is followed, with sea level rise ranging from 0.57 to 1.10 m by 2100 (with lower and upper 5-95 % confidence limits of 0.36 m to 1.65 m, Table 3), largely due to distinct differences in fossil fuel burning projections. The maximum rate of sea level rise by 2100 reaches 17 mm/yr for the RCP8.5 scenario. Even for the low emission RCP3PD scenario with the peak in radiative forcing around 2050 and declining forcing thereafter, sea level continues to rise by 0.57 m at the end of the 21st century, despite the decrease in forcing. 2162

Sea level projections of 0.57-1.10 m by 2100 with the new RCP [Representative Concentration Pathways] scenarios are slightly lower than our previous estimated range of 0.6-1.6 m using six Special Report on Emission Scenarios (SRES)(Jevrejeva et al, 2010), which reflect the differences in radiative forcings between the old (SRES) and new (RCP) scenarios. The new RCP3PD scenario is more optimistic, in terms of emissions, than any previous scenario. 2163

Fig. 4a shows how, even after stabilization in radiative forcing, sea level continues to rise. Even for the RCP3PD [Representative Concentration Pathways] low emission scenario sea level will rise to 0.74 m in AD2240 compared with 0.32 m in AD2050 (time of stabilization). For the RCP4.5 scenario with stabilization of forcing before AD2100 the rate of sea level rise will fall to the 20th century mean rate of 1.8 mm/yr only between AD2300-2400, at least 200 years after stabilization in radiative forcing (Fig. 4b). For the high emission scenario RCP8.5 [Representative Concentration Pathways] the total sea level rise at the end of 25th century will be 5.49 m, with a 2.86 m rise from AD2200 to AD2500. Maximum rate of sea level rise is 20 mm/yr around AD2150 with a decline to 3.3 mm/yr (similar to the rate of present day sea level rise calculated over the satellite altimetry time period 1992-2008) at the end of 25th century.

Sea level rise of 0.57-1.10 m by 2100 has been estimated as medians from 2000000 runs by our model. 2165
Simulation shows that sea level will continue to rise for many centuries after stabilization of radiative forcing, eventually reaching 1.84-5.48 m by 2500 for all scenarios, except the RCP3PD [Representative Concentration Pathways] low emission scenario.

Langevin, C. D. and Zygnerski, M. (2012). Effect of Sea-Level rise on salt water intrusion near a coastal well field in southeastern florida. Ground Water, online first. doi:10.1111/j.1745-6584.2012.01008.x

More recent projections by the IPCC (Meehl et al. 2007) seem to project sea level rising at a slower rate, but the revised estimates do not include some feedback mechanisms that are anticipated to occur, such as rapid ice sheet melting. Recent studies (Pfeffer et al. 2008) have shown that sea level may rise by 0.8 to 2.0 m by 2100.

Mastrandrea, M. D. & Luers, A. L. (2011). Climate change in California: scenarios and approaches for adaptation. Climatic Change, DOI 10.1007/s10584-011-0240-4

Furthermore, research indicates that warming over this century has the potential to destabilize the Greenland Ice Sheet, increasing the magnitude and rate of global sea level rise and eventually contributing 6.6 to 23 ft (2 to 7 m) of sea level rise, although complete melting could take many centuries (Schneider et al. 2007). Studies suggest this process could be initiated by sustained global average warming of 3.6 to 8.1°F (2 to 4.5°C) (Meehl et al. 2007), well within the range of temperature increase expected by late in this century under high emissions scenarios, although it is unclear for how long this warming must be sustained to destabilize the Greenland Ice Sheet.

Moser, S., Franco, G., Pittiglio, W., Chou, W., & Cayan, D. (2009) The future is now: An update on climate change science impacts and response options for California. California Energy Commission Public Interest Energy Research Program, CEC-500-

Estimates of future global sea-level rise have recently been revised upwards. Estimates by Rahmstorf 904
(2007) suggest global sea-level rise could increase by over 4 feet by 2100, depending on the warming scenario employed, as opposed to the very modest 0.6 to 1.9 feet (7.12 to 23.4 inches) projected in the most recent assessment of the IPCC (Intergovernmental panel on climate change) (2007). However, a recent paper in the journal Science asserts that artificial water reservoirs (dams) around the world have had a significant impact on sea-level rise, reducing the magnitude of global sea level rise by about 30 millimeters (1.2 inches) during the last half of the 20th century (Chao, Wu and Li, 2008). In other words, if there had been no dams retaining water on land, global sea level rise would have been 30 mm (1.18 inches) higher than they actually are, suggesting that warming of the oceans and/or water additions to the oceans from land-based ice must have been greater than previously assumed.

Rotzoll, K. & Fletcher, C. H. (2012). Assessment of groundwater inundation as a consequence of sea-level rise. Nature Climate Change, online first, 1758-6798. doi:10.1038/nclimate1725

Rising groundwater levels could cause long-term problems related to water management (aquifer salinization) and infrastructure (flooding) in coastal areas, which could be costly to mitigate even when they are not catastrophic (Nicholls 1995). Thus, groundwater inundation requires a more complex assessment of adaptation tools and strategies than marine inundation alone.

At first, groundwater inundation will occur infrequently, usually when high tide is coinciding with heavy rainfall. In the [global scale] chronology implied by semi-empirical models (Rahmstorf 2012), areas lying within 0.33 m of modern MHHW [mean higher high water] are especially vulnerable to the impacts of SLR [sea level rise] by mid-century, whereas those lying between 0.66 and 1 m are vulnerable in the latter half of the century. 4338

Urban drainage systems in coastal areas rely on the ability to drain surface runoff into the ocean. As sea level rises, groundwater inundation will prevent infiltration and drainage. It is likely that future urban settings will be characterized by standing pools of brackish water, maximized at high tide. This may affect traffic, walkways, and any movement in urbanized coastal areas.

Developed coastal aquifers are generally more vulnerable to groundwater extraction than to SLR [sea level rise] (Ferguson & Gleeson 2012), and because withdrawals lower water tables, it reduces the likelihood for them to rise and cause flooding. Thus, groundwater withdrawals can be used to mitigate the effects of a rising water table, even if it means pumping brackish water to avoid inundation. 4341

Seneviratne, S. I., Nicholls, N., Easterling, D., Goodess, C.M., Kanae, S., Kossin, J., … & Zhang, X. (2012). Changes in climate extremes and their impacts on the natural physical environment. In: Field, C.B et al. (Eds.), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK, and New York, NY, USA: Cambridge University Press, 109-230.

Thus, studies since the AR4 [IPCC Assessment Report 4] conclude that trends in extreme sea level are generally consistent with changes in mean sea level (e.g., Marcos et al., 2009; Haigh et al., 2010; Menendez and Woodworth, 2010) although some studies note that the trends in extremes are larger than the observed trend in mean sea levels (e.g., Church et al., 2006a; Ullmann et al., 2007; Abeysirigunawardena and Walker, 2008) and may be influenced by modes of climate variability, such as the PDO [Pacific Decadal Oscillation] on the Canadian west coast (e.g., Abeysirigunawardena and Walker, 2008). These studies are consistent with the conclusions from the AR4 that increases in extremes are related to trends in mean sea level and modes of variability in the regional climate.

To summarize, post-AR4 [IPCC Assessment Report 4] studies provide additional evidence that trends in extreme coastal high water across the globe reflect the increases in mean sea level, suggesting that mean sea level rise rather than changes in storminess are largely contributing to this increase (although data are sparse in many regions and this lowers the confidence in this assessment). It is therefore considered likely that sea level rise has led to a change in extreme coastal high water levels. 2863

To summarize, recent observational studies that identify trends and impacts at the coast are limited in regional coverage, which means there is low confidence, due to insufficient evidence, that anthropogenic climate change has been a major cause of any observed changes. However, recent coastal assessments at the national and regional scale and process-based studies have provided further evidence of the vulnerability of low-lying coastlines to rising sea levels and erosion, so that in the absence of adaptation there is high confidence that locations currently experiencing adverse impacts such as coastal erosion and inundation will continue to do so in the future due to increasing sea levels in the absence of changes in other contributing factors.

Warner, N. N. & Tissot, P. E. (2012). Storm flooding sensitivity to sea level rise for Galveston Bay, Texas. Ocean Engineering, 44, 23-32.

Sea level rise, whether caused by downward vertical land motion or global sea level rise, will cause 2615
storm surge floods to progress further inland, thereby increasing flood damage and the recurrence interval of present 20- or 100-year floods.

Werner, A. D. & Simmons, C. T. (2009). Impact of Sea-Level rise on sea water intrusion in coastal aquifers. Ground Water, 47(2), 197-204. p. doi:10.1111/j.1745-

In particular, sea-level rise associated with climate change (by way of changes to atmospheric pressure, expansion of oceans and seas as they warm, and melting of ice sheets and glaciers) is one potentially significant process that is expected to play a role in sea water intrusion. The Intergovernmental Panel on Climate Change (IPCC 2001) predicts that by 2100, global warming will lead to a sea-level rise of between 110 and 880 mm, and it is generally understood that sea-level rise is expected to result in the inland migration of the mixing zone between fresh and saline water (FAO 1997). This is because the rise in sea water levels leads to increased saline water heads at the ocean boundary, and enhanced sea water intrusion is the logical consequence.

Using representative parameters for the Nile Delta case analyzed by Sherif and Singh (1999) (L ¼ 150 km, z0 ¼ 400 m, K ¼ 100 m/d, hi ¼ 14 m [above sea level], W ¼ 0 mm/year) and in our method proposed here, we obtained reasonably consistent estimates of sea water intrusion in response to sea-level rise compared to their study (i.e., our analysis and that of Sherif and Singh [1999] both indicate toe migration on the order of 5 km inland for a 500-mm sea-level rise).

In the case of constant flux conditions, the upper limit for sea water intrusion due to sea-level rise (up to 1500 mm) is no greater than 50 m for typical values of recharge, hydraulic conductivity, and aquifer depth. This is in striking contrast to the constant head cases, in which the magnitude of salt water toe migration is on the order of hundreds of meters to in excess of a kilometer for the same sea-level rise.

Williams, K., Ewel, K. C., Stumpf, R. P., Putz, F. E., & Workman, T. W. (1999). Sea-level rise and coastal forest retreat on the west coast of Florida, USA. Ecology, 80(6), 245-263. doi: 10.1890/0012-9658(1999)080[2045:SLRACF]2.0.CO;2

The mechanisms by which rising seas cause forest retreat may vary with geomorphological and hydrological characteristics of the coast.

Increases in rainfall associated with global climate change may slow coastal forest retreat in the face of sea- 2445
level rise, while the increased incidence of droughts or consumptive water use by humans may accelerate it.

Zecca, A. & Chiari, L. (2012). Lower bounds to future sea-level rise. Global and Planetary Change, In Press. doi:10.1016/j.gloplacha.2012.08.002

Global-mean sea level has risen by 17 ± 5 cm over the 20th century and is projected to increase by further 18-59 cm (90% confidence level) in AD 2100 relative to AD 1990 (Meehl et al., 2007) owing to anthropogenic global warming.

Despite the fact that atmospheric CO_2 concentration and global-mean temperature are predicted to peak around the turn of the 21st century and then start to decline under these scenarios (see Chiari and Zecca, 2011), Fig. 2 shows that sea level is expected to continue rising also during the 22nd century and reach 150-229 cm at the end of that century above the level in AD 2000. Sea level will likely continue to increase for several centuries even after the radiative forcing has stabilised or started to turn down (Jevrejeva et al., 2012). This is not surprising, as it reflects the persistent state of thermal disequilibrium in a changing climate, between the various components of the climate system, that leads to heat being incessantly moved into the deep ocean, and land ice continuing to melt and disintegrating faster than it is being re-formed.

The rate of sea-level change will be positive for centuries, in agreement with the recent finding of 3751
Jevrejeva et al. (2012). The increase in the rate of sea-level rise is expected to continue until at least the last decades of this century and the highest rate we find is +13.7 mm per year (with an uncertainty ranging from 9.1 to 21.2 mm per year) close to the middle of the next century. This number turns out to be one order of magnitude higher than the estimate of 1.8 ± 0.4 mm for the calculated rate of sea-level rise in the time period from 1972 to 2008 (Church et al., 2011). The comparison between these two numbers highlights how crucial the implementation of adaptation measures will be in the future in order to cope with such a rapid sea-level rise.

R8: SOUTHERN

Biasutti, M., Sobel, A. H., Camargo, S. J., & Creyts, T. T. (2011) Projected changes in the physical climate of the Gulf Coast and Caribbean. Climatic Change, early online, 1-27. doi:10.1007/s10584-011-0254-y

It is clear from the correspondence between the spatial patterns of precipitation change and SST [sea surface temperature] change that the two are related. Precipitation is projected to increase strongly over the near-equatorial regions of the east Pacific and Atlantic in which SST rises the most, and to decrease over the band of minimum increase, which includes most of the Caribbean and Gulf.

Globally averaged sea level rises by an amount of water equal to the volume of ice above an equivalent sea level. However, meltwater from rapid retreats is not distributed equally across the globe. Large changes in ice volume in Antarctica, for example, yield sea level changes 15– 30% higher than the global average for the Gulf of Mexico and Caribbean (Mitrovica et al. 2009).

Besides direct inundation, sea level rise increases the risk to coastal areas from storm surge associated 1870
with tropical cyclones (even if the risk that a storm of a given intensity will strike does not increase).

Cruise, J. F., Limaye, A. S., & Al-Abed, N. (1999). Assessment of impacts of climate change on water quality in the Southeastern United States. Journal of the American Water Resources Association, 1530-1550.

First, a number of the basins that exhibit current problems are located along the Gulf Coast where they will be significantly impacted by sea level rise during the next century as well as the decrease in fresh water inflow predicted by the Hadley Center model. If the model projections are correct, these basins and estuaries in Louisiana, Mississippi, Alabama, and Florida should see significantincreases in salinity levels associated with saltwater intrusion as well as a degraded quality of the inflows that do occur. Based on these observations itis quite possible that many of these areas could exhibit brackish and eutrophic conditions throughout much of the year. These conditions may negatively impact the aquaculture and tourism industries.

Day, J. W., Christian, R. R., Boesch, D. M., Yбcaz-Arancibia, A., Morris, J., Twilley, R. R., … & Stevenson, C. (2008). Consequences of Climate Change on the Ecogeomorphology of Coastal Wetlands. Estuaries and Coasts, 31, 477-491. doi: 10.1007/s12237-008-9047-

Not all estuarine wetlands are equally vulnerable to the consequences of climate change. For example, the northern Gulf of Mexico is particularly vulnerable to sea level rise, flooding, and erosion from storms (Hammar- Klose and Thieler 2001; Fig. 2), and the southern Gulf of Mexico is much more vulnerable to sea level rise than the Caribbean portion of Mexico (Ortiz-Perez et al. 2008).

Karl, T. R., Melillo, J. M., & Peterson, T. C. (2009). Global climate change impacts in the United States. New York, NY, USA: Cambridge University Press.

Even with no increase in hurricane intensity, coastal inundation and shoreline retreat would increase as 171
sea-level rise accelerates, which is one of the most certain and most costly consequences of a warming climate (Field et al., 2007).

Langevin, C. D. and Zygnerski, M. (2012). Effect of Sea-Level rise on salt water intrusion near a coastal well field in southeastern florida. Ground Water, online first. doi:10.1111/j.1745-6584.2012.01008.x

As shown by Werner and Simmons (2009), [coastal aquifer] systems that are head controlled are more susceptible to salt water intrusion caused by sea-level rise than those that are flux controlled. For confined aquifers that are flux controlled, sea-level rise may not have any effect on salt water intrusion (Chang et al. 2011).

Williams, K., Ewel, K. C., Stumpf, R. P., Putz, F. E., & Workman, T. W. (1999). Sea-level rise and coastal forest retreat on the west coast of Florida, USA. Ecology, 80(6), 245-263. doi: 10.1890/0012-9658(1999)080[2045:SLRACF]2.0.CO;2

Whereas failure of tree regeneration in the Mississippi Delta has been linked to rising water levels and increased flooding stress (Baumann 1987, DeLaune et al. 1987, Conner and Day 1988), and failure of Sabal regeneration on sandy coasts has been attributed to erosion (Brown 1973), failure of tree regeneration in this system [on the west coast of Florida] was associated with exposure to tidal water and increasing salinity of the groundwater.

SOUTH ATLANTIC

Daniels, R. C., White, T. W., & Chapman, K. K. (1993). Sea-level rise: destruction of threatened and endangered species habitat in South Carolina. Environmental Management, 17(3), 373-385. doi:10.1007/bf02394680

Cape Romain's barrier islands will suffer from the effects of coastal erosion in addition to inundation as 4820
sea levels rise. The destruction of these barrier islands will be accelerated by the lack of a suitable supply

of medium-grained sands to maintain the barrier islands in the Cape Romain area [in South Carolina]. This is primarily due to the southward direction of the longshore currents. These currents contain fine sand, mud, and silt from the South and North Santee Rivers. This sediment, although suitable for marsh accretion in coastal embayments, is easily mobilized and does not provide suitable material to allow the barrier islands, such as Cape Island, to roll over (through storm overwash) and move landward.

Thus, the barrier islands [in the Cape Romain area, South Carolina] may become fragmented as a result 4821
of subsidence and sea-level rise. The destruction of these barrier islands will allow increased wave energies to enter and attack the refuge's marsh (Figures 3A and 3B). The increase in wave action in the refuge will cause marsh materials to be resuspended and the large tide range (i.e., mean tide range is ≈1.5 m) may flush this material back out to sea, accelerating the demise of Cape Romain's marshlands.

The Cape Romain [South Carolina] case study demonstrates the extent to which sea-level rise would 4825
affect coastal habitats that have been identified, based on the CVI [coastal vulnerability index], as being at risk to future increases in sea level. The low sea-level rise scenario predicts a 31-cm rise in sea level and 22 cm of subsidence by the year 2100. This 53-cm is very close to, or exceeds, the estimated vertical accretion rate of the marsh (i.e., ~5 mm/yr), and as a result, may inundate 51.4% of Cape Romain.

Gedan, K. B., Altieri, A. H., & Bertness, M. D. (2011). Uncertain future of New England salt marshes. Marine Ecology Progress Series. 434. 229-237. doi: 10.3354/meps09084

Using current IPCC sea level rise scenarios and a ‘sea level affects marshes model’ (SLAMM) of salt marsh accretion, Craft et al. (2009) predicted that 20 to 45% of salt marsh area in a Georgia estuary will be converted to low salinity marsh, tidal flat, or open water by 2100.

Guha, H. & Panday, S. (2012). Impact of sea level rise on groundwater salinity in a coastal community of South Florida. Journal of the American Water Resources Association, 1-19. doi:10.1111/j.1752-1688.2011.00630.x

Three separate sea level rise increase simulations were conducted by increasing sea level to 0.6, 0.9, and 1.22 m. Results of the simulation clearly show significant increase in groundwater levels and relative chloride concentrations with increase in sea level [in South Florida] (Figures 16a and 16b). In well F-319 an increase of sea level from 0.34 to 0.6, 0.9, and 1.22 m results in an average of 4, 9, and 15% increase in groundwater elevation respectively. Similarly, in well G-3229 the average relative chloride concentrations would increase by 103, 310, and 639% respectively. The increase in groundwater elevations and salinity concentrations varies from location of the wells and its proximity to the coast.

Kemp, A. C., Horton, B. P., Culver, S. J., Corbett, D. R., van de Plassche, O., Gehrels, W. R., … & Parnell, A. C. (2009). Timing and magnitude of recent accelerated sea-level rise (North Carolina, United States). Geology, 37(11), 1035-1038. doi:10.1130/G30352A.1

The measured rate of relative sea-level rise in North Carolina during the twentieth century was 3.0–3.3 3570
mm/a, consisting of a background rate of ~1 mm/a, plus an abrupt increase of 2.2 mm/a, which began between A.D. 1879 and 1915. This acceleration is broadly synchronous with other studies from the Atlantic coast. The magnitude of the acceleration at both sites is larger than at sites farther north along the U.S. and Canadian Atlantic coast and may be indicative of a latitudinal trend.

Using Bayesian change point linear regression (Carlin et al., 1992), we identify a 2.2 mm/a increase in the rate of sea-level rise in excess of the background rate at Sand Point and Tump Point [North Carolina] that began between A.D. 1879 and 1915.

Comparison of the Sand Point and Tump Point [North Carolina] records (2.2 mm/a above background rate) with these other salt-marsh studies suggests that the magnitude of accelerated RSLR [relative sea-level rise] may exhibit a latitudinal trend. Tide-gauge records support this inference (e.g., Douglas, 1991; Peltier, 2001; Wake et al., 2006); gauges north of New York City show rates (average 1.5 mm/a) lower than those to the south (average 2.5 mm/a; Douglas, 1991). Wake et al. (2006) attributed this latitudinal variation to ocean thermal expansion. In contrast, this latitudinal trend could also be a fingerprint of mass loss from the Greenland Ice Sheet because water migrates away from the ice sheet as its gravitational attraction is diminished (Conrad and Hager, 1997; Mitrovica et al., 2001).

Langevin, C. D. and Zygnerski, M. (2012). Effect of Sea-Level rise on salt water intrusion near a coastal well field in southeastern florida. Ground Water, online first. doi:10.1111/j.1745-6584.2012.01008.x

Results of a numerical modeling analysis suggest that groundwater withdrawals [from a shallow coastal aquifer system in the Pompano Beach well-field and southeastern Florida area] were the dominant cause of a multi-decade salt water intrusion event, and that historical sea-level rise (about 25 cm for the simulation period) contributed to the extent of the intrusion by about 1 km.

Seneviratne, S. I., Nicholls, N., Easterling, D., Goodess, C.M., Kanae, S., Kossin, J., … & Zhang, X. (2012). Changes in climate extremes and their impacts on the natural physical environment. In: Field, C.B et al. (Eds.), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK, and New York, NY, USA: Cambridge University Press, 109-230.

On the North American Atlantic coast, Komar and Allan (2008) found a statistically significant trend of 0.059 m yr-1 in waves exceeding 3 m during the summer months over 30 years since the mid-1970s at Charleston, South Carolina, with weaker but statistically significant trends at wave buoys further north. These trends were associated with an increase in intensity and frequency of hurricanes over this period (see Section 3.4.4). In contrast, winter waves, generated by extratropical storms, were not found to have experienced a statistically significant change. 2864

Williams, K., Ewel, K. C., Stumpf, R. P., Putz, F. E., & Workman, T. W. (1999). Sea-level rise and coastal forest retreat on the west coast of Florida, USA. Ecology, 80(6), 245-263. doi: 10.1890/0012-9658(1999)080[2045:SLRACF]2.0.CO;2

For the four tree species that occurred in island plots [on the west coast of Florida] (Sabal, Juniperus, Quercus, and Celtis), mature individuals existed in more frequently flooded sites [indicative of future sea level rise] than did their seedlings, suggesting that regeneration failed before mature individuals were eliminated (Table 2).

Mean relative sea level at Cedar Key, Florida, rose an average of 1.5 mm/yr between 1939 and 1994, a rate consistent with most estimates of global sea-level rise (Warrick and Oerlemans 1990, Davis and Mitrovica 1996). MHHW [mean higher high water for the year] rose at a higher rate (~2.8 mm/yr, Fig. 3, Stumpf and Haines 1998). Sea level and MHHW during 1991 and 1992 were the highest on record.

A change in understory composition accompanied forest decline at the seaward margin of coastal forest [on the west coast of Florida]. Whereas the tree species in frequently flooded plots were a subset of those occurring in adjacent coastal forest, the understory experienced complete species turnover (Appendix).

Salinization of groundwater appeared to occur during early to middle stages of stand decline: shallow groundwater beneath [plot] H1, where ample regeneration of Sabal, Juniperus, and Quercus occurred, was brackish at certain times of year (up to ~15 g sea salt/L several times during 1994–1995). Groundwater salinity under plots H2 and H3, where no regeneration of Quercus occurred and that of Sabal and Juniperus was marginal, was substantially higher than under H1 when it was measured in 1997. This pattern suggests that the salinization of groundwater could be a cause of regeneration failure. However, its role in forest decline on carbonate coasts [such as on the west coast of Florida] is unclear.

Of the species studied [on the west coast of Florida], Sabal and Juniperus were best able to maintain green leaves under conditions of continuous salt exposure, whereas Quercus could survive extremely high salt exposure by dying back and resprouting following salt removal.

Coastal forest retreat on this relatively undeveloped carbonate coastline [in Waccasassa Bay State Preserve on the west coast of Florida], therefore, appears fully consistent with impacts of continuing sea-level rise, whereby salt exposure associated with tidal flooding eliminates tree regeneration well before mature trees die.

SOUTH CENTRAL

Blum, M. D., & Roberts, H. H. (2009). Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise. Nature Geoscience, 2, 488-491. doi: 10.1038/NGEO553

Previous projections of twentieth-century land-loss trends suggest submergence of 5,700 km2 of the [Mississippi] delta plain between 1950 and 2050, mostly on the Teche, St Bernard and Lafourche deltas, with 400 km2 gained through deposition in the Plaquemines- Balize and Atchafalaya-Wax Lake deltas (Barras et al. 2003) (see Supplementary Information). We project submergence to the year 2100 using conservative subsidence rates, and sea-level rise that accelerates linearly from 3 mmyr_1 in the year 2000 to 4mmyr_1 in 2100: in the absence of sediment input, land surfaces that are now below 1m in elevation will be converted to open water or marsh (Fig. 3b). Landward of the barrier-island chains of the St Bernard and Lafourche deltas, ~7000 km2 of the delta plain already lies below sea level, with estimated submergence of an extra 10,500-13,500 km2 by the year 2100 (Fig. 3c).

With modern sediment loads for the combined Mississippi and Atchafalaya rivers, a trapping efficiency of 40% and sea-level rise of 1mmyr_1, the creation of accommodation outpaces sediment supply and results in a mass deficit of ~1-5 BT [billion tons] by the year 2100: even with typical late Holocene rates of sea-level rise, further land loss would be inevitable unless the trapping efficiency approaches 100%.

With sediment loads restored to pre-dam values of 400-500MTyr_1 [for the combined Mississippi and Atchafalaya rivers], supplies would be sufficient to sustain the deltaic landscape with rates of sea-level rise of ~1mmyr_1.

Chavez-Ramirez, F., Wehtje, W., (2011). Potential impact of climate change scenarios on whooping crane life history. Wetlands, online first, 1-10.

Rising sea levels are an ongoing concern along the Texas coast and are likely to continue into the future. Since 1948, average sea level at the Rockport tidal gauge has risen by 4.6 mm/year, due to a combination of absolute sea level rise and local land subsidence (Montagna et al. 2007; Snay et al. 2007). By combining the rate of local land subsidence with IPCC climate models, the projected relative sea-level rise at Rockport for 2000 to 2100 is estimated at 0.46 to 0.87 m (Montagna et al. 2007).

Sea level rise will increase the volume of the estuaries by deepening the bays and also increasing the 2019
extent of open water. This will most likely lead to an increase in estuary salinities due to increased evaporation, greater inflows of ocean water, and decreases in freshwater inflow due to predicted changes in

precipitation (Montagna et al. 2007).

The higher sea level will reduce the relative height of the barrier islands, making them more vulnerable to overwash by tropical storms (Montagna et al. 2007). 2021

Williams, K., Ewel, K. C., Stumpf, R. P., Putz, F. E., & Workman, T. W. (1999). Sea-level rise and coastal forest retreat on the west coast of Florida, USA. Ecology, 80(6), 245-263. doi: 10.1890/0012-9658(1999)080[2045:SLRACF]2.0.CO;2

On deltaic coasts with high freshwater outflows, such as the Mississippi Delta, rising seas may boost freshwater tables, eliminating tree regeneration through increased freshwater flooding (e.g., Baumann 1987, DeLaune et al. 1987, Conner and Day 1988).

Regardless of the mechanism by which rising seas eliminate coastal forest, tree regeneration may be much more sensitive to rising seas than mature-tree survival. Increases in hydroperiod in the Mississippi Delta have eliminated tree regeneration in forest stands (DeLaune et al. 1987, Conner and Day 1988, Conner and Brody 1989). Failure of tree regeneration has also been linked to saltwater intrusion (e.g., Penfound and Hathaway 1938).

EAST

Erwin, M. R., Cahoon, D. R., Prosser, D. J., Sanders, G. M., & Hensel, P. (2006) Surface Elevation Dynamics in Vegetated Spartina Marshes Versus Unvegetated Tidal Ponds Along the Mid-Atlantic Coast, USA, with Implications to Waterbirds. Estuaries and Coasts, 29(1), 96-106.

From an ecological perspective, one of the major implications of rising seas is potential inundation of vast areas of low-lying emergent Spartina-dominated marshes, which are among the most productive ecosystems on earth (Mitsch and Gosselink 1993; Bertness 1999). 1340

Only in the case of Nauset Marsh [Massachusetts] does it appear that marsh elevation change is capable of maintaining pace with sea-level rise (Fig. 5 and Table 2). The Spartina plots at the other three sites [1 at Edwin B. Forsythe National Wildlife Refuge, New Jersey, and 2 at Virginia Coastal Reserve, Eastern Shore, Virginia] all show a deficit of about 2.5 mm per annum relative to mean sea-level rise.

Najjar, R. G., Walker, H. A., Anderson, P. J., Barron, E. J., Bord, R. J., Gibson, J. R., Kennedy, V. S., … & Swanson, R. S. (2000). The potential impacts of climate change on the mid-Atlantic coastal region. Climate Research, 14, 219-233.

In the mid-Atlantic region, RSLR [relative sea-level rise] is between 3 and 4 mm yr–1 (Titus & Narayanan 1995), suggesting a local component of RSLR of about 2 mm yr–1, which may be due to variations in the accumulations of Holocene sediments and their subsequent compaction (Psuty 1992, Nicholls & Leatherman 1996), regional differential crustal warping (Walker & Coleman 1987) and possibly removal of groundwater by humans (Leatherman et al. 1995).

The best estimate of Warrick et al. (1996) is that, by 2030 and 2095, global sea level will be about 11 and 45 cm higher, respectively, than in 1990. Adding in a local RSLR [relative sea-level rise] of 2 mm yr–1, these figures increase to 19 and 66 cm, respectively, for MAC [mid-Atlantic coastal] waters (Table 1). For the MAC region, therefore, global climate change, as opposed to local effects, is predicted to account for about 60 and 70% of the sealevel change from 1990 to 2030 and 2095, respectively.

Thus, those wetlands lacking inputs of riverine sediments will be most vulnerable to sea-level rise. These wetlands include microtidal marshes of the Chesapeake Bay, extensive non-tidal wetlands of the

Albermarle- Pamlico Peninsula (Moorhead & Brinson 1995), and upland and marsh islands in Chesapeake Bay.

Thus, all 3 of these climate-related changes (CO2, temperature and hydrology) have the potential to reduce some of the flooding effect of sea-level rise in coastal wetlands.

For the CCC model, the mid-Bay [Chesapeake Bay] salt front is projected to migrate upstream by 3 km 1673
(0.94% of the Bay's length) by 2030 and 7 km (2.2% of the Bay's length) by 2095. For the Hadley model, the mid-Bay salt front is projected to migrate downstream by 11 km (3.4% of the Bay's length) by 2030 and 48 km (15% of the Bay's length) by 2095. Clearly, streamflow changes could either offset or compound the effects of sea-level rise on the salinity of MAC [mid-Atlantic coastal] waters.

Sallenger, A. H., Doran, K. S., & Howd, P. A. (2012). Hotspot of accelerated sea-level rise on the Atlantic coast of North America. Nature Climate Change, In Press. doi:10.1038/nclimate1597

Mean NEH [northeast hotspot] SLRD [sea-level rate differences] is a factor of ~3-4 larger than global SLRD. For the 60-yr window, the global SLRD during 1950-2009 is 0.59-0.26mmyr-1 (using reconstructed time series14), compared with NEH SLRD of 1.97-0.64mmyr-1. For the 40-yr window, global SLRD during 1970-2009 was 0.98-0.33mmyr-1, compared with NEH SLRD of 3.80-1.06mmyr-1. These strong NEH SLRDs may be associated with AMOC [Atlantic Meridional Overturning Current] weakening; for observed NEH, model (Levermann et al. 2005, Yin et al. 2009) results suggest ~4.4-19 Sv of weakening by 2100 dependent on scenario and regression window length.

Our analyses support a recent acceleration of SLR [sea-level rise] on ~1,000 km of the east coast of North 3806
America north of Cape Hatteras [North Carolina]. This hotspot is consistent with SLR associated with a slowdown of AMOC [Atlantic Meridional Overturning Current].