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THE PATH TO RESILIENCY IN LOW GRADIENT COASTAL REGIONS FOR PRESENT AND FUTURE CONDITIONS

Lead Speaker: Robert Nicholls

MANAGEMENT AND MIXED COASTAL PROTECTION MEASURES IN HIGHLY VULNERABLE AND EDGE RISK AREAS. COSTA DA CAPARICA CASE STUDY

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ABSTRACT

Shoreline mobility and erosion is an important scientific, technical and management issue to take into consideration along almost all the coastal regions. High energetic wave and tidal action dominate the extremely diverse nature of the North Atlantic west coast and this represents a challenge when compared with other coasts. The natural and the anthropogenic forcing has evolved into several high risk situations for urban settlements and economic activities. Climate change probably will increase the existent risk level. The sandy coastal stretch Cova do Vapor - Costa da Caparica near the Tagus river mouth (Portugal, Lisbon area) is influenced by a high wave action. Since 1870, important physiographic transformations and retreat events of the coastline has been occurring. The study of alternative scenarios of management and coastal protection in highly vulnerable and edge risk areas, based on scenarios of shoreline mobility, led to design and implementation of several mixed solutions. Based on a 17 years' scientific and technical experience, the paper will present and discuss the geographic and historic framework of the urban development, the erosion process and coastal defense interventions, coastal management and coastal protection of the urban seafront, the described interventions, the construction phases, the bathymetric survey and sediment balance.

Keywords: Coastal management; sediment balance; coastal protection; sand nourishment; monitoring.

1 GEOGRAPHIC CONTEXT AND PROJECT MOTIVATION

The coastal area is located south of the Tagus river mouth (Portugal, Lisbon area) and north of Setúbal Peninsula (Figure 1). The study area extends from Cova do Vapor (left bank of river mouth) to south of Costa da Caparica town.

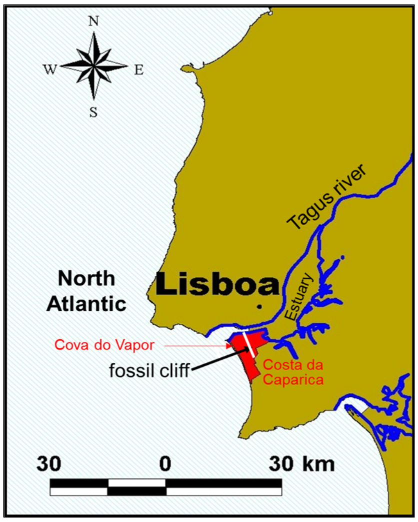

Figure 1. Study area.

This sandy coastal plain Cova do Vapor - Costa da Caparica is influenced by a high wave action. The topography of the study area has a simple characterization, it is a circle arc coast, and presents an orientation SSE-NNW.

Significant wave above 5 m high can occur locally. Remarkable hydrodynamic and morpho-dynamic interaction phenomena between waves / tides / river flow occur (Figure 2).

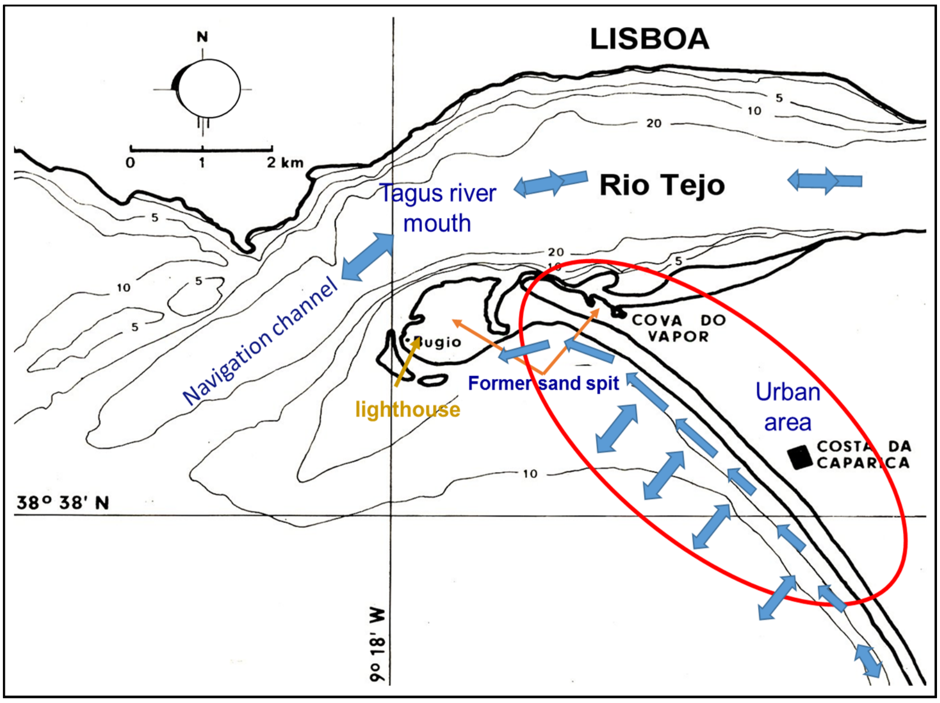

Figure 2. Costa da Caparica / Cova do Vapor study area. Former sand spit. Main estuary and littoral currents.

Since 1870, important physiographic transformations and retreat events of the coastline has been occurring.

A 3,000 m long sand spit connecting the shore and the Bugio lighthouse has disappeared with negative consequences on the wave protection and sand trapping provided by such natural barrier (Figure 3).

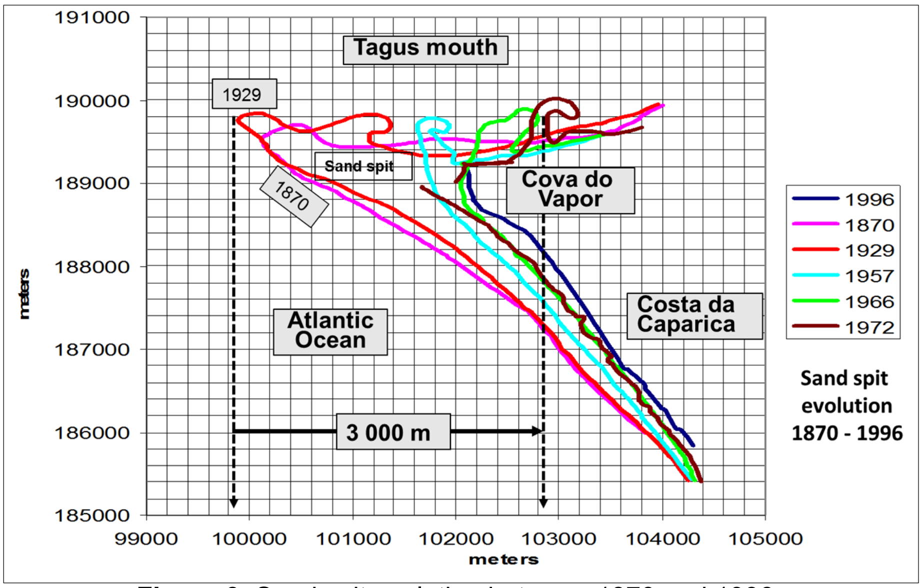

Figure 3. Sand spit evolution between 1870 and 1996.

The 14 m (above CD) high dune retreat reached 80 m up to the construction of a seawall in 1959. The dune crest level has decreased by 8 m (Figure 4).

The natural limit to coastal recession in the lowland Caparica coastal plain is a fossil sharp cliff of 70 m high, 13 km long and parallel to the coast line at a distance of 1000 m. This is a geological protected landscape presenting an unusually paleontological interest. The cliff consists of unconsolidated fluvial sediments deposited during the Pliocene and corresponding to the landward Tagus paleo-valley.

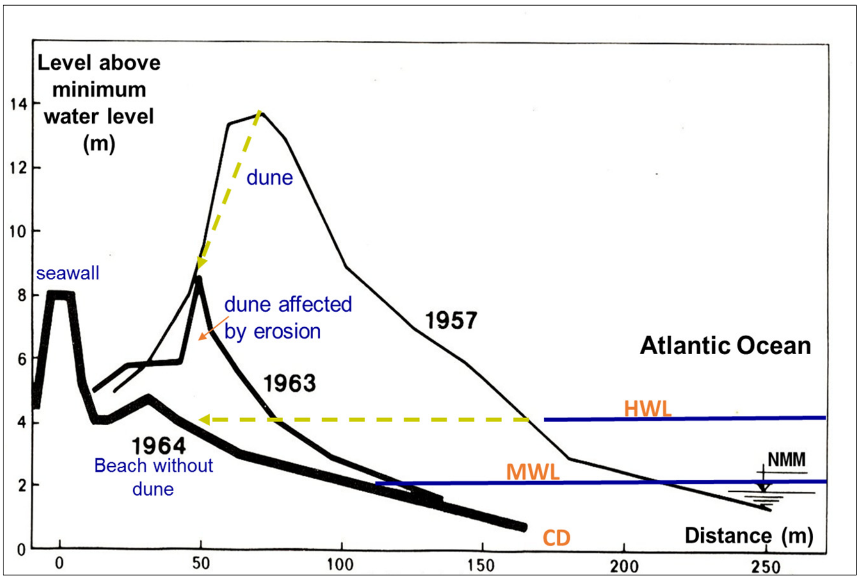

Figure 4. Dune and beach recession between 1957 and 1964 before the construction of hard coastal protection structures.

In this study area, reports of erosion on south of Cova do Vapor date from 1947, particularly reaching the village of Costa da Caparica in 1958. Flooding events affecting the small fisherman village occur before 1937. The army was mobilized to build an emergency long dyke (Figure 5).

Figure 5. Old aerial photo of the small fishing village of Costa da Caparica (1937) protected by a long dyke built by the army after a flooding wave event.

As referred, it has been verified that since 1870 an important physiographic transformation and retreat in the coastline of the area has occurred. The disappearance of the sand spit and the retreat of the coastline are evident. The sand spit moved by wave action up to the NATO pier (Figure 6). This process was reduced by the construction of coastal protection structures, a 2500 m length rocky seawall, built between 1959 and 1963.

The situation became worse in 1964, when destruction in the central area of Costa da Caparica occurred. The seawall was reinforced and a small groin was constructed. At that time it was evident that the influence of groins built in Cova do Vapor was too small to originate sand accumulation on the southern beach, and to reduce the erosion process. Between 1968 and 1971 the two groins of Cova do Vapor were expanded. The bigger one was extended to 600 m in length (the biggest in Portugal), while recognizing the necessity to expand it even more providing a trapping sand magnitude similar to the related with the disappeared sand spit.

Between 1972 and 1996, a strong urban development occurred (Figure 6) despite the fact that the coastal stretch was still vulnerable to storms, even though the existence of coastal protection structures. The most popular beaches of Lisbon region are located in this coastal plain. Five hundred thousand of people use Costa da Caparica beach during the summer time (30% local residents).

Urban seafront improvement has been included in a major national program for urban area re-qualification, known as the POLIS Program (CostaPolis 2001-2013, 650 ha).

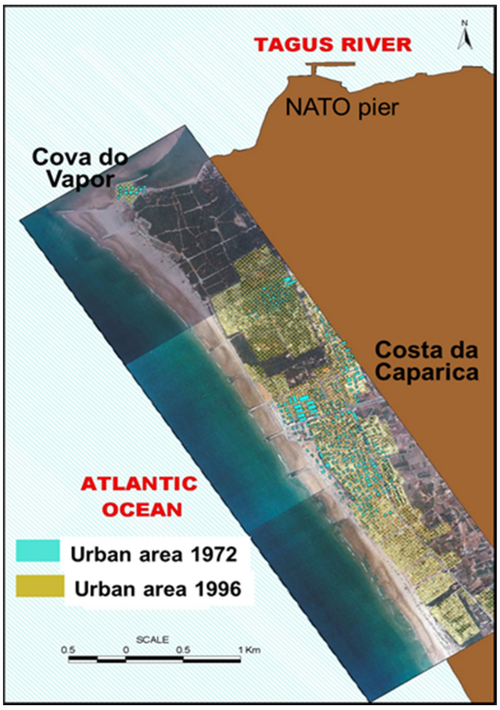

Figure 6. Evidence of strong urban development between 1972 and 1996.

Between 1972 and 2000, the coastline remain more or less stable. However, in the winter of 2000/2001, severe and persistent sea storms occurred, showing that the area is still very unstable and vulnerable. In Costa da Caparica, after this winter it was verified that:

- There was little sand on the beaches, and during high tide (+3.0 to +4.0 m above datum) the sandy beaches were almost completely covered by water.
- A great extension of the coastal protection structures in Costa da Caparica were damaged: generalized groin shortening, damage to the groin heads and trunks, reduction and destruction of structures in important sections.
- The destruction of the beach supports (buildings) located improperly above primary dune in S. João beach (between Cova do Vapor and Costa da Caparica), occurred. At this beach, it was verified that the disappearance of a great amount of sand and dunes suffered an intense erosive process. The beach supports must and will be relocated. The beach and the dunes, according to the historical knowledge and the recent dynamic, will difficultly recover the profiles by natural actions.

Several small emergency works were carried out during the 2002/2003 and 2003/2004 winters to minimize the damages that occurred.

A comprehensive study about coastal management and alternative coastal protection measures Veloso-Gomes (2001) started to be developed.

2 COASTAL PROCESSES

The study area is composed of alluvium deposits (coastal plain) formed after the interaction between sea and river flow regimes. Bathymetric lines close to the shore are almost parallel to the coast line and with a very small slope (Figure 7). Near the Tagus river mouth, there are two sand banks parallel to the navigation channel of the important Lisbon harbor, the north Cabeça do Pato (or north Cachopo) and the south Bugio bar (or south Cachopo), which has suffered very significant morphologic changes in last decades. Between 1939 and 1985, the Bugio bar has moved 700 m to the north and suffered an accentuated loss of sand volume as found in Veloso-Gomes et al. (2003).

The astronomic tides are semidiurnal type, with tidal cycles of approximately 12h 25 m. The maximum spring tide reach in neighbor Cascais tide gauge is about 3.9 m and neap tide is about 0.2 m. Storm surges are smaller than 1 m. The velocities of tidal currents in the Tagus estuary are strong although with low heights. In spring tide, they exceed the 2.0 m/s during the flood and 1.8 m/s during the ebb. The medium values are 1.5 m/s. In the Costa da Caparica ocean waterfront, near the river inlet, the residual tidal currents have a smaller intensity (velocities smaller than 0.2 m/s) and with directions from south to north in front of the Costa da Caparica beach.

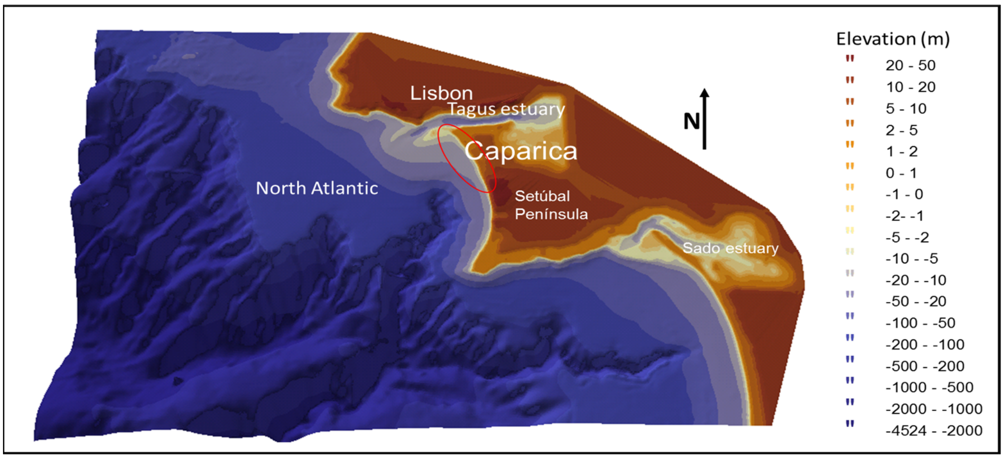

Figure 7. Study area and digital terrain model (DTM) adopted for off-shore wave numerical simulation.

The local wave climate in general is characterized by significant wave heights from 0.5 and 2.5 m, with periods ranging from 5 to 15 seconds, with higher frequencies and intensities came from the WSW to WNW directions. This coastal zone is more exposed to sea storms from SW. During storms significant wave heights Hs can reach 5 m or more. It means that the approaching maximum wave heights H_{max} can reach 9 m before breaking due to shallow waters. There are important local diffraction/refraction phenomena. Several hydrodynamic models have been applied to this coastal area and to the low estuary (Figure 8). From their results and from local observations, it can be concluded that refraction and diffraction patterns explain the fact that the dominant littoral drift transport near the coastal waterfront is from south to north. The coastal configuration north from the sector provides some shelter from the most intense and frequent northwest conditions. Severe wave conditions are mainly coming from the southwest quadrant.

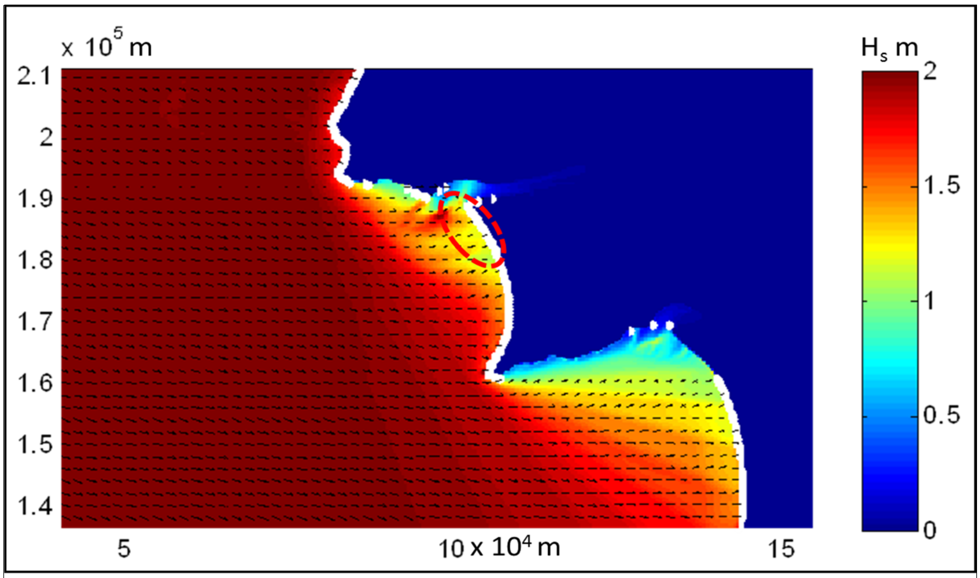

Figure 8. Example of swell numerical simulation (SWAN, H_s = 2 m, T_p = 10 s, θ = 285°).

The swell waves reaches the stretch Cova do Vapor - South of Caparica rotated to Southwest, due the diffraction phenomenon effect (around the Cape Raso, for the coming sea conditions of the quadrants North and West) and refraction (due the area complex bathymetry), inducing a net local alluvium transport from South to North. The ebb tide currents conjugated with action on the bar, reinforce the sand movement capacity in the same direction, depositing finally in the north face of the bar slope, contributing this way for its progression in the same direction. During the ebb, strong currents that are verified in the natural channel promote sand transport into the external side of the bar, depositing them as its intensity decreases, and contributing to the depth reduction that is verified by Veloso-Gomes et al. (2004).

Up to the 90s important dredging activities occur at Lisbon harbor navigation channel and at the NATO navy pier near Cova do Vapor. The dredged sand was used for estuary bank landfills and an unknown percentage was placed offshore. These activities behave like sediment sinks and they induce a negative impact on Caparica sediment balance. River Tagus is the main sediment source but the sediment delivery to the shore line is very intermittent and connected with flow variability and the wave regime. The amounts and locations of such activities have not been released so far and this is a problem in order to evaluate sediment budgets.

Figure 9 identifies and presents the main characteristics of the groins and seawalls that “hold the line” protecting the waterfront of Cova do Vapor and Costa da Caparica. They interfere locally with the natural phenomena in order to retain part of the littoral sand transport and to reduce wave overtopping. The existent structurally degraded solution of defense could be improved. This solution worked for 30 years in terms of coastal protection but it did not provide a beach sufficiently developed for bathing purposes. A beach is important for the stability of structures also. Between those waterfronts, there is a dune system (São João beach) and no hard structures have been built there.

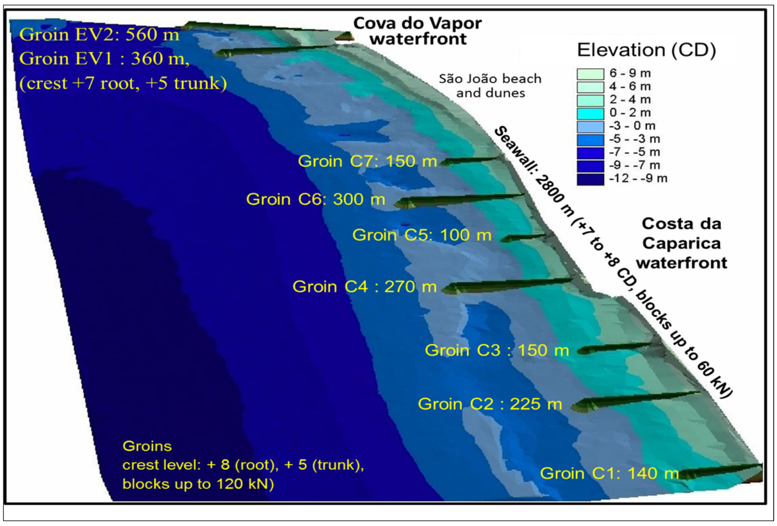

Figure 9. Characteristics of existing coastal protection structures (groin fields and seawalls).

3 MANAGEMENT AND COASTAL PROTECTION MEASURES

Cova do Vapor waterfront and the town of Costa da Caparica waterfront are located at lowlands, under risk of the flooding and destruction of infrastructures. The beaches and dunes will not recover past profiles by natural action.

On this area several economic and tourist activities such as recreational beach and seawall promenade, small fishing boats, two camping sites, surfing activities supported by several schools and international competitions, waterfront restaurants, Lisbon harbor navigation channel, fishing village, etc. are being developed, which generate many economic interest and conflicts.

It is likely that sea level rises will induce negative effects mostly on the local wave climate, level and propagation of tides, coastal erosion, flooding and sediment balance. Climate change can also induce changes in the spectra of off-shore wave climate (storm pathway, wave directions, heights and periods), river and estuary regime, sediment balance. In the study area of Cova do Vapor – Costa da Caparica those effects could be aggravated by the fact that this is an alluvial coast with a limited resistance to the sea action.

Potential scenarios of shoreline mobility, coastal management and coastal protection of the urban seafront have been presented and discussed with authorities, users (surfers, restaurant owners, fishermen, and camping users) and local people.

3.1 Coastal Management Plan

A Coastal Management Plan (POOC) has been prepared and approved in 2003 by the Government after public discussion.

A planned retreat option was considered, but from the socio – economic point of view, it was not considered acceptable for the town of Costa da Caparica.

Due to safety and landscape reasons, this Plan considers the planned retreat of Cova do Vapor settlement (more than one hundred houses) and the planned retreat of two camping sites located closed to the shoreline between Costa da Caparica e São João beach (along 400 m of the coastline). It includes seafront urban development control in the coastal zone south of the groin field. Up to now there is a very strong social resistance against planned retreat.

A program for the re-qualification of urban area and waterfront (CostaPolis) has been prepared, approved (2005/2006) and implemented. Several waterfront restaurants and some dozens of small houses (close to the coastline, along 400 m) have been demolished and relocated. But there was a lack of perception of coastal risks by planners and architects because nine new light structures restaurants have been built along the inside slope of the seawall.

3.2 Coastal Protection Plan

To cope with existing erosion problems, a coastal protection program was launched. In this area, the erosion problems are very serious and with repercussions in terms of patrimony losses and great socio-economical level impacts. For this reason, it is important to defend the area with soft or hard interventions that could reduce the erosion rate. This area has a lack of beach area for the number of users.

Several options were analyzed and discussed including the removal of hard structures and alternative solutions like detached breakwaters. This was not considered acceptable due to safety reasons. The proposed solution, a combined solution of reshaping the existing groins and seawall with artificial sand nourishment, is a commitment to improve the existing solutions, despite the difficulties of forecasting the performance of interventions.

The coastal protection program consists basically of:

- Reshaping of the existent groins, increasing the length of those that will have a "structural" role and reducing the length of the ones that could be, in a medium period, eliminated.
- Reshaping of the existent adherent works (seawall) in the urban waterfront recognizing the vital importance of this structure in terms of defense and the existence of alternatives different than an accentuated retreat of built waterfront (streets and buildings). The platform of the seawall crest should be rehabilitated in order to accommodate pedestrians and biking activities.
- Walk paths along dunes.
- Artificial sand nourishment with origin in dredging works of the Lisbon harbor administration for navigation proposes and/or with origin off-shore (sand sources locations already identified as suitable).
- Feeding the beaches up drift (south) the groins field of Costa da Caparica, between the groins of Costa da Caparica and up drift (south) of São João beach.
- Rehabilitation of São João dunes and all other remaining dunes.

The first phase was concluded in 2006 and consisted in the reshaping of the groin field and seawall. It was expected to implement a maintenance program for these vital structures with very small engineering works in every two years and a reshaping in 2016. This program has not been performed up to now.

The artificial sand nourishment operations of the beach and dunes started in September 2007, when a volume of 500,000 m^3 was placed (Figure 9) between Cova do Vapor southern groin (EV1) and Costa da Caparica middle groin (C4). The second nourishment, carried out between August and October of 2008, was extended to the entire area of intervention, a total of 1 million m^3 of sand were placed. A third-nourishment with 1 million m^3 was completed in July/September 2009. The cost of these operations was shared 50% between the harbor authority and the Ministry of Environment.

The fourth beach nourishment to complete the project should be performed in 2010 but it was delayed by government decision. During the stormy winter 2013/2014, overtopping of the seawall occur and some of the new restaurants glass windows were partially damaged. After public claim, there was a political decision to complete in 2014 the project with a new 1 million m^3 beach nourishment. In this case, the cost was totally supported by the Ministry of Environment.

The origin of the sediments is the Tagus estuary navigation channel dredging. A total amount of 3.5 million m^3 of sand (0.25 to 0.05 mm diameter particles) was introduced in the system in four nourishments.

The impact mitigation measures taken, related with fishing, bathing, surfing and tourism activities were successful. The coastal protection plan was completed without major conflicts with stakeholders and without personal accidents.

A new coastal protection plan is needed at least do provide structural maintenance and new beach nourishment using dredged sediments coming from the maintenance of the navigation channel.

4 MONITORING PROGRAM AND SEDIMENT BALANCE

The approved coastal protection interventions include a monitoring program. It is important to implement a monitoring plan to improve the understanding and comprehension of the dynamic process in the area and to improve the design/configuration and the maintenance of the coastal defense interventions as well as their behavior in case of extreme storm conditions.

There was no past experience related with artificial sand nourishment programs in the high energetic Portuguese west coast. In this environment, it is expected that medium/long term positive effects can only be achieved if new reloads are made periodically. The time life of such first nourishment will be very important to improve cost-benefits results.

In the less wave exposed southern coast of Portugal (Algarve), there are several beach nourishment interventions with different degrees of success. If such nourishments are implemented between breakwaters and groins (Vilamoura) or between breakwaters and natural caps (Praia da Rocha) they behave very well in respect to the fill residence time that can reach more than forty years. If they are implemented in open coast (Vale do Lobo), the life span can be about five years.

In the high exposed northern west coast of Portugal, artificial sand nourishment can be an impracticable solution if there are no transverse trapping structures due to the high potential littoral drift transport that can reach two million cubic meters per year. This is what happened in Porto (Matosinhos beach) with a two million cubic meters nourishment project from dredging harbor activities that had no significant positive impact on the beach.

The monitoring program for Costa da Caparica consists of the following (Silva et al., 2013):

- Structures survey – Proposed one annual overall survey to be realized in May of every year, as well as coastal structures inspection after major storms.
- Global hydrographic survey – Proposed two annual hydrographic surveys to be realized in May (after the storm season) and September (after the calm season) of every year.
- Local hydrographic survey - Proposed two annual hydrographic surveys to be realized in May and September of every year, near the groins
- Aerial images survey – Proposed one high resolution orthogonal photo annual survey to be realized in low spring tide August/September of every year.

It is of major importance to do one global hydrographic survey before and after the beach nourishment. The first is very important for the evaluation as an initial reference and to adjust the technical procedures. The second one is of great significant to assess the technical intervention and to evaluate/understand the movement/dynamic of sands as well as the cross shore profile evolution and the time that sand remained in the system, through comparison with other future surveys and aerial images (medium term assessment). Due to financial constraints the monitoring program was partially performed.

The first comparison of bathymetric survey has been done using the September 2001 and 2005 surveys (Figure 10).

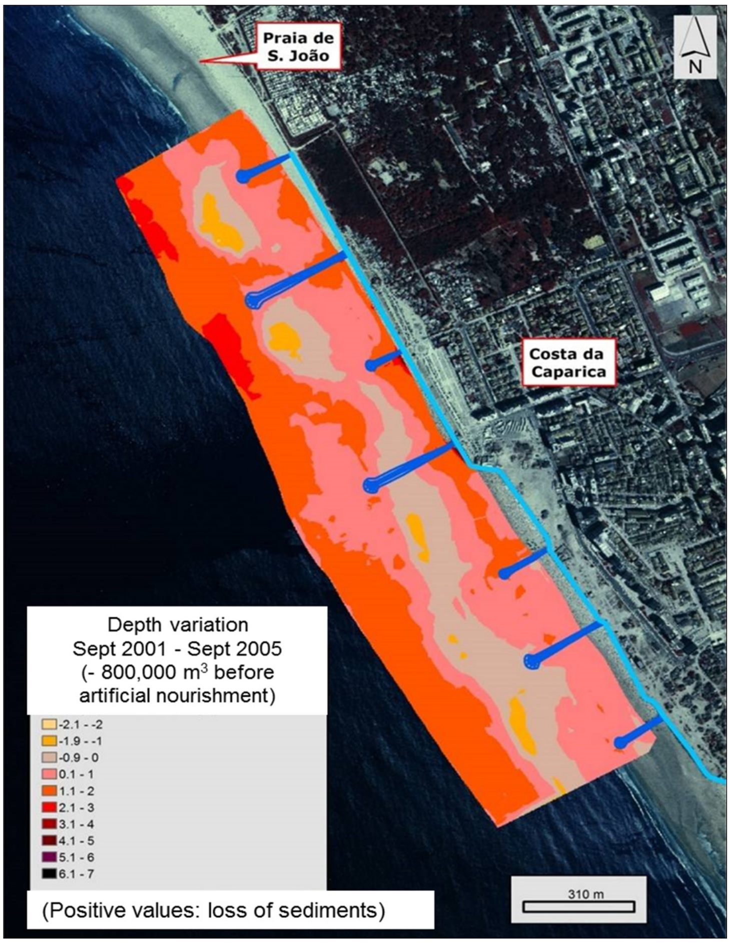

Figure 10. Depth variation between September 2001 and September 2005.

It has been verified that the bathymetric lines of smaller depths are moving to landward. This could indicate an increase of profile steepness, as well as that the higher waves will break more close to the coastline and more close to the coastal structures increasing local scour. These facts will increase the wave energy on the coastal structures and the need for maintenance, as well as on the beaches and dunes, removing the sediments with more intensity. The sediment balance estimate, between September of 2001 and September of 2005, was the loss of 800,000 m^3 of sand only in the groins field area.

During storms and at high tides there are significant pattern changes (refraction, diffraction and reflection phenomena inside the cells, rip-current formation and dispersal points for sediments and eddies and local scour).
Several comparisons of bathymetric survey have been done using the surveys from September 2001 till June 2013 (Figure 11).

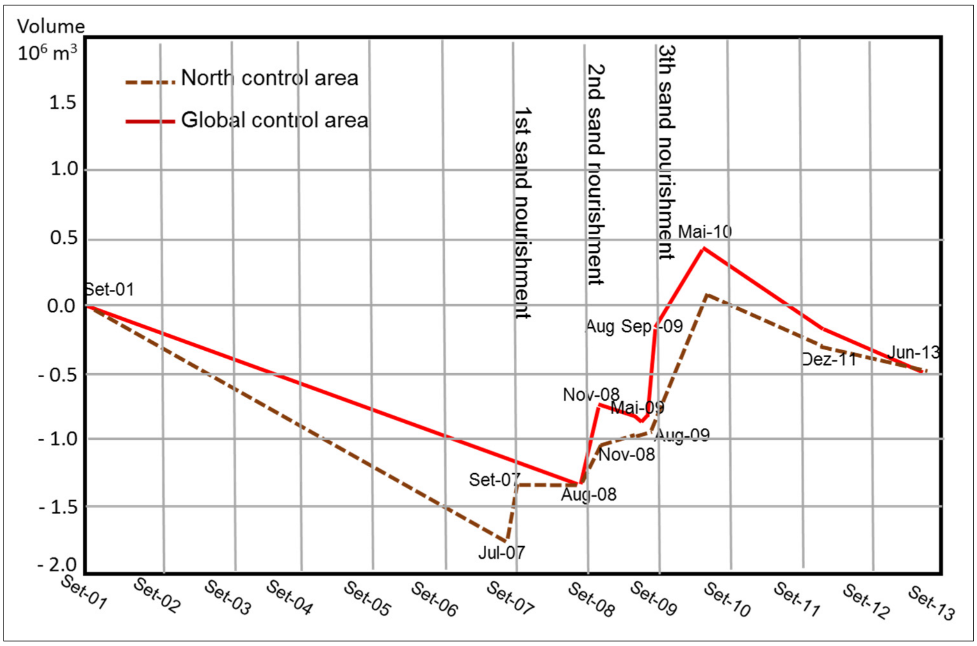

Figure 11. Sediment balance between 2001 and 2013 considering two control areas.

The groin field functions in retaining sand in the surrounding area. The sand that artificially nourished the beaches doesn't appear to be lost to higher depths than 12 m.

Better nourishment efficiency would be expected if the operations would have been conducted in spring time, under conditions proper for sediments consolidation on the beach. However, the nourishment timing is constrained by legal issues for more than strictly technical and operations took place during the late summer (Silva et al., 2013). As a first assessment conclusion, the stability of the beaches requires a mean nourishment rate of about 300,000 m^3 /year.

5 CONCLUSIONS

The capacity to forecast the medium and long term beach and dune evolution in highly vulnerable and edge risk areas continues to be very limited due to scientific constraints and to lack of long term field data namely topo-hydrographic.

It is necessary to adopt a preventive policy as well as a curative one because of the severity of the present problems. The adopted decision in the urban area was to hold the coastline in the urban water front. Hard solutions were combined with soft solutions framed by urban planning control and planed retreat. Buffer zones are very important so the urban development cannot occupy the remaining dunes.

The impact mitigation measures taken, related with fishing, bathing, surfing and tourism activities, were successful. The coastal protection plan was completed without major conflicts with stakeholders and without personal accidents.

A new coastal management plan is needed at least to provide structural maintenance and periodic beach nourishment using sediments from the maintenance dredging of the navigation channel.

An artificial nourishment program should be pursued to shape the coast approximately to previous configurations. It could be a hybrid intervention with beach profile fill and near shore berm fill. The wave and tide natural actions will provide a more adaptable profile. The question is how long this nourishment will be effective. The groin field is functioning in retaining sand in the surrounding area. As a first assessment conclusion, the stability of the beaches requires a mean nourishment rate of about 300,000 m^3 / year.
It is important to pursue the monitoring plan to improve the understanding and comprehension of the dynamic process in the area and to improve the design and the maintenance plan of the coastal protections interventions.

ACKNOWLEDGEMENTS

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REFERENCES

Silva, R., Veloso-Gomes, F. & Pais-Barbosa, J. (2013). Morphological Behaviour of Costa da Caparica Beaches Monitored during Nourishment Operations. *Journal of Coastal Research* 65(sp2), 1862-2867.

Veloso-Gomes (2001). *Estudo de Reabilitação das obras de defesa Costeira e de Alimentação Artificial na Costa da Caparica, Estudo Prévio e Projecto Base*. IHRH / Faculdade de Engenharia da Universidade do Porto, Porto, 1-9.

Veloso-Gomes, F., Taveira Pinto, F., Neves, L. & Pais Barbosa, J. (2003), Eurosion Project, (ENV.B3/SER/ 2001/0030 (RIKZ-1146)), Volume 2, IHRH/FEUP, Porto, 95 pp.

Veloso-Gomes, F., Taveira-Pinto, F. & Pais-Barbosa, J. (2004). Rehabilitation Study of Coastal Defense Works and Artificial Sand Nourishment at Costa da Caparica, Portugal. *Proceedings of 29th International Conference of Coastal Engineering*, ASCE, 3429-3440.

THE RESILIENCY OF COASTAL MARSH SYSTEMS UNDER SEA LEVEL RISE

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ABSTRACT

Coastal wetlands, specifically salt marsh systems, are ecosystems that are at risk of increased flooding, reduced productivity, and potential collapse under increasing rates of sea level rise (SLR). Salt marsh systems will respond differently to changes in mean sea level due to their geographic location, sediment source, salinity, and tide range. Therefore, it is critical to study how various estuaries and their salt marshes may respond to SLR. Herein, we focus on estuarine systems along the northern Gulf of Mexico (Mississippi, Alabama, and the Florida panhandle) coasts. Hydrodynamics and biomass productivity for each study site were simulated using the Hydro-MEM model to examine the marsh response to changes in mean sea level across four SLR projections for the year 2100. The Hydro-MEM model uses the ADvanced CIRCulation (ADCIRC) code to incorporate the dynamics of SLR and the complex flooding and ebbing within a marsh system. Results demonstrated the response of salt marsh productivity and the potential for upland migration for each estuarine system. To make the ecosystems more resilient through natural recovery, removing additional stressors is recommended. This research demonstrates that preparing higher lands for wetland migration can help these ecosystems become more resilient to SLR. The end product serves as a tool for coastal managers to make informed decisions about wetland vulnerability to SLR and allow for proper planning to foster resiliency.

Keywords: Salt marsh; Hydro-MEM; sea level rise; northern Gulf of Mexico.

1 INTRODUCTION

The resilience of an ecosystem can be described as the system's ability to absorb changes and adapt to evolving situations (Elliott et al., 2007). Coastal wetlands in the Northern Gulf of Mexico (NGOM) are experiencing diverse stressors including sea level rise (SLR) and climate change that can affect their future productivity (Nicholls et al., 1999; Thieler and Hammer-Klose, 1999). Several studies have demonstrated that under SLR salt marshes may lose their productivity, migrate to higher lands, be replaced by other species or become completely inundated (Donnelly and Bertness, 2001; Warren and Niering, 1993). Due to their critical role in coastal ecosystems, and wave and storm surge protection, it is necessary to assess future changes to inform resource managers.

Marsh systems and estuarine responses to SLR have been the focus of numerous studies (Hagen et al., 2013; Hearn and Atkinson, 2001; Leorri et al., 2011; Liu, 1997; Valentim et al., 2013) and several integrated models have been developed (D' Alpaos et al., 2007; Kirwan and Murray, 2007; Temmerman et al., 2007). However, most of these models span local marsh systems and do not consider the long-term marsh migration. This study applied the spatially-explicit Hydro-MEM model for three vast marsh systems located within the National Estuarine Research Reserves (NERRs) across the NGOM. The Hydro-MEM model incorporates biological feedbacks via information exchange between hydrodynamic and biological models within a time step framework (Alizad et al., 2016a). Marsh platform topography was adjusted using Real Time Kinematic (RTK) surveying data to avoid perturbing the inherent error in the lidar-derived topographic data (Alizad et al., 2016b; Medeiros et al., 2015).

Hydro-MEM was developed to capture the dynamics of SLR and its effect on marsh productivity. The model calculates Mean High Water (MHW) within the bay, rivers, creeks, and across the marsh platform to include the dynamics of SLR and water level changes induced by complex physics of low-gradient coastal systems (Passeri et al., 2015) in biomass density calculation. Four SLR projections of low, intermediate low, intermediate high, and high for the year 2100 (Parris et al., 2012) were employed in the simulations.

The three NERRs are located in Grand Bay, MS, Weeks Bay, AL, and Apalachicola, FL (Figure 1) and are fluvial, marine, and mixed estuarine systems with unique hydrodynamic and topographic characteristics that can influence marsh productivity. The Apalachicola River is the largest river in terms of discharge in Florida and 17% of the estuary is covered with marsh that is a habitat for many species (Halpin, 2000; Isphording, 1985; Pennings and Bertness, 2001). Grand Bay, MS is located at the border of Alabama and Mississippi. This marine dominated estuary does not have any fluvial source and the marsh system covers 49% of the estuary (Peterson et al., 2007). Weeks Bay, AL is a mixed estuary that receives annual average inflow of 5 cubic meters per second from the Fish and Magnolia Rivers, which is less than 1% of the Apalachicola River's discharge.

Due to the vulnerability of the three selected estuarine systems in the NGOM because of stressors (Eleuterius and Criss, 1991; Livingston, 1984; Shirley and Battaglia, 2006), it is critical to provide the means for coastal managers to aid the resilience of these systems.

2 METHODS

Three different estuarine systems were investigated using the Hydro-MEM model: Apalachicola River, FL; Grand Bay, MS; and Weeks Bay, AL. The model (Alizad et al., 2016a) is comprised of two main elements, hydrodynamic and parametric marsh model, and are interconnected within a time stepping framework. The depth-integrated, hydrodynamic model (ADCIRC-2D) inputs include initial sea level, bottom friction, astronomic tides, and an unstructured finite element mesh that resolves the marsh landscape with high resolution (15m horizontal). The hydrodynamic model provides input in the form of mean low water (MLW) and mean high water (MHW) derived from tidal constituents for the marsh equilibrium model (MEM) (Morris et al., 2002). The MEM updates bottom friction and elevation from biomass density and accretion to characterize the hydrodynamic model inputs for the next time step. The sea level is also updated for each time step. The SLR scenarios used in this study are low (0.2m), intermediate low (0.5m), intermediate high (1.2m), and high (2m) for the year 2100 (Parris et al., 2012). The simulation continues with a time step of 5 years for intermediate high and high SLR and 10 years for intermediate low and low SLR and terminates at the simulation targeted time (2100). The results are in the form of biomass density and categorized as low, medium, and high productivity.

The hydrodynamic model was developed and extensively validated in previous studies (Bilskie et al., 2016; Passeri et al., 2016). The marsh platforms were adjusted due to the error in the lidar-derived elevations as a result of the laser being blocked and reflected by elevated vegetation (Medeiros et al., 2015). The inflow boundary conditions for Apalachicola, Fish, and Magnolia Rivers were applied using USGS gage data. The discharge was considered constant for all of the scenarios. Manning's n was initialized using NLCD 2001 (Homer et al., 2004) and empirical observation methods (Arcement and Schneider, 1989) and updated at each time step incorporating different appropriate values associated with low, medium, and high marsh productivity (Alizad et al., 2016b; Medeiros et al., 2012).

The MEM part of the model calculates biomass density and marsh platform accretion rate using a parabolic function that is derived from extensive field experiments. The parabolic curve is a function of the MHW depth above marsh platform elevation and three experimental constants that are unique for each estuarine system (Alizad et al., 2016b; Morris et al., 2002). The empirical formula for accretion rate uses biomass density, depth, and the constants for organic and inorganic accumulation were applied to update marsh platform elevation at each time step.

3 RESULTS AND DISCUSSIONS

The results showed spatial and temporal marsh productivity change which are categorized as low, medium, and high productivity and demonstrated by red, yellow, and green respectively. Figure 1 shows marsh productivity for the three estuarine systems. The marsh systems in Grand Bay, MS (Figure 1a) and Apalachicola, FL (Figure 1c) are larger in area compared to the Weeks Bay marsh (Figure 1b).

In the year 2030, under low and intermediate low SLR scenarios, marsh systems remain similar to current conditions (Figure 1) with some productivity changes (Figure 2a-f), whereas higher SLR affects each selected estuarine system uniquely. The Grand Bay marsh was projected to widen and become more productive in the year 2030 under intermediate high and high SLR (Figure 2g,2j) while the Apalachicola marsh area was reduced (Figure 2i,2l). Higher SLR was shown to benefit the marsh system in Weeks Bay. The higher topography helped to generate the new marsh systems near Bon Secour Bay and the expansion of the current wetlands in the Weeks Bay estuary (Figure 2h,2k).

The first row of the year 2050 maps in Figure 3 (the low SLR scenario) shows extensive marsh area expansion in Apalachicola (Figure 3c) whereas the effects are less pronounced in Grand Bay and Weeks Bay. Although intermediate low SLR did not affect the marsh systems in all of the selected estuaries (Figure 3d-f), the intermediate high SLR scenario provided a suitable situation for the marsh system in Weeks Bay (Figure 3h) to extend their territory while marshes in Apalachicola were projected to lose their productivity and reduce in the year 2050. Figure 5g shows the most highly productive salt marsh in Grand Bay (dark green color) which expanded into higher lands. However, the yellow colors close to the bay in addition to some drowned wetlands and ponds indicated the starting point of the potential for marsh collapse (Figure 3g). Under the high SLR scenario in the year 2050, Grand Bay and Apalachicola wetlands lost their productivity, drowned, and migrated to higher lands (Figure 3j,3l), but Weeks Bay marsh system showed higher productivity and expanded into higher lands because of suitable topography and the narrow inlet positive controlling role between Weeks Bay and Bon Secour Bay.

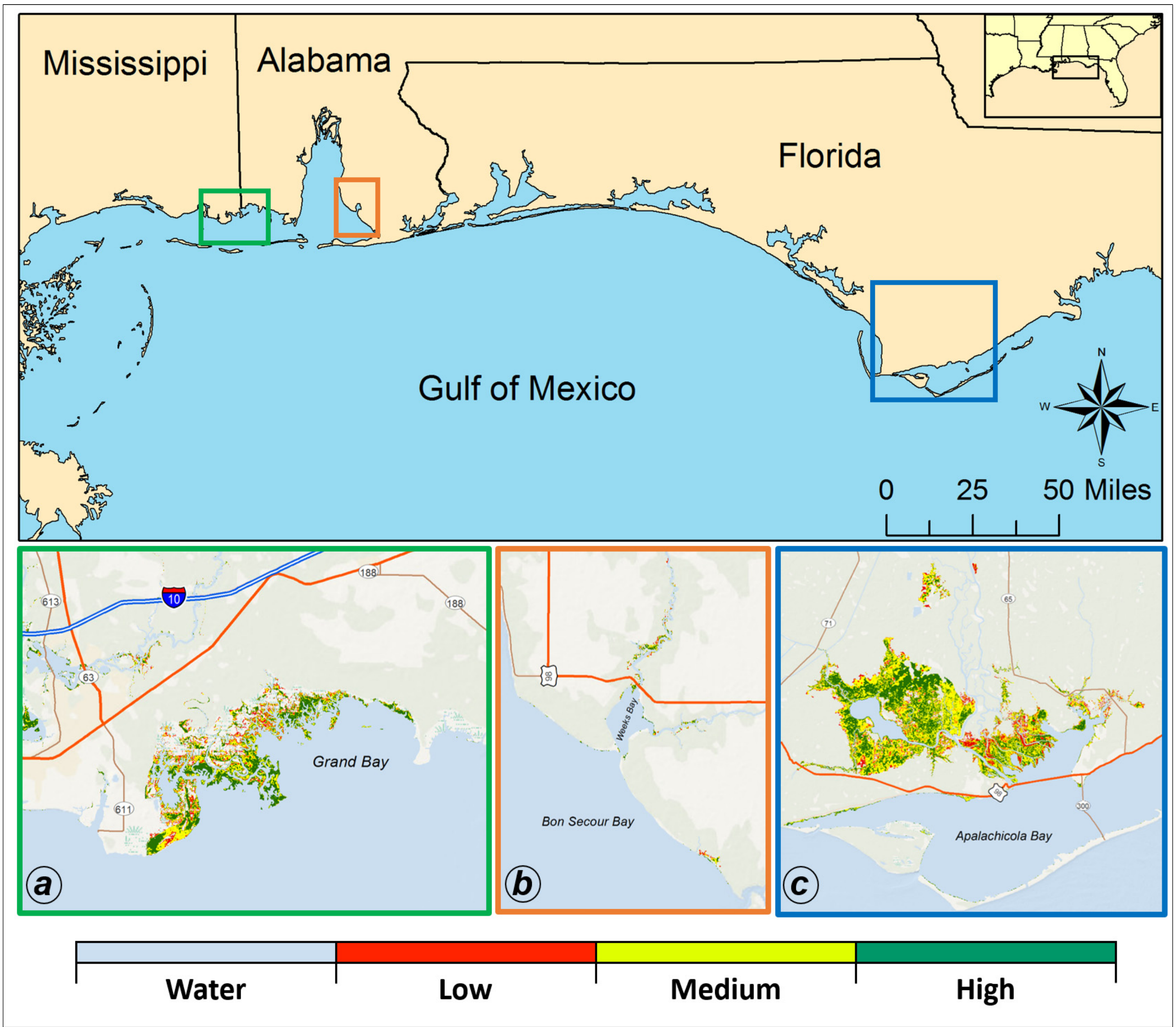

Figure 1. The location of Grand Bay, MS, Weeks Bay, AL, Apalachicola, FL estuarine systems (top figure) and simulated current marsh system productivity in figures a, b, and c (Alizad et al., 2016b). Red, yellow, and green shows low, medium, and high productivity.

In the year 2080, the same trend as the year 2050 for the low and intermediate low SLR scenarios was projected to continue (Figure 4 a-f). The Weeks Bay marsh also followed the same trend as 2050 under the intermediate high SLR scenario. However, the changes for the Apalachicola and Grand Bay estuaries under the intermediate high SLR sped up where the marsh systems mostly drowned and the remaining spots had low productivity except for the marshes that migrated to higher lands (Figure 4g,4i). As demonstrated in Figure 4j, the marsh system in Grand Bay completely drowns and the bay is extended to ultimately connect with the Escawtapa River. As previously mentioned, the narrow inlet protects Weeks Bay from SLR. In the year 2080, the inlet was projected to become wider as a result of SLR. This induces higher water level in the Weeks Bay that causes marsh system loss around the bay, and Fish and Magnolia Rivers as well as producing new marsh lands between Weeks Bay and Bon Secour Bay (Figure 4k). The marsh system in Apalachicola under the high SLR scenario in the year 2080 was projected to become completely inundated with some marsh migration to the higher lands (Figure 4l).

The projections for the year 2100 are mostly similar to the year 2080 (Figure 5). By this year, Apalachicola marsh was projected to be more productive under the low SLR than the intermediate low SLR (Figure 5c,5f), whereas the Grand Bay marsh benefits more from the intermediate low SLR (Figure 5a,5d). The Grand Bay marsh was predicted to be under water for both intermediate high and high SLR with the generation of some marsh islands under high SLR as a result of the Grand Bay and Escawtapa River connection (Figure 5g,5j).

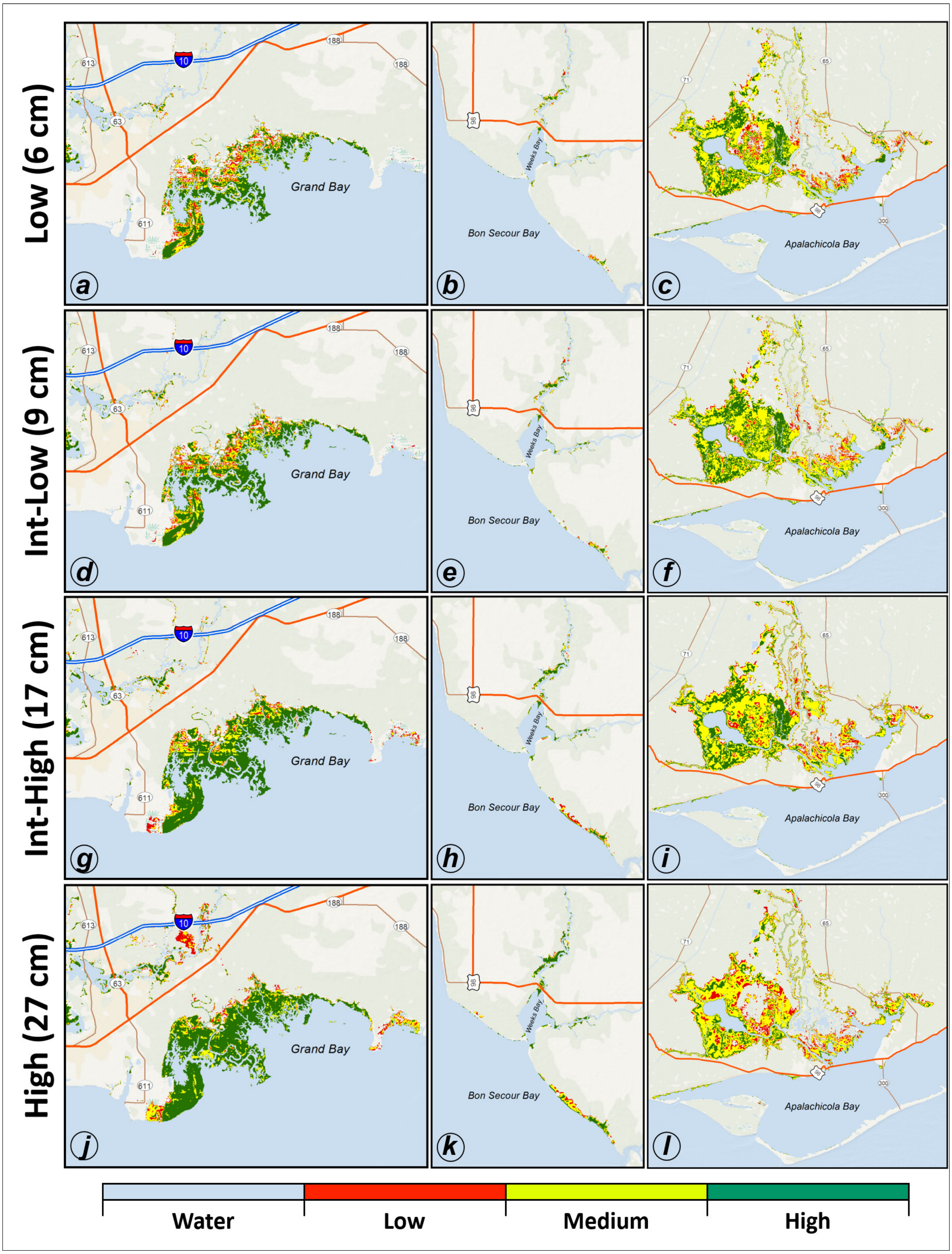

Figure 2. Salt marsh productivity projection maps for the year 2030 for the Grand Bay, MS, Weeks Bay, AL, Apalachicola, FL estuaries shown in the first to third columns, respectively. The top to bottom rows represent low, intermediate low, intermediate high and high SLR scenarios. The red, yellow, and green colors in the maps demonstrates low, medium, and high productivity.

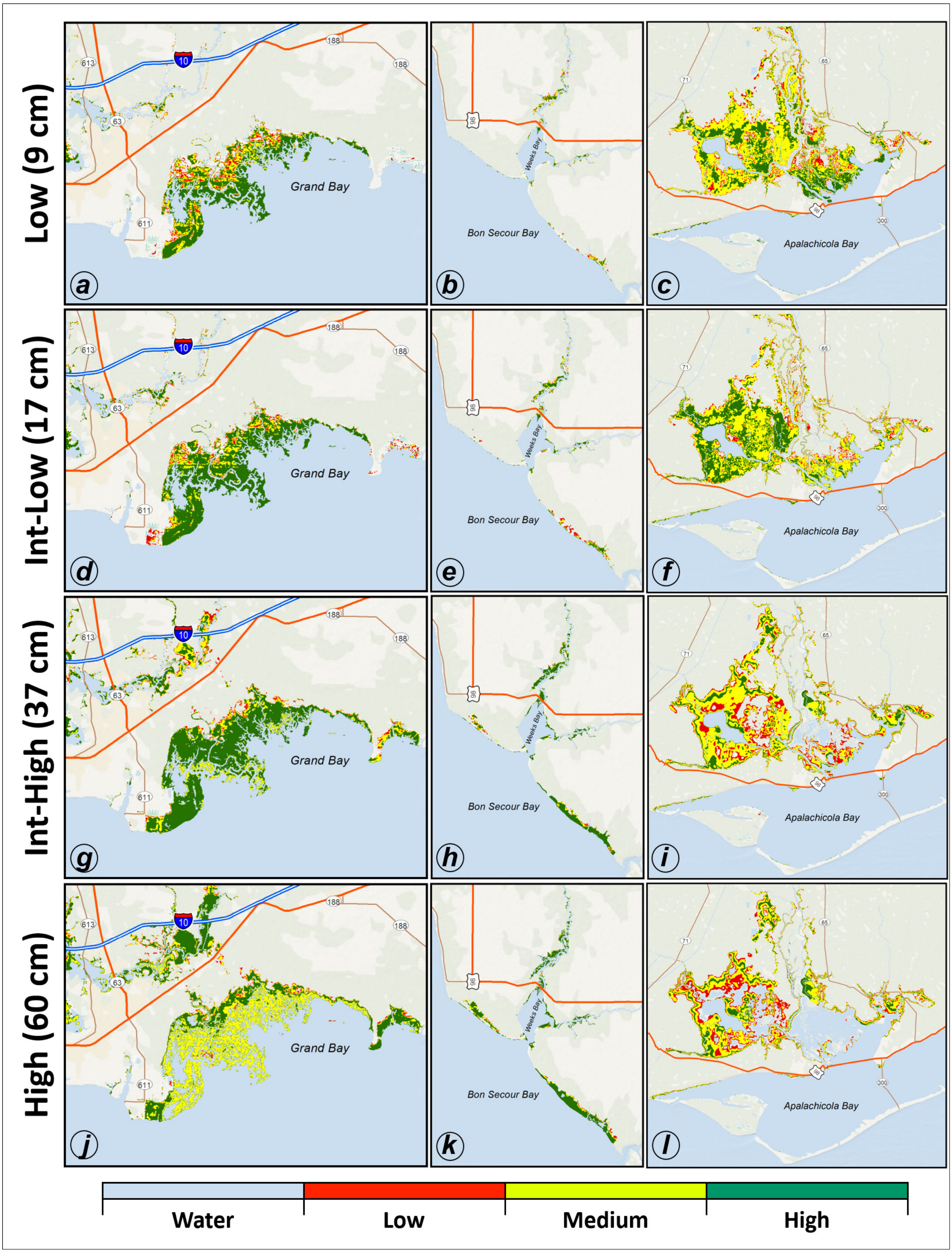

Figure 3. Salt marsh productivity projection maps for the year 2050 for the Grand Bay, MS, Weeks Bay, AL, Apalachicola, FL (Alizad et al., 2016b) estuaries shown in the first to third columns, respectively. The top to bottom rows represent low, intermediate low, intermediate high and high SLR scenarios. The red, yellow, and green colors in the maps demonstrates low, medium, and high productivity.

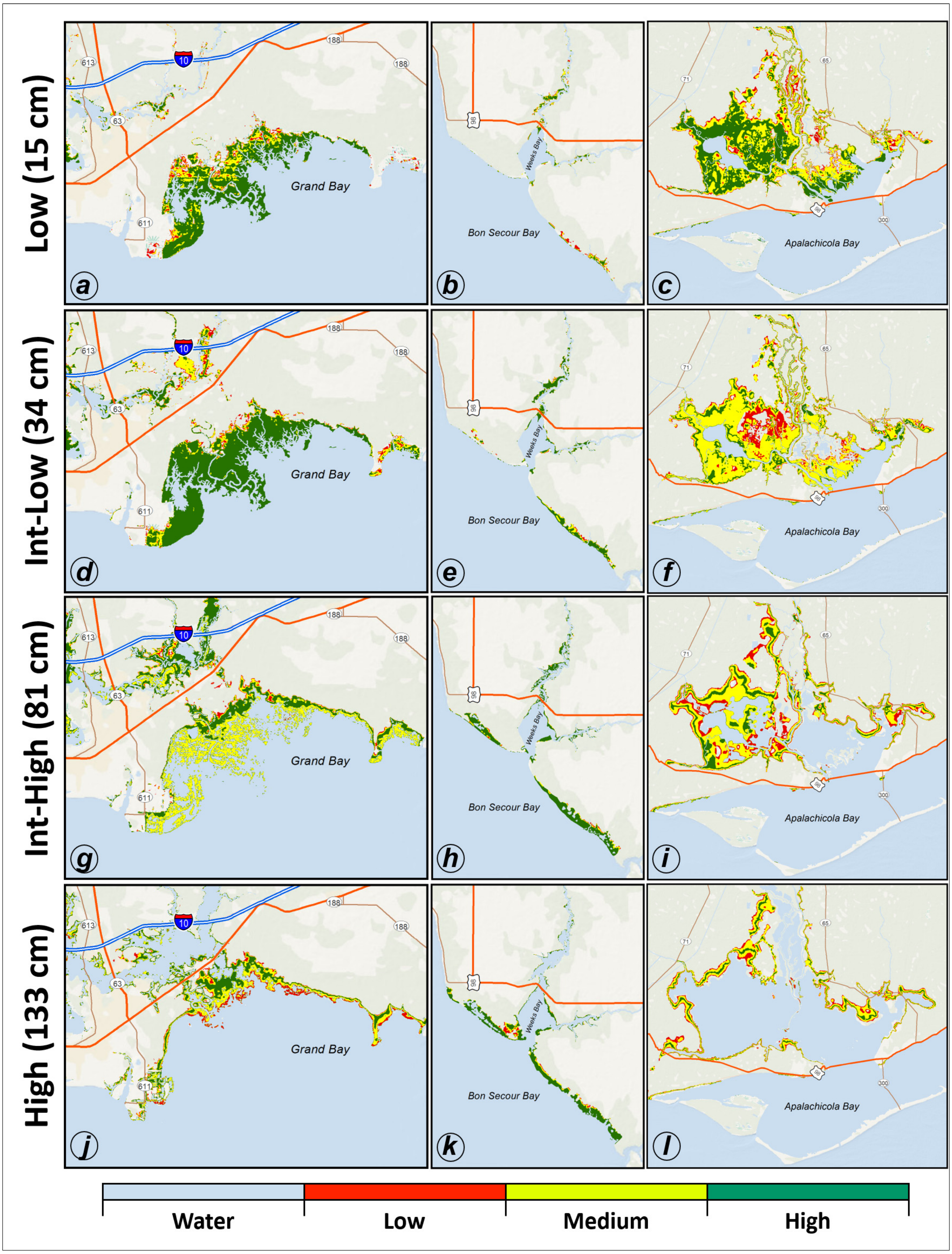

Figure 4. Salt marsh productivity projection maps for the year 2080 for the Grand Bay, MS, Weeks Bay, AL, Apalachicola, FL (Alizad et al., 2016b) estuaries shown in the first to third columns, respectively. The top to bottom rows represent low, intermediate low, intermediate high and high SLR scenarios. The red, yellow, and green colors in the maps demonstrates low, medium, and high productivity.

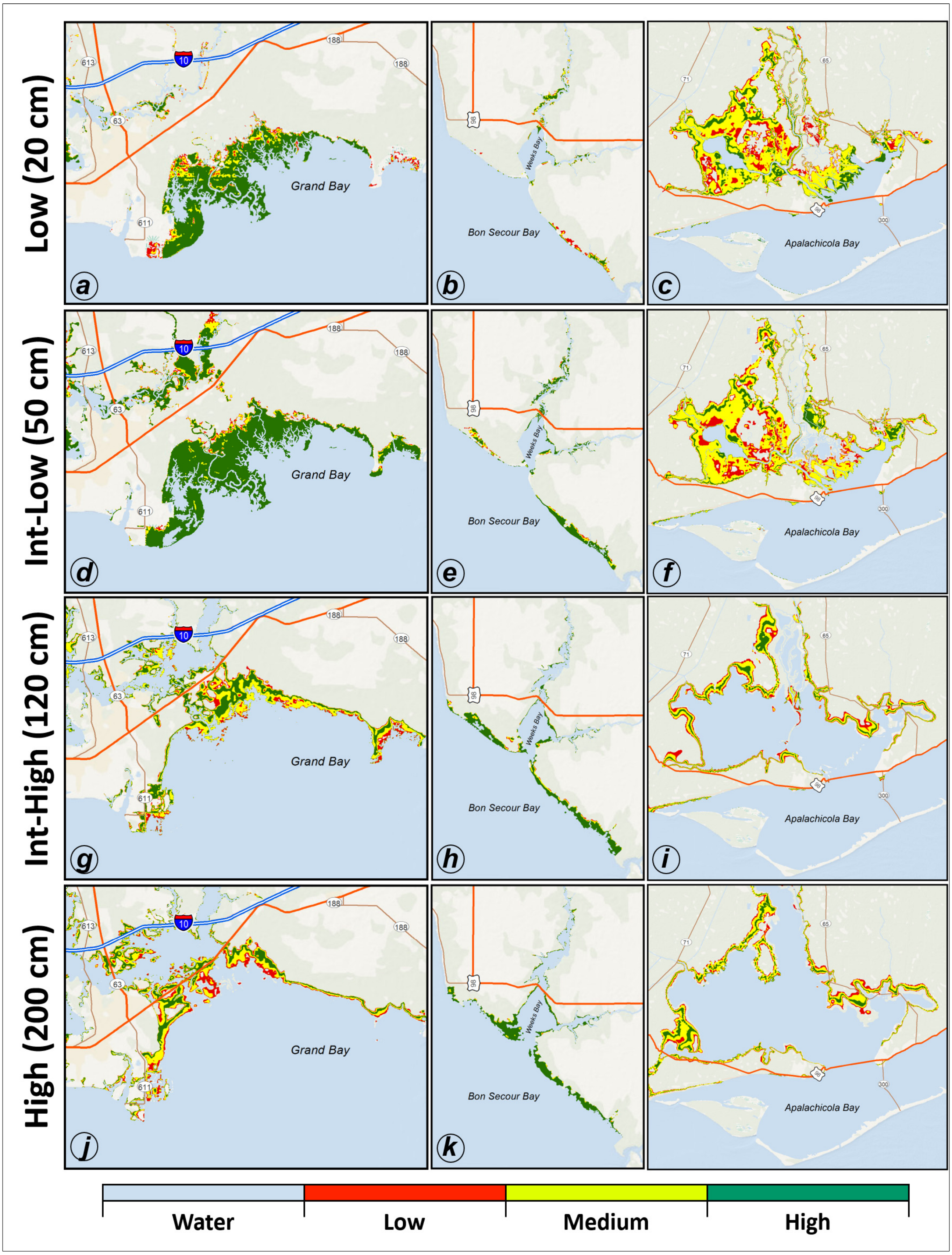

Figure 5. Salt marsh productivity projection maps for the year 2100 for the Grand Bay, MS, Weeks Bay, AL, Apalachicola, FL (Alizad et al., 2016b) estuaries shown in the first to third columns, respectively. The top to bottom rows represent low, intermediate low, intermediate high and high SLR scenarios. The red, yellow, and green colors in the maps demonstrates low, medium, and high productivity.

The transition between maps (Figure 1-5) for each estuarine system specifically under higher SLR scenarios demonstrated marsh migration paths. This migration is possible if the lands are not developed or not obstructed by the private lands. The Hydro-MEM model outputs showed the potential for marsh migration based on the topography. The results also indicated that the estuaries' hydrodynamic characteristics play a key role in their responses to rising sea level. The lack of fluvial source in Grand Bay and marsh system topography and open bay in Apalachicola make them more vulnerable to SLR than the Weeks Bay estuary. Weeks Bay is benefited from its unique topography and unique geometry characteristics of the narrow inlet between Bon Secour Bay and Weeks Bay that protects it from higher water levels and flows induced by SLR. The marsh system in Apalachicola starts losing its productivity at 30cm of SLR and becomes fully inundated at 60cm while Grand Bay loses its productivity at 55cm and is fully drowned at 80cm. This inundation limit for Weeks Bay of 1m is because of the higher lands and the bay's narrow inlet.

Several studies used the Hydrologic Unit Codes (HUC) to facilitate geo-referencing and mapping wetland or erosion assessments (Jang et al., 2015; Nestlerode et al., 2014). This helps in dividing the maps into the small regions to facilitate management process for coastal managers. Future study will apply this geographical reference to provide marsh migration and biomass density projections to be employed in ecosystem services valuations and economic assessments. This will provide stakeholders with tools to prepare for the potential effects of SLR.

4 CONCLUSIONS

This research applied the Hydro-MEM model to assess salt marsh response to SLR and provide inputs for coastal managers to make them more resilient to the projected sea level changes. The model included the dynamic effects of SLR as well as biological feedbacks using a time stepping integrated framework. The results in three different estuarine systems from the current condition to 2100 showed different responses based on the topography, SLR scenarios, and geometric characteristics of the estuaries. Apalachicola and Grand Bay estuaries showed more vulnerability than Weeks Bay which is protected from tidal flows from Bon Secour Bay and Mobile Bay by its narrow inlet and higher lands. Marsh migrations to the higher lands were projected under the higher SLR scenarios in Weeks Bay while all of the marsh systems become inundated in Apalachicola and Grand Bay estuaries. The biomass projection maps will help to guide restoration and monitoring projects as well as generate tools to perform economic assessments and ecosystem services valuations. The combined set of biogeophysical, economic assessment and ecosystem services valuations tools will aid in the assessment of natural restorative measures (*e.g.*, thin layer disposal of dredging material, barrier island restoration) and in the identification of potential regions for future marsh migration. The opportunity to enhance coastal resiliency exists through such a systems-based analysis.

ACKNOWLEDGEMENTS

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REFERENCES

Alizad, K., Hagen, S.C., Morris, J.T., Bacopoulos, P., Bilskie, M.V., Weishampel, J. & Medeiros, S.C. (2016a). A Coupled, Two-Dimensional Hydrodynamic-Marsh Model with Biological Feedback. *Ecological Modeling*, 327, 29-43.

Alizad, K., Hagen, S.C., Morris, J.T., Medeiros, S.C., Bilskie, M.V. & Weishampel, J.F. (2016b). Coastal Wetland Response to Sea-Level Rise in a Fluvial Estuarine System. *Earth's Future*, 4(11), 483-497.

Arcement, G.J. & Schneider, V.R. (1989). *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains*, US Government Printing Office, Washington, DC, USA.

Bilskie, M.V., Hagen, S.C., Medeiros, S.C., Cox, A.T., Salisbury, M. & Coggin, D. (2016). Data and Numerical Analysis of Astronomic Tides, Wind-Waves, and Hurricane Storm Surge along the Northern Gulf of Mexico. *Journal of Geophysical Research: Oceans*, 121(5), 3625-3658.

D' Alpaos, A., Lanzoni, S., Marani, M. & Rinaldo, A. (2007). Landscape Evolution in Tidal Embayments: Modeling the Interplay of Erosion, Sedimentation, and Vegetation Dynamics. *Journal of Geophysical Research: Earth Surface*, 112(F1).

Donnelly, J.P. & Bertness, M.D. (2001). Rapid Shoreward Encroachment of Salt Marsh Cordgrass in Response to Accelerated Sea-Level Rise, *Proceedings of the National Academy of Sciences*, 98(25), 14218-14223.

Eleuterius, C.K. & Criss, G.A. (1991). *Point aux Chenes: Past, Present, and Future Persepctive of Erosion*, Physical Oceanography Section Gulf Coast Research Laboratory, Ocean Springs, Mississippi.

Elliott, M., Burdon, D., Hemingway, K.L. & Apitz, S.E. (2007). Estuarine, Coastal and Marine Ecosystem Restoration: Confusing Management and Science – A Revision of Concepts. *Estuarine, Coastal and Shelf Science*, 74(3), 349-366.

Hagen, S., Morris, J., Bacopoulos, P. & Weishampel, J. (2013). Sea-Level Rise Impact on a Salt Marsh System of the Lower St. Johns River. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 139(2), 118-125.

Halpin, P.M. (2000). Habitat Use by an Intertidal Salt-Marsh Fish: Trade-Offs between Predation and Growth. *Marine Ecology Progress Series*, 198, 203-214.

Hearn, C.J. & Atkinson, M.J. (2001). *Sea-level Changes and Their Effects.* World Scientific Publishing, Singapore, USA and UK, 25-47.

Homer, C., Huang, C., Yang, L., Wylie, B. & Coan, M. (2004). Development of a 2001 National Land-Cover Database for the United States. *Photogrammetric Engineering & Remote Sensing*, 70(7), 829-840.

Isphording, W.C. (1985). *Sedimentological Investigation of the Apalachicola Bay, Florida Estuarine System,* prepared for the Mobile District, Corps of Engineers, University of Alabama.

Jang, T., Vellidis, G., Kurkalova, L.A., Boll, J. & Hyman, J.B. (2015). Prioritizing Watersheds for Conservation Actions in the Southeastern Coastal Plain Ecoregion. *Environmental Management*, 55(3), 657-670.

Kirwan, M.L. & Murray, A.B. (2007). A Coupled Geomorphic and Ecological Model of Tidal Marsh Evolution, In *Proceedings of the National Academy of Sciences*, 104(15), 6118-6122.

Leorri, E., Mulligan, R., Mallinson, D. & Cearreta, A. (2011). Sea-Level Rise and Local Tidal Range Changes in Coastal Embayments: An Added Complexity in Developing Reliable Sea-Level Index Points. *Journal of Integrated Coastal Zone Management*, 11(3), 307-314.

Liu, S.K. (1997). Using Coastal Models to Estimate Effects of Sea Level Rise. *Ocean & Coastal Management*, 37(1), 85-94.

Livingston, R.J. (1984). *Ecology of the Apalachicola Bay System: An Estuarine Profile*, report No. FWS/OBS-82/05, Dept. of Biological Science, Florida State Univ., Tallahassee, USA.

Medeiros, S., Hagen, S., Weishampel, J. & Angelo, J. (2015). Adjusting Lidar-Derived Digital Terrain Models in Coastal Marshes Based on Estimated Aboveground Biomass Density. *Remote Sensing*, 7(4), 3507-3525.

Medeiros, S.C., Hagen, S.C. & Weishampel, J.F. (2012). Comparison of Floodplain Surface Roughness Parameters Derived from Land Cover Data and Field Measurements. *Journal of Hydrology*, 452, 139-149.

Morris, J.T., Sundareshwar, P.V., Nietch, C.T., Kjerfve, B. & Cahoon, D.R. (2002). Responses of Coastal Wetlands to Rising Sea Level. *Ecology*, 83(10), 2869-2877.

Nestlerode, J.A., Hansen, V.D., Teague, A. & Harwell, M.C. (2014). Application of a Three-Tier Framework to Assess Ecological Condition of Gulf of Mexico Coastal Wetlands. *Environmental Monitoring and Assessment*, 186(6), 3477-3493.

Nicholls, R.J., Hoozemans, F.M. & Marchand, M. (1999). Increasing Flood Risk and Wetland Losses due to Global Sea-Level Rise: Regional and Global Analyses. *Global Environmental Change*, 9, S69-S87.

Parris, A., Bromirski, P., Burkett, V., Cayan, D., Culver, M., Hall, J., Horton, R., Knuuti, K., Moss, R., Obeysekera, J., Sallenger, A. & Weiss, J. (2012). *Global Sea Level Rise Scenarios for the US National Climate Assessment*, Tech Memo OAR CPO, National Oceanic and Atmospheric Administration, 1-37.

Passeri, D.L., Hagen, S.C., Medeiros, S.C., Bilskie, M.V., Alizad, K. & Wang, D. (2015). The Dynamic Effects of Sea Level Rise on Low-Gradient Coastal Landscapes: A Review. *Earth's Future*, 3(6), 159-181.

Passeri, D.L., Hagen, S.C., Plant, N.G., Bilskie, M.V., Medeiros, S.C. & Alizad, K. (2016). Tidal Hydrodynamics under Future Sea Level Rise and Coastal Morphology in the Northern Gulf of Mexico. *Earth's Future*, 4(5), 159-176.

Pennings, S.C. & Bertness, M.D., (2001). *Salt Marsh Communities*. In: Bertness, M.D., Gaines, S.D. & Hay, M., editors (Ed.), Marine Community Ecology, Sinauer Associates, Sunderland, Massachusetts, USA, 289-316.

Peterson, M.S., Waggy, G.L. & Woodrey, M.S. (2007). *Grand Bay National Estuarine Research Reserve: An Ecological Characterization*, Grand Bay National Estuarine Research Reserve, Moss Point, Mississippi, 268.

Shirley, L. & Battaglia, L. (2006). Assessing vegetation change in coastal landscapes of the northern Gulf of Mexico. *Wetlands*, 26(4), 1057-1070.

Temmerman, S., Bouma, T.J., Van de Koppel, J., Van der Wal, D., De Vries, M.B. & Herman, P.M.J. (2007). Vegetation Causes Channel Erosion in a Tidal Landscape. *Geology*, 35(7), 631-634.

Thieler, E.R. & Hammer-Klose, E.S. (1999). *National Assessment of Coastal Vulnerability to Sea Level Rise: Preliminary Results for the U.S. Atlantic Coast*, US Geological Survey, Woods Hole, Massachusetts.

Valentim, J.M., Vaz, L., Vaz, N., Silva, H., Duarte, B., Cacador, I. & Dias, J. (2013). Sea Level Rise Impact in Residual Circulation in Tagus Estuary and Ria de Aveiro Lagoon. *Journal of Coastal Research*, 65(sp2), 1981-1986.

Warren, R.S. & Niering, W.A. (1993). Vegetation Change on a Northeast Tidal Marsh: Interaction of Sea-Level Rise and Marsh Accretion. *Ecology*, 74(1), 96-103.

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PATHWAYS TO RESILIENCY THROUGH ECONOMIC ASSESSMENTS OF DYNAMIC SEA LEVEL RISE IMPACTS

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ABSTRACT

This paper introduces the extension of a system-of-systems approach to: (1) refine, enhance, and extend coupled dynamic, bio-geo-physical models of coastal morphology, tide, marsh, and surge; (2) establish and engage stakeholders throughout the entire project process; (3) advance the paradigm shift for SLR assessments by linking economic impact analysis and ecosystem services valuation directly to these coastal dynamics of SLR; and (4) deliver results via a flexible, multi-platform mechanism that allows for region-wide or place-based assessment of natural and nature-based features. The presentation will include discussion of how to assess tradeoffs between economic damages and ecosystem services valuations at the coastal land margin under impacts of sudden (decadal) rises in sea levels and provide strategies that can promote pathways to resiliency.

Keywords: Economic assessments; ecosystem services valuations; low-gradient coastal regions; sea level rise, transdisciplinary research.

1 INTRODUCTION

Over the majority of the 20th century, the largely linear rate of eustatic sea level rise (SLR) was due to thermal expansion of seawater, which is a function of a gradual increase in the average annual global temperature. Research into tide gauge data (Church and White, 2006; Church and White, 2011; Jevrejeva et al., 2006; Jevrejeva et al., 2008) and global satellite altimetry (Nerem et al., 2010) indicates that the rate of global mean SLR has accelerated from approximately 1.6 to 3.4mm/year. While the year-by-year acceleration of the rate of rise cannot be measured adequately, it is reasonable to assume that it was relatively stable throughout the 20th century. For the 21st century, general circulation models project that posed atmospheric carbon emission scenarios will generate higher global average temperatures. A warmer global system will further induce mechanisms (*e.g.*, land ice loss, isostatic adjustments, and changes in land water storage) that will contribute to relatively abrupt changes in sea state levels. The additions to thermal expansion will result in even higher sea levels and the increases in sea level will be attained by further accelerations in the rate of the rise. Because of the nature of the new mechanisms that will govern sea levels, it is unlikely that future accelerations in the rate of rise will be smooth.

Our extensive transdisciplinary efforts since 2010 in the northern Gulf of Mexico (Mississippi, Alabama, and the Florida panhandle) have resulted in a capability to model the coastal dynamics of SLR and assess hydrodynamic, hydrologic, and ecological impacts at the coastal land margin (Alizad et al., 2016; Bilskie et al., 2016; DeLorme et al., 2016; Hovenga et al., 2016; Huang et al., 2016; Kidwell et al., 2017; Morris et al., 2016; Passeri et al., 2015; Passeri et al., 2016; Plant et al., 2016). The establishment of this paradigm shift (*i.e.*, beyond "bathtub" approaches) was made possible, in no small part, by directly involving coastal resource managers at the initial stages and throughout the project process. Potential deleterious effects of SLR to barrier islands, shorelines, dunes, marshes, etc., are now better understood. The paradigm shift, input from coastal resource managers, and future expected conditions provide a rationale to evaluate and quantify the ability of Natural and Nature-based Feature (NNBF) approaches to mitigate the present and future effects of surge and nuisance flooding.

For the northern Gulf of Mexico (NGOM), as defined in Figure 1, we have found that under future projections of sea level rise (SLR), coastal communities and ecosystems may experience land loss, altered habitats, and increased vulnerability to coastal storms and nuisance flooding (Bilskie et al., 2016; Hovenga et al., 2016; Huang et al., 2016; Kidwell et al., 2017). This results from nonlinear increases in tidal ranges, tidal velocities (Passeri et al., 2016), surge heights, and inundation of present-day shorelines. Long-term shoreline erosion rates are also expected to increase under future SLR, which may have detrimental consequences for barrier islands (Plant et al., 2016). Additionally, as Figure 2 exemplifies, coastal salt marshes struggle to keep pace with SLR and rely on sediment accumulation and availability of suitable uplands for migration (Alizad et al., 2016; Morris et al., 2016).

The following introduces an extension to our system-of-systems approach (Hagen et al., 2017). Section 2 describes a paradigm shift to refine, enhance, and extend coupled dynamic, bio-geo-physical models of coastal morphology, tide, marsh, and surge. In Section 3 we emphasize the importance of and provide example literature to establish and engage stakeholders throughout the entire project process. To establish an advancement of the paradigm shift for SLR assessments Section 4 provides an overview of how to link economic impact analysis and ecosystem services valuation directly to these coastal dynamics of SLR. Finally, Section 5 delineates how to deliver results via a flexible, multi-platform mechanism that allows for region-wide or place-based assessment of NNBFs, ending with conclusions in Section 6. This presentation discusses how to assess tradeoffs between economic damages and ecosystem services valuations at the coastal land margin under impacts of sudden (decadal) rises in sea levels and provide strategies that can promote pathways to resiliency.

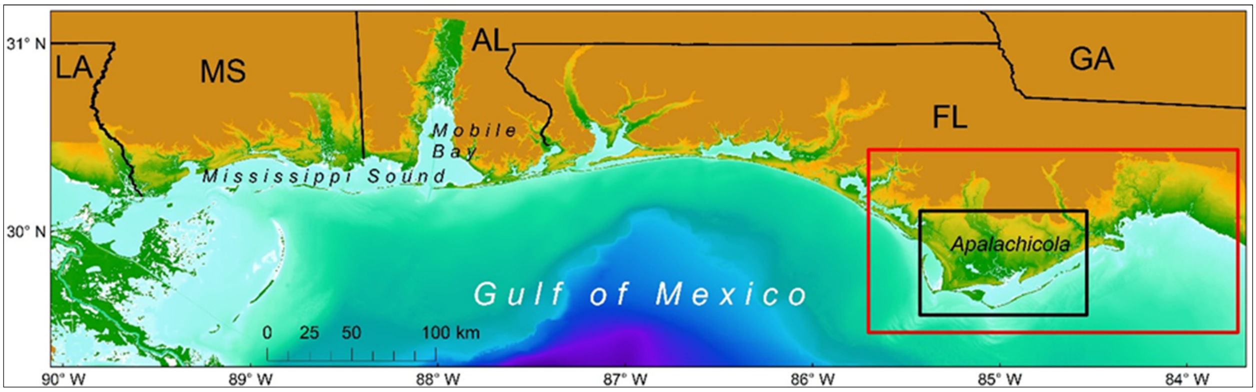

Figure 1. Topography of the northern Gulf of Mexico coastal land margin where black and red inset boxes define the regions for Figures 2 and 3 respectively. The tide and surge model extends up to the 15 meter NAVD88 elevation contour, which permits surge inundation during extreme SLR.

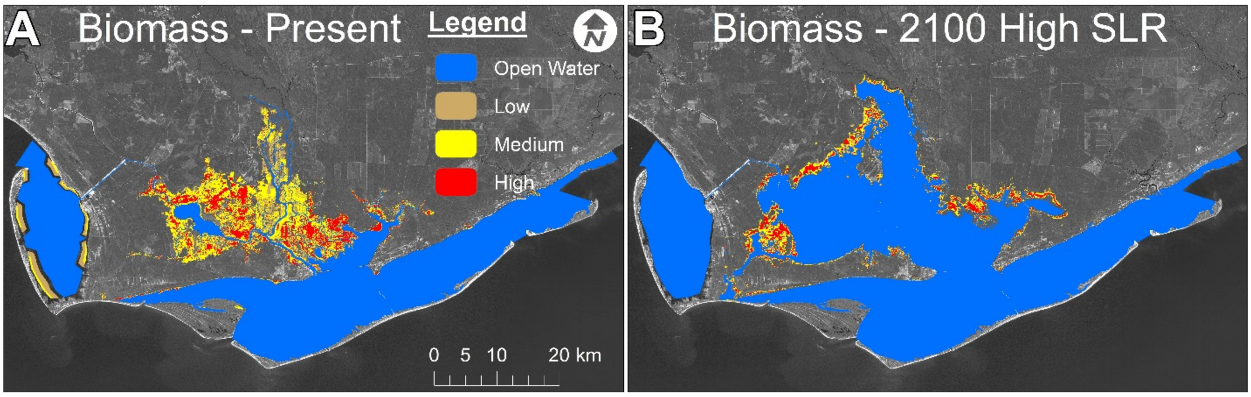

Figure 2. Biomass predictions of the Apalachicola marsh from the hydro-marsh model for present day (A) and under a 2.0m sea level rise for Year 2100 (B) for the black inset in Figure 1.

2 SEA LEVEL RISE AND COASTAL DYNAMICS

Increased SLR will have significant socioeconomic consequences for the vast number of coastal communities worldwide. In 2003, it was estimated that 1.2 billion people (23% of the world's population) lived within 100km of a shoreline and 100m in elevation of sea level (Small and Nicholls, 2003). In addition to human communities, coastal areas include ecologically- and economically-significant estuaries and wetlands. Coastal wetlands and marshes provide food, shelter, and nursery areas for commercially-harvested fish and shellfish. Wetlands also help protect coastal communities by mitigating impacts of storm surge and erosion (NOAA, 2011). As populations increase, coastal areas are also susceptible to additional stresses due to land-use and hydrologic changes (Nicholls et al., 2007).

Whether hydrodynamic, morphologic, or ecologic, SLR impacts are dynamic and inter-related. Synergistic studies that move beyond the "bathtub" approach and integrate the dynamic interactions between physical and ecological environments are required to better predict the impacts of SLR on coastal systems

(Passeri et al., 2015). Individually, observations and modeling are insufficient for making detailed and credible assessments of the dynamic response of the coastal region to SLR. However, the capability exists, as we have demonstrated, to model the bio-geo-physical system, link that modeling to the historic record, and produce a dynamic coastal response to SLR. Further, incorporating economic and ecosystem services valuations will enable stakeholders to better understand and assess the impacts of potential future conditions to enhance coastal resilience.

3 STAKEHOLDER ENGAGEMENT

There has been increased attention by scholars, practitioners, politicians, and the public to a disconnect between what scientists and decision-makers consider useful climate change-related knowledge (Lemos et al., 2012). In response to this complex and pressing concern, transdisciplinary research approaches are being proposed (Allen et al., 2013). Transdisciplinary projects are generally characterized as having: (1) a practical real-world problem focus; (2) an evolving methodology that integrates different scholarly disciplines iteratively; and (3) engagement mechanisms for collaborating with non-academic stakeholders during the entire research process (Allen et al., 2013; DeLorme et al., 2016; Leavy, 2011; Wickson et al., 2006).

Identified benefits of stakeholder engagement included contributing local system knowledge and verifying assumptions; improving the quality and credibility of scientific data and models; promoting trust, a sense of ownership, and adoption of results; accelerating broad distribution of findings; and motivating subsequent collaborations (Bartels et al., 2013; Frazier et al., 2010; Hage et al., 2010; Jakeman et al., 2006; Liu et al., 2008; McNie, 2007; Phillipson et al., 2012; Podesta et al., 2013; Roux et al., 2006; Stephens et al., 2015; Thompson et al., 2015; Voinov and Bousquet, 2010). A myriad of stakeholder analysis and engagement strategies have been reported and explained in the literature (Allen et al., 2013; Carney et al., 2009; Hage et al., 2010; Lauber et al., 2008; Lynam et al., 2007; Reed, 2008; Reed et al., 2009). Projects commonly used a combination of engagement techniques (Jacobs et al., 2005). Hallmarks of effective engagement included involving stakeholders from the beginning and frequently interacting with them throughout the entire project in an inclusive collaborative learning partnership with encouragement of ongoing feedback and consideration of various perspectives (Bartels et al., 2013; Jacobs et al., 2005; Jakeman et al., 2006; Liu et al., 2008; Phillipson et al., 2012; Podesta et al., 2013; Reed, 2008; Roux et al., 2006; Thompson et al., 2015).

4 ECONOMICS & ECOSYSTEM SERVICES VALUATION

Recognition of the economic importance of the environment and impact on human well-being, beyond traditional measures, continues to grow as federal and state agencies look for opportunities to make the case for natural resource protection and enhancement (Yoskowitz and Russell, 2015). Ecosystem services assessment and valuation have increased in use to connote the importance of natural resources, especially in coastal and marine environments (Barbier, 2012; NRC, 2012; Yoskowitz et al., in press 2017). Applying ecosystem service assessments to benefits specifically derived by NNBFs, or coastal green infrastructure, has been lacking (OSTP, 2015). Yet the need is great, given the damage that tropical storms and persistent nuisance flooding can inflict and the role that NNBFs can play in reducing impacts. For example, the estimated impact of hurricanes Sandy and Katrina was $67 billion and $151 billion respectively (NOAA, 2015).

Federal policy regarding valuation of ecosystem services and coastal green infrastructure has undergone major advancements during 2015. The White House recently issued two important directives. The first was the *Ecosystem-Service Assessment: Research Needs for Coastal Green Infrastructure* (OSTP, 2015) which identifies significant opportunities for advancing use of NNBFs as well as filling science gaps, including explicit linkages between bio-geo-physical structure, function, and processes and the value of ecosystem services. The second was a directional memo (*Incorporating Ecosystem Services into Federal Decision Making*) in October of 2015 that "*…provides direction to agencies on incorporating ecosystem services into Federal planning and decision making.*" These new policies provide viable avenues to initiate connecting NNBFs with ecosystem services and examining impacts on community resilience.

5 HYDROLOGIC UNIT CODES (HUCs)

Hydrologic units were established by the U.S. Geologic Survey (USGS) in 1987 to provide a basis for hydrologic data analysis that does not conform to political boundaries (Seaber et al., 1987). By dividing the U.S. into regions, sub-regions, accounting, and cataloging units within a nested coding framework, communication of water resources information is accelerated systematically. The number of digits used to describe a HUC indicates the level of granularity: fewer digits indicate larger areas and more digits indicate smaller areas.

Previous studies in coastal areas have utilized HUCs to add spatial context to their results and recommendations. For example, Nestlerode et al (2014) used HUCs to facilitate the mapping and geo-referencing of their coastal wetland assessment tool, specifically at the sub-watershed scale (12-digit HUC) for the NGOM. Jang et al. (2015) used 8-digit HUCs within the southern coastal plain to prioritize application of erosion control Best Management Practices (BMPs) for agricultural lands. Further, NOAA Fisheries currently

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uses HUCs in their Recovery Action Mapping Tool to assist in geo-locating specific actions to assist in the recovery of threatened or endangered species (https://www.webapps.nwfsc.noaa.gov/wcr/).

The study area for the proposed effort is the NGOM (Figure 1) and is wholly contained in the South Atlantic Gulf Region (HU 03) which covers the southeastern U.S. west of the Lower Mississippi River Region (HU 08) and south of the Tennessee Region (HU 06). Figure 3 displays how HUCs (*i.e.*, the 12-digit HUC) are divided on a local scale in and around Apalachicola, Florida. We take advantage of this existing geographical framework by referencing all SLR impacts (storm surge, nuisance flooding, economic costs and ecosystem services valuations) to the HUCs. In doing so, we enabled policy/decision makers to fully assess the ability of NNBFs to mitigate surge and nuisance flooding as visualized in Figure 4.

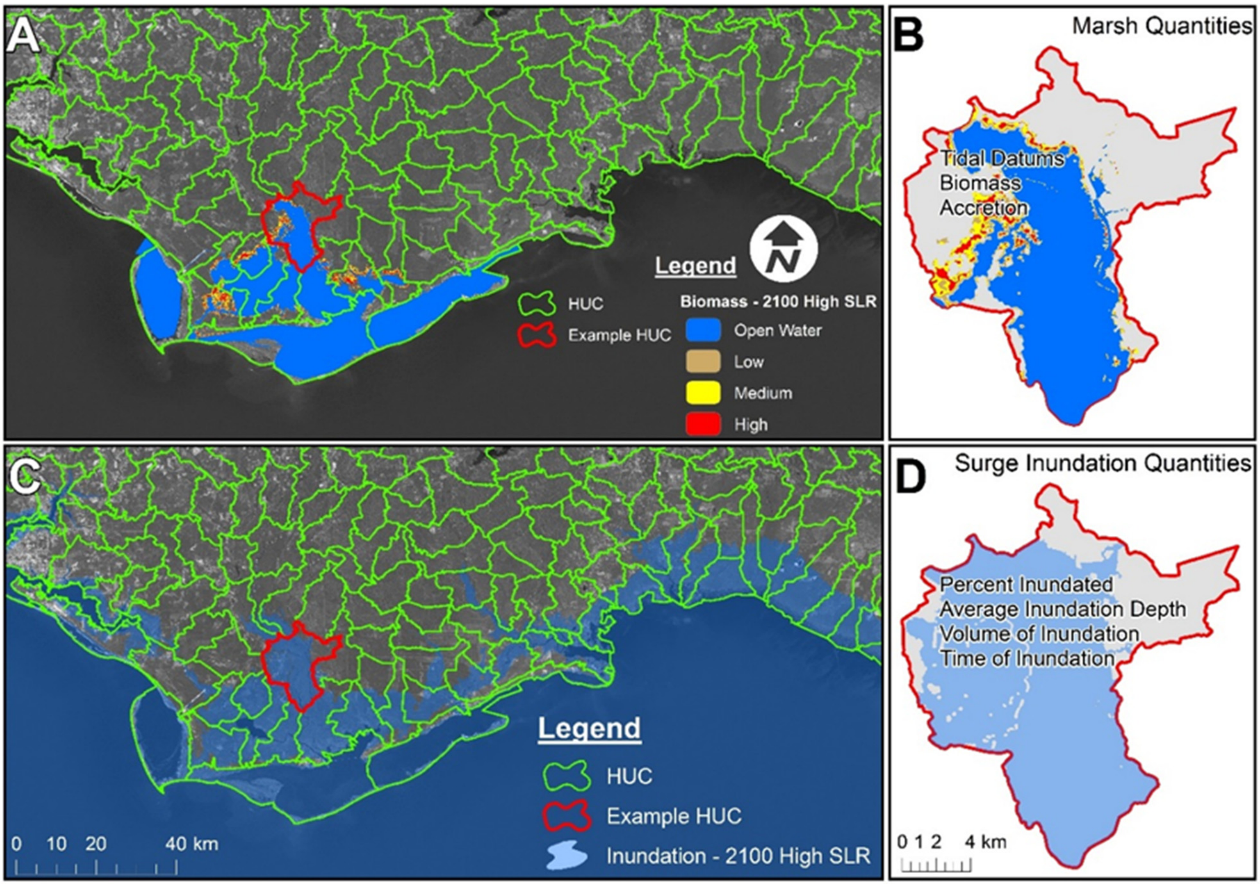

Figure 3. HUCs for the Apalachicola, FL region with biomass predictions (A) and surge inundation (C). Example marsh (B) and surge inundation (D) quantities for an individual HUC.

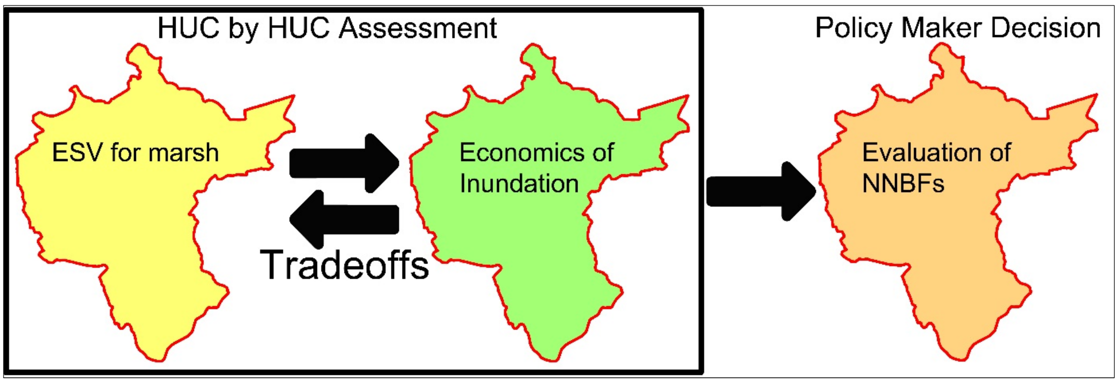

Figure 4. Given the productivity of a natural feature (*e.g.*, salt marsh), the ecosystem service valuation (ESV) can be performed and from the inundation quantities (*e.g.*, time, depth, area, and volume of surge) an economic loss may be estimated. The tradeoffs in terms of NNBF value vs. the ability of the NNBF to mitigate inundation can then be assessed. The approach permits an evaluation of NNBFs to aid decision makers and inform the public. The assessment can be performed by the end-user for a given HUC or an assemblage of HUCs to inform regional decisions. A streamlined communication of those results, on a HUC-by-HUC basis, to stakeholders through web-based delivery is an essential benefit.

6 CONCLUSIONS

A paradigm shift was established to model the coastal dynamics of SLR and assess hydrodynamic and ecological impacts at the coastal land margin. This capability to more fully assess the dynamic impacts of climate change has been expanded to include ecosystem services valuations and economic damage estimates due to nuisance and surge flooding. Involvement of policy and decision makers in the process from the beginning and throughout leads to transdisciplinary research outcomes that provide pathways to coastal resiliency.

ACKNOWLEDGEMENTS

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REFERENCES

Alizad, K., Hagen, S.C., Morris, J.T., Medeiros, S.C., Bilskie, M.V. & Weishampel, J.F. (2016). Coastal Wetland Response to Sea-Level Rise in a Fluvial Estuarine System. *Earth's Future*, 4(11), 483-497.

Allen, E., Kruger, C., Leung, F.Y. & Stephens, J.C. (2013). Diverse Perceptions of Stakeholder Engagement within an Environmental Modeling Research Team. *Journal of Environmental Studies and Sciences*, 3(3), 343-356.

Barbier, E.B. (2012). Progress and Challenges in Valuing Coastal and Marine Ecosystem Services. *Review of Environmental Economics and Policy*, 6(1), 1-19.

Bartels, W.L., Furman, C.A., Diehl, D.C., Royce, F.S., Dourte, D.R., Ortiz, B.V., Zierden, D.F., Irani, T.A., Fraisse, C.W. & Jones, J.W. (2013). Warming Up to Climate Change: A Participatory Approach to Engaging with Agricultural Stakeholders in the Southeast US. *Regional Environmental Change*, 13(1), 45-55.

Bilskie, M.V., Hagen, S.C., Alizad, K., Medeiros, S.C., Passeri, D.L., Needham, H.F. & Cox, A. (2016). Dynamic Simulation and Numerical Analysis of Hurricane Storm Surge under Sea Level Rise with Geomorphologic Changes along the Northern Gulf of Mexico. *Earth's Future*, 4(5), 177-193, doi:10.1002/2015ef000347.

Carney, S., Whitmarsh, L., Nicholson-Cole, S.A. & Shackley, S. (2009). *A Dynamic Typology of Stakeholder Engagement within Climate Change Research,* Tyndall Working Paper 128, Tyndall Centre for Climate Change Research, 1-37

Church, J.A. & White, N.J. (2006). A 20th Century Acceleration in Global Sea-Level Rise. *Geophysical Research Letters*, 33(1), doi: 10.1029/2005gl024826.

Church, J.A. & White, N.J. (2011). Sea-Level Rise from the Late 19th to Early 21st century. *Surveys in Geophysics*, 32(4-5), 585-602, doi:10.1007/s10712-011-9119-1.

Delorme, D.E., Kidwell, D., Hagen, S.C. & Stephens, S.H. (2016). Developing and Managing Transdisciplinary and Transformative Research on the Coastal Dynamics of Sea Level Rise: Experiences and Lessons Learned. *Earth's Future*, 4(5), 194-209, doi:10.1002/2015ef000346 .

Frazier, T.G., Wood, N. & Yarnal, B. (2010). Stakeholder Perspectives on Land-Use Strategies for Adapting to Climate-Change-Enhanced Coastal Hazards: Sarasota, Florida. *Applied Geography*, 30(4), 506-517.

Hage, M., Leroy, P. & Petersen, A.C. (2010). Stakeholder Participation in Environmental Knowledge Production. *Futures*, 42(3), 254-264.

Hagen, S.C., Bilskie, M.V., Passeri, D.L., DeLorme, D.E. & Yoskowitz, D. (2017). Systems Approaches for Coastal Hazard Assessment and Resilience. *Oxford Research Encyclopedias: Natural Hazard Science*. Edited by Susan Cutter. In press.

Hovenga, P.A., Wang, D., Medeiros, S.C., Hagen, S.C. & Alizad, K. (2016). The Response of Runoff and Sediment Loading in the Apalachicola River, Florida to Climate and Land Use Land Cover Change. *Earth's Future*, 4(5), 124-142, doi:10.1002/2015ef000348 .

Huang, W., Hagen, S.C., Wang, D., Hovenga, P.A., Teng, F. & Weishampel, J.F. (2016). Suspended Sediment Projections in Apalachicola Bay in Response to Altered River Flow and Sediment Loads under Climate Change and Sea Level Rise. *Earth's Future*, 4(10), 428-439, doi:10.1002/2016ef000384.

Jacobs, K., Garfin, G. & Lenart, M. (2005). More Than Just Talk: Connecting Science and Decision Making. *Environment: Science and Policy for Sustainable Development*, 47(9), 6-21.

Jakeman, A., Letcher, R.A. & Norton, J.P. (2006). Ten Iterative Steps in Development and Evaluation of Environmental Models. *Environmental Modelling & Software*, 21(5), 602-614.

Jang, T., Vellidis, G., Kurkalova, L.A., Boll, J. & Hyman, J.B. (2015). Prioritizing Watersheds for Conservation Actions in the Southeastern Coastal Plain Ecoregion. *Environmental Management*, 55(3), 657-670.

Jevrejeva, S., Grinsted, A., Moore, J.C. & Holgate, S. (2006). Nonlinear Trends and Multiyear Cycles in Sea Level Records. *Journal of Geophysical Research*, 111(C9), 2156-2202, doi:10.1029/2005JC003229.

Jevrejeva, S., Moore, J.C., Grinsted, A. & Woodworth, P.L. (2008). Recent Global Sea Level Acceleration Started over 200 Years Ago?. *Geophysical Research Letters*, 35(8), doi:10.1029/2008GL033611

Kidwell, D.M., Dietrich, J.C., Hagen, S.C. & Medeiros, S.C. (2017). An Earth's Future Special Collection: Impacts of the Coastal Dynamics of Sea Level Rise on Low Gradient Coastal Landscapes. *Earth's Future*, 5(1), 2–9, doi:10.1002/2016EF000493.

Lauber, T.B., Decker, D.J. & Knuth, B.A. (2008). Social Networks and Community-Based Natural Resource Management. *Environmental Management*, 42(4), 677-687.

Lemos, M.C., Kirchhoff, C.J. & Ramprasad, V. (2012). Narrowing the Climate Information Usability Gap. *Nature Climate Change,* 2(11), 789-794.

Leavy, P. (2011). *Essentials of Trandisciplinary Research: Using Problem-Centered Methodologies*. Routledge, New York, USA.

Liu, Y., Gupta, H., Springer, E. & Wagener, T. (2008). Linking Science with Environmental Decision Making: Experiences from an Integrated Modeling Approach to Supporting Sustainable Water Resources Management. *Environmental Modelling & Software*, 23(7), 846-858.

Lynam, T., De Jong, W., Sheil, D., Kusumanto, T. & Evans, K. (2007). A Review of Tools for Incorporating Community Knowledge, Preferences, and Values into Decision Making in Natural Resources Management. *Ecology and Society*, 12(1), 5-18.

McNie, E.C. (2007). Reconciling the Supply of Scientific Information with User Demands: An Analysis of the Problem and Review of the Literature. *Environmental Science & Policy*, 10(1), 17-38.

Morris, J.T., Barber, D.C., Callaway, J., Chambers, R., Hagen, S.C., Johnson, B.J., Megonigal, P., Neubauer, S., Troxler, T. & Wigand, C. (2016). Contributions of Organic and Inorganic Matter to Sediment Volume and Accretion in Tidal Wetlands at Steady State. *Earth's Future*, 4(4), 110-121, doi:10.1002/2015ef000334.

National Research Council (NRC). (2012). *Approaches for Ecosystem Services Valuation for the Gulf of Mexico After the Deepwater Horizon Oil Spill*, National Academies Press.

Nerem, R.S., Chambers, D.P., Choe, C. & Mitchum, G.T. (2010). Estimating Mean Sea Level Change from the TOPEX and Jason Altimeter Missions. *Marine Geodesy*, 33(1), 435-436, doi:10.1080/01490419.2010.491031.

Nestlerode, J.A., Hansen, V.D., Teague, A. & Harwell, M.C. (2014). Application of a Three-Tier Framework to Assess Ecological Condition of Gulf of Mexico Coastal Wetlands. *Environmental Monitoring and Assessment*, 186(6), 3477-3493.

Nicholls, R.J., Wong, P.P., Burkett, V.R., Codignotto, J.O., Hay, J.E., McLean, R.F., Ragoonaden, S. & Woodroffe, C.D. (2007). *Coastal Systems and Low-Lying Areas*. In Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. & Hanson, C.E. (ed). *Climate Change 2007: Impacts, Adaptation, and Vulnerability.* Contribution of working group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

National Oceanic and Atmospheric Administration (NOAA). (2015). Billion-Dollar Weather and Climate Disasters: Table of Events. National Centers for Environmental Information. Retrieved December 17, 2015, from https://www.ncdc.noaa.gov/billions/events.

National Oceanic and Atmospheric Administration (NOAA). (2011). *The Gulf of Mexico at a Glance: A Second Glance*, Department of Commerce, National Oceanic and Atmospheric Administration, Washington DC, US.

Office of Science and Technology Policy (OSTP). (2015). *Ecosystem-Service Assessment: Research Needs for Coastal Green Infrastructure*, National Science and Technology Council, 1-48, from https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/cgies_research_agenda_final_082515.pdf

Passeri, D.L., Hagen, S.C., Plant, N.G., Bilskie, M.V., Medeiros, S.C. & Alizad, K. (2016). Tidal Hydrodynamics under Future Sea Level Rise and Coastal Morphology in the Northern Gulf of Mexico. *Earth's Future*, 4(5), 159-176.

Passeri, D.L., Hagen, S.C., Medeiros, S.C., Bilskie, M.V., Alizad, K. & Wang, D. (2015). The Dynamic Effects of Sea Level Rise on Low-Gradient Coastal Landscapes: A Review. *Earth's Future*, 3(6), 159-181.

Phillipson, J., Lowe, P., Proctor, A. & Ruto, E. (2012). Stakeholder Engagement and Knowledge Exchange in Environmental Research. *Journal of Environmental Management*, 95(1), 56-65.

Plant, N.G., Thieler, E.R. & Passeri, D.L. (2016). Coupling Centennial-Scale Shoreline Change to Sea-Level Rise and Coastal Morphology in the Gulf of Mexico Using a Bayesian Network. *Earth's Future*, 4(5), 143-158, doi:10.1002/2015ef000331.

Podestá, G.P., Natenzon, C.E., Hidalgo, C. & Toranzo, F.R. (2013). Interdisciplinary Production of Knowledge with Participation of Stakeholders: A Case Study of a Collaborative Project on Climate Variability, Human Decisions and Agricultural Ecosystems in the Argentine Pampas. *Environmental Science & Policy*, 26, 40-48.

Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H. & Stringer, L.C. (2009). Who's in and Why? A Typology of Stakeholder Analysis Methods for Natural Resource Management. *Journal of Environmental Management*, 90(5), 1933-1949.

Reed, M.S. (2008). Stakeholder Participation for Environmental Management: A Literature Review. *Biological Conservation*, 141(10), 2417-2431.

Roux, D.J., Rogers, K.H., Biggs, H.C., Ashton, P.J. & Sergeant, A. (2006). Bridging the Science–Management Divide: Moving from Unidirectional Knowledge Transfer to Knowledge Interfacing and Sharing. *Ecology and Society*, 11(1), 4, from http://www.ecologyandsociety.org/vol11/iss1/art4.

Seaber, P.R., Kapinoa, F.P. & Knapp, G.L. (1987). *Hydrologic Unit Maps*. United States Geological Survey.

Small, C. & Nicholls, R.J. (2003). A Global Analysis of Human Settlement in Coastal Zones. *Journal of Coastal Research,* 19(3), 584-599.

Stephens, S.H., Delorme, D.E. & Hagen, S.C. (2015). Evaluating the Utility and Communicative Effectiveness of an Interactive Sea-Level Rise Viewer Through Stakeholder Engagement. *Journal of Business and Technical Communication*, 29(3), 314-343.

Thompson, J.L., Lemieux, C.J. & Davis, S. (2015). Climate Change Adaptation Planning: An Analysis of Process and Practice in Two Regional Case Studies, *2015 Conference on Communication and Environment*, International Environmental Communication Association, Boulder, Colorado.

Voinov, A. & Bousquet, F. (2010). Modelling with Stakeholders. *Environmental Modeling & Software*, 25(11), 1268-1281.

Wickson, F., Carew, A. & Russell, A.W. (2006). Transdisciplinary Research: Characteristics, Quandaries and Quality. *Futures*, 38(9), 1046-1059.

Yoskowitz, D.W., Werner, S.R., Carollo, C., Santos, C., Washburn, T. & Isaksen, G.H. (2016). Gulf of Mexico Offshore Ecosystem Services: Relative Valuation by Stakeholders. *Marine Policy*, 66, 132-136.

Yoskowitz, D. & Russell, M. (2015). Human Dimensions of Our Estuaries and Coasts. *Estuaries and Coasts*, 38(1), 1-8.

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CAN WE IMPROVE THE RESILIENCE OF LARGE RIVER DELTAS? A MISSISSIPPI RIVER CASE STUDY

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ABSTRACT

River deltas and the communities upon them are threatened globally by the combined effects of relative sea-level rise, reduced sediment supply, and other unintended consequences of river-management strategies. Globally, this constitutes a threat to communities hosting >500 million residents, massive infrastructure, and major agricultural, navigation, and other resource sectors. The State of Louisiana in the United States is home to the delta of the Mississippi River (Mississippi River Delta, or MRD), a coastal landscape of approximately 18,000km^2 that has formed over the last 8,000 years, where the Mississippi discharges into the Gulf of Mexico. Since the 1930's, land area of the MRD has decreased by >5,000km^2, and estimates of potential future land loss under possible future sea-level-rise scenarios exceed an additional 10,000km^2. Key causes of this land loss included dam construction on upper tributaries; construction of levees along the river mainstem, and deltaic subsidence. Extensive human outmigration has occurred in the MRD, with socio-political consequences. In response, the State of Louisiana established a Coastal Master Plan in 2007 to guide coastal conservation efforts. Mostly as a result of projected increases in sea-level rise, projects included in the 2017 draft plan will no longer be able to eliminate future land loss. So, what can be done? We propose three new concepts. First, consider a smaller, but more sustainable delta area. Second, attempt to reduce loss of sediment passing through the MRD for more efficient land building. Third, increase the volume of sediment delivered from the catchment to the delta, via controlled floods and engineered increases in river gradient. None of these possible strategies are without risk. Nevertheless, in order to sustain a Mississippi River Delta for future generations, creative solutions must be sought, tested, and implemented.

Keywords: River delta; resilience; sediment supply; Mississippi.

1 INTRODUCTION

River deltas and the communities upon them are threatened globally by the combined effects of relative sea-level rise, reduced sediment supply, and other unintended consequences of river-management strategies. Globally, this constitutes a threat to communities hosting >500 million residents, massive infrastructure, and major agricultural, navigation, and other resource sectors (Giosan et al., 2014). The State of Louisiana in the United States is home to the delta of the Mississippi River (Mississippi River Delta, or MRD), a coastal landscape of approximately 18,000km^2 that has formed over the last 8,000 years, where the Mississippi discharges into the Gulf of Mexico (Figure 1). Since the 1930's, land area of the MRD has decreased by >5,000km^2, and estimates of potential future land loss under possible future sea-level-rise scenarios exceed an additional 10,000km^2 (Figure 2) (Blum and Roberts, 2009). Key causes of this land loss included dam construction on upper tributaries (reducing sediment supply, mostly in the early 20th century), construction of levees and armored banks along the river mainstem (middle and late 20th century), and deltaic subsidence that may have been exacerbated by subsurface fluid withdrawals (late 20th century). These changes have placed population centers, major cultural resources (such as the city of New Orleans), some of the largest commercial fisheries and migratory bird habitats in North America, infrastructure supporting the largest offshore petroleum province in the world, and the entrance to the largest inland river transport network in the US at risk.

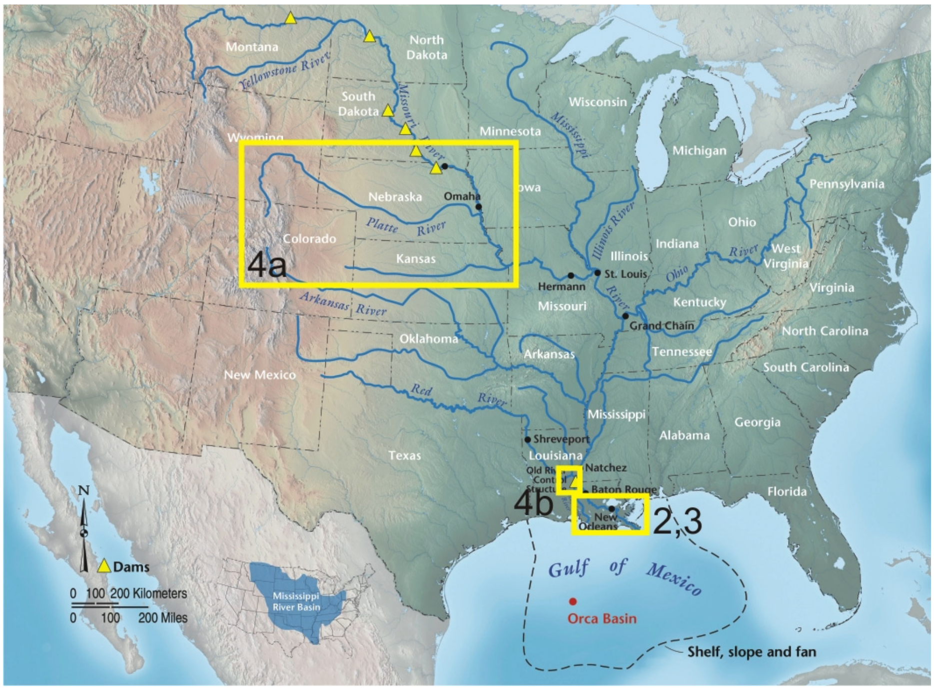

Figure 1. Extent of the Mississippi River catchment, and location of potential study areas identified herein; black numbers and yellow boxes identify section numbers in text associate width each project concept. The MRD falls within the yellow box labeled “2,3.” Figure adapted from Bentley et al., 2015, identifying the location of major dams (yellow triangles) and control structures (black circles) on the Mississippi and Missouri rivers.

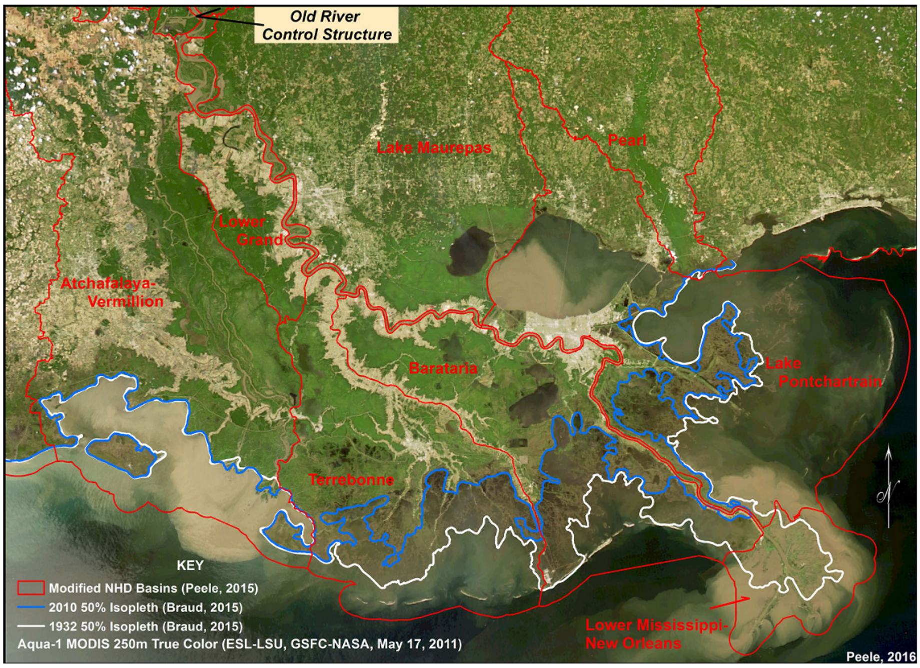

Figure 2. Representation of land loss in the MRD from 1932 to 2010, shown by the landward migration of isopleths for the 50%:50% land-water ratio at these points in time; adapted from Twilley et al. (2016).

Extensive human outmigration has occurred in the MRD, with socio-political consequences (Figure 3) (Twilley et al., 2016). For example, during the period of 2000-2010 alone, sufficient outmigration occurred to cause Louisiana to lose one of its seven federal legislative representatives (New York Times, 2010). One interpretation of this change is that Louisiana is the subject of political disenfranchisement due to environmental changes, some of which were initiated by human actions far outside the delta itself.

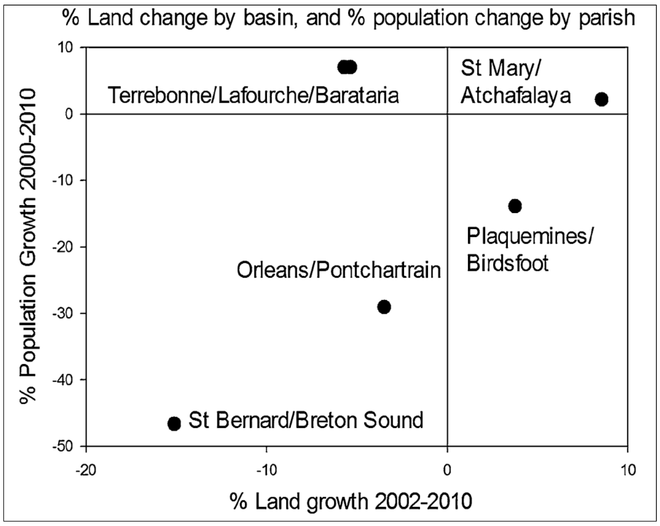

Figure 3. Patterns of land-area change and population change for coastal parishes and drainage basins in the Louisiana coastal zone; adapted from Twilley et al. (2016).

In response to the existential threat to the MRD, the State of Louisiana established a Coastal Master Plan in 2007 to guide coastal restoration, flood protection, and conservation efforts (LaCPRA 2012; 2017). The Master Plan is adaptively managed via mandated study and revision every five years, using new science, engineering, and climate knowledge to update and improve the plan. The 2012 revision of the Master Plan outlined an extensive program of engineering measures (at a cost of $50 billion over 50 years) to slow land loss and reduce flood risk to coastal communities (primarily from tropical cyclones), including use of river-sediment diversions and constructed wetlands. 2012 simulations of future conditions on the MRD that incorporated all Master Plan design elements suggested that by ca. 2041, the MRD land area would have been stabilized, with no future net land loss (LaCPRA, 2012). The Master Plan is presently undergoing revision (for 2017), using more recent IPCC sea-level-rise estimates than were used in 2012. Mostly as a result of projected increases in sea-level rise, projects included in the 2017 draft plan will no longer be able to eliminate future land loss (LaCPRA, 2017). So, what can be done?

The land area of the delta can be envisioned as a mass balanced between sediment input (mineral and organic), sediment loss (bypass and erosion) and submergence (due to subsidence and sea level rise). From this perspective, we envisioned three possible avenues by which a coastal delta can be maintained. First, consider a smaller, but more sustainable delta area. Second, attempt to reduce loss of sediment passing through the MRD for more efficient land building. Third, increase the volume of sediment delivered from the catchment to the delta, via controlled floods and engineered increases in river gradient, and engineered onshore sediment transport. These concepts are explored in more detail below.

2 SMALLER, MORE SUSTAINABLE DELTA LAND AREA

First, we considered a smaller, but more sustainable delta area, under present sediment supplies, and accelerated sea level rise in the future. The present coastal deltaic plain is vast, and reducing the area considered for conservation will allow concentration of valuable sediment resources. During the years 2013-2015, an international design competition entitled “Changing Course” was held to develop new concepts for adapting communities, the river, and the deltaic landscape of the Mississippi to present and future environmental conditions, including reduced sediment load, and rising seas (http://changingcourse.us/). Although the finalist teams developed different strategies and detailed proposals, these same teams converged independently on four shared fundamental objectives: (1) reconnect the Mississippi to its coastal deltaic floodplain to help restore those wetlands; (2) proactively plan for a sustainable delta, to promote community shifts and adaptations and enhance community security; (3) realign and shorten the Mississippi River, and enhance port facilities, to allow for future stability and expansion of regional and global shipping networks; and (4) focus on sustaining a smaller deltaic plain that can be more readily maintained than the present expansive delta plain, with respect to limited sediment supplies, and rising seas (Hird et al., 2016; Hoal et al., 2016; Nairn et al., 2016). Reconnection of the river to coastal wetlands and encouraging community adaptation are both concepts that are incorporated into the present Louisiana Coastal Master Plan (LaCPRA, 2017), but river realignment and proactively reducing the area of the MRD coastal deltaic plain to be conserved are not part of the Master Plan. For these two concepts, the Changing Course competition ended before engineering and design progressed beyond the conceptual stage for all competitors. However, sufficient diagnostic simulations and calculations were completed to suggest that these two strategies could be both feasible and beneficial to long-term delta sustainability. We recommend that these management concepts for the river and delta be evaluated in more detail for future consideration and implementation.

3 MORE EFFICIENT SEDIMENT CAPTURE

We can attempt to reduce loss of sediment passing through the MRD, to retain more sediment and build land more efficiently. Not all sediment delivered to the MRD is retained to build land or adjacent seabed sediment deposits. Estimates of sediment retention in the MRD vary widely depending on location (from <25% to nearly 100%; Xu et al., 2016), but are generally highest for depositional environments in the delta interior that receive river flows, and lowest for receiving basins along the MRD margin, that are exposed to waves and currents from the open sea, or large coastal bays (Xu et al., 2016). For the most exposed settings that have the lowest sediment retention, Lo et al. (2014) and Xu et al. (2016) have suggested that sediment resuspension by small, locally generated waves (coupled with local currents) is a critical factor in preventing sediment accumulation. These studies further suggested that the construction of artificial islands and tidal flats from dredged sediment could help reduce wind fetch, wave height, and enhance sediment retention.

In the Netherlands and Indonesia, engineered placement of dredged sediment has been used not only to broadly enhance sediment retention, but to steer sediment suspensions transported by local currents to sites in need of sediment accumulation, such as beaches, marshes, and mangrove swamps (Stive et al., 2013; Ecoshape, 2016). For the Sand Engine Delfland pilot project (in the Netherlands), a 21.5 million m^3 sand nourishment was placed to feed a 20km shoreline for 20 years. In 2016, evaluation of sand engine evolution during the first five years of its lifetime showed that nourished sand was successfully dispersed along the coast, while new beaches, lake and lagoon offered new habitats and recreation. Monitoring found dune formation to lag behind predictions, which was attributed to the presence of the lake and lagoon that trapped sediments prior to arrival to the dunes.

Pilot Mud Engine projects have been developed in the Wadden Sea (the Netherlands) and Demak, Indonesia to provide beneficial use of locally dredged muddy sediment, in contrast to the beach sands of the Sand Engine (Ecoshape, 2016). These projects are designed to harness local wave-current fields and deliver sediment to specific areas targeted for nourishment by muddy sediment, such as mangrove swamps and vegetated intertidal flats. Such projects designed for engineered passive-sediment delivery (Mud Engine) and sediment trapping (*e.g.*, fetch reduction of Xu et al., 2016) have potential for application to the MRD, for enhancing sediment retention. Such projects would be particularly well suited to operation with river-sediment diversions, which likely produce muddy plumes suitable for capture, as well as dedicated dredged-sediment pipelines that can carry sediment from the Mississippi River to nearby coastal basins (LACPRA, 2017).

4 CONTROLLED FLOODS AND OPTIMIZATION OF RIVER GRADIENT

We explored mechanisms to increase the volume of sediment delivered from the catchment to the delta. Possible approaches included controlled floods on upstream river tributaries, to entrain muddy suspended sediment for downstream capture, and engineered management of river gradient in the backwater reach of the lower Mississippi River. The most substantial reduction in sediment load of the Mississippi River in the last century occurred following large dam constructions on the upper Missouri River, in the mid-20th century (Blum and Roberts, 2009). The geometry of the large dams and reservoirs on the upper Missouri River makes them unsuitable for efficient sediment bypass, even during large floods (J. Remus, USACE, personal communication). However, sediment-budget analyses by Kemp et al. (2016) identified a number of dams and reservoirs on other tributaries (Platte, Kansas rivers) that could be potential targets for sediment bypass. Controlled floods on these sediment-rich tributaries of the Mississippi could be explored to deliver more sediment downstream past the networks of dams. However, many complications exist in the implementation of such projects, including sediment quality with respect to the Clean Water Act, and suitability of tributary levees for containing energetic controlled floods, among other factors. Nevertheless, the calculations of Kemp et al. (2016) suggested that more detailed evaluation of both potential sediment capture, and mitigation of potential downsides, should be undertaken.

Some channel beds along the backwater reach of the Mississippi are aggrading due to reduced stream power (Nittrouer et al., 2012; Nittrouer, 2013; Bentley et al., 2015), resulting in the accumulation of extensive sandy deposits (Wang and Xu, 2016) (Figure 4). Hoal et al. (2016) hypothesized that sediment from these deposits might be entrained by river flows, if the local river gradient (and hence stream power) could be increased by coordinated operation of river-sediment diversions downstream from these sediment deposits. Preliminary calculations by Hoal et al. (2016) suggested that such diversion operations could increase bed material load by 10% or more above typical flood transport rates, making this additional sediment supply available for downstream capture by diversions or dredge intakes in the river. Although much additional study is required to determine the feasibility of both controlled floods and backwater river-gradient management for augmenting sediment supply, these preliminary evaluations suggested the potential for increasing the amount of sediment delivered by the Mississippi River to the delta.

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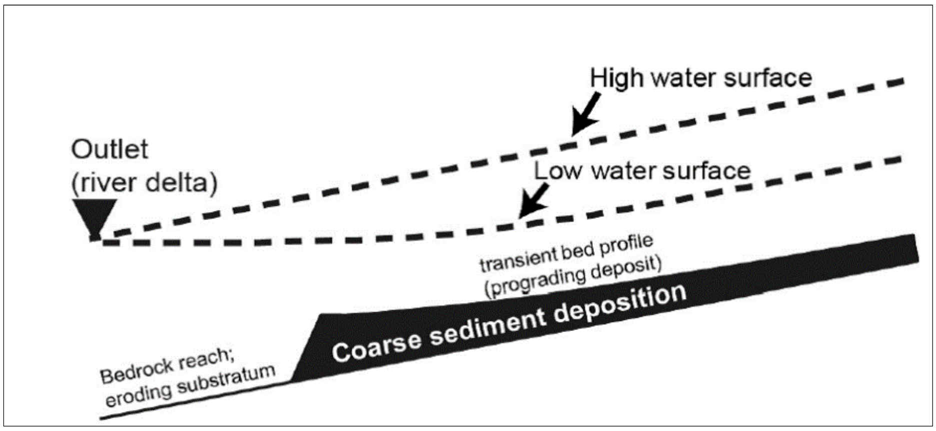

Figure 4. Schematic diagram of coarse grain bed material sediment deposition occurring at the normal flow to backwater transition (after Parker, 2004; Nittrouer, 2013). Across this hydrodynamic transition, sediment transport capacity decreases progressing downstream, leading to the permanent storage of the coarse bed material sediment.

5 CONCLUSIONS

We have identified a suite of potential projects and approaches that could increase the long-term sustainability of the MRD, by reducing the delta area targeted for conservation, increasing sediment delivery, and increasing sediment capture. None of these possible strategies are without risk. Fine sediments trapped behind dams for decades may be laden with contaminants. Communities facing controlled floods may be concerned about levee failure. Large river-sediment diversions may alter salinity and water-elevation patterns in receiving basins, which could have negative impacts on human communities and aquatic ecosystems, if not managed carefully. Nevertheless, in order to sustain a Mississippi River Delta for future generations, creative solutions must be sought, tested, and implemented.

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REFERENCES

Bentley, S.J., Blum, M.D., Maloney, J., Pond, L. & Paulsell, R. (2016). The Mississippi River Source-To-Sink System: Perspectives on Tectonic, Climatic, and Anthropogenic Influences, Miocene to Anthropocene. *Earth-Science Reviews*, 153,139-174.

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(7), 488-491.

Ecoshape (2016). Mud Motor for Salt Marsh Development, https://www.ecoshape.org/en/projects/mud-motor/, accessed 01/24/2017.

Giosan, L., Syvitski, J., Constantinescu, S. & Day, J. (2014). Protect the World's Deltas. *Nature,* 516(7529), 31-33.

Hird, J.P., Twilley, R., Carney, J., Georgiou, Y. & Agre, C. (2016). Changing Course – The Moffat and Nichol Team Solution – A "Systems Approach" to a Consolidated and Sustainable Lower Mississippi River Delta. *2016 AGU-ASLO Ocean Sciences Meeting*, New Orleans, paper EC41A-06.

Hoal, J. & Studio MISI-ZIIBI (2016). Changing Course: The STUDIO MISI-ZIIBI Team: New MISI-ZIIBI Living Delta. *2016 AGU-ASLO Ocean Sciences Meeting*, New Orleans, paper EC41A-05.

Kemp, G.P., Day, J.W., Rogers, J.D., Giosan, L. & Peyronnin, N. (2016). Enhancing Mud Supply from the Lower Missouri River to the Mississippi River Delta USA: Dam Bypassing and Coastal Restoration. *Estuarine, Coastal and Shelf Science,* 183, 304-313, http://dx.doi.org/10.1016/j.ecss.2016.07.008.

Louisiana Coastal Protection and Restoration Authority (LaCPRA). (2017). Louisiana's Comprehensive Master Plan for a Sustainable Coast. http://coastal.la.gov/a-common-vision/2017-draft-coastal-master-plan/, accessed 01/12/2017.

Louisiana Coastal Protection and Restoration Authority (LaCPRA). (2012). Louisiana's Comprehensive Master Plan for a Sustainable Coast. http://coastal.la.gov/a-common-vision/2012-coastal-master-plan/, accessed 01/12/2017.

Lo, E.L., Bentley Sr, S.J. & Xu, K. (2014). Experimental Study of Cohesive Sediment Consolidation and Resuspension Identifies Approaches for Coastal Restoration: Lake Lery, Louisiana. *Geo Marine Letters,* 34(6), 499-509, doi:10.1007/s00367-014-0381-3.

Nairn, R.B. & Baird and Associates Team (2016). Changing Course - The Baird Team Solution: A Delta for All. *2016 AGU-ASLO Ocean Sciences Meeting*, New Orleans, paper EC41A-07.

New York Times (2010). Census 2010: Gains and Losses in Congress. http://www.nytimes.com/interactive/2010/12/21/us/census-districts.html, accessed 02/02/2017.

Nittrouer, J.A., Shaw, J., Lamb, M.P. & Mohrig, D. (2012). Spatial and Temporal Trends for Water-Flow Velocity and Bed-Material Sediment Transport in the Lower Mississippi River. *Geological Society of America Bulletin,* 124(3-4), 400-414.

Nittrouer, J.A. (2013). Backwater Hydrodynamics and Sediment Transport in the Lowermost Mississippi River Delta: Implications for the Development of Fluvial-Deltaic Landforms in a Large Lowland River. *Deltas: Landforms, Ecosystems, and Human Activities: International Association of Hydrological Sciences Publication,* 358, 48-61.

Parker, G. (2004). *1D Sediment Transport Morphodynamics with Applications to Rivers and Turbidity Currents*. St. Anthony Falls Laboratory, University of Minnesota, Minneapolis, http://vtchl.uiuc.edu/people/parkerg/morphodynamics_e-book.htm, January 14, 2017.

Stive, M.J., de Schipper, M.A., Luijendijk, A.P., Aarninkhof, S.G., van Gelder-Maas, C., van Thiel de Vries, J.S., de Vries, S., Henriquez, M., Marx, S. & Ranasinghe, R. (2013). A New Alternative to Saving Our Beaches from Sea-Level Rise: The Sand Engine. *Journal of Coastal Research*, 29(5),1001-1008.

Twilley, R.R., Bentley Sr, S.J., Chen, Q., Edmonds, D.A., Hagen, S.C., Lam, N.S.N., Willson, C.S., Xu, K., Braud, D., Peele, R.H. & McCall, A. (2016). Co-Evolution of Wetland Landscapes, Flooding, and Human Settlement in the Mississippi River Delta Plain. *Sustainability Science,* 11(4), 711-731, DOI: 10.1007/s11625-016-0374-4.

Wang, B. & Xu, Y.J. (2016). Long-Term Geomorphic Response to Flow Regulation in a 10-km Reach Downstream of the Mississippi–Atchafalaya River Diversion. *Journal of Hydrology: Regional Studies*, 8, 10-25.

Xu, K., Bentley, S.J., Robichaux, P., Sha, X. & Yang, H. (2016), Implications of Texture and Erodibility for Sediment Retention in Receiving Basins of Coastal Louisiana Diversions. *Water*, 8(1), 26, doi: 10.3390/w8010026.

ESTABLISHING AND PROMOTING AN INTERDISCIPLINARY CENTER FOR COASTAL RESILIENCY IN LOUISIANA, U.S.A.

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ABSTRACT

This paper describes the planning and implementation processes and activities involved in launching a new interdisciplinary Center for Coastal Resiliency (CCR), at Louisiana State University (LSU) in the United States. The CCR focuses on advancing and applying computational hydrodynamic and hydrologic models to include overland flow, river discharge, tides, wind-waves, and hurricane storm surge. Particular focus is placed on the development of such models to be used for real-time forecasting throughout the northern Gulf of Mexico. The CCR is also developing advanced systems-based models for assessment of the effects of climate change and associated sea level rise at the coastal land margin. In addition, the center plans to further similar modeling approaches to oil transport and fate and the Gulf dead zone. CCR scholars collaborate with natural and social scientists, engineers, government agencies, and stakeholders to produce transdisciplinary research outcomes that provide accessible and useful decision-support tools capable of enhancing coastal resiliency. Establishing the CCR involved ten distinct yet interrelated steps, each of which are discussed along with six ongoing activities to promote this new center to various stakeholders. Throughout the paper, connections are made to the scholarly literature on university research centers and on institutional branding. The paper concludes by providing practical considerations and future research recommendations.

Keywords: University research center; coastal resilience; interdisciplinary; transdisciplinary; computational modeling.

1 INTRODUCTION

This paper describes the planning and implementation processes and activities involved in launching a new interdisciplinary research center, the Center for Coastal Resiliency (CCR), at the main campus of Louisiana State University (LSU) in the United States. Coastal Louisiana has a long and storied history of resilience that prior to the arrival of western civilization was solely enhanced by natural systems (Twilley et al., 2016). With the establishment of channelization and control of the Mississippi River, the flood protection system became dependent on both natural and built infrastructure. That long-standing resilience has been threatened in recent decades by a dramatic loss of coastal wetlands and a lack of recognition of the strong interaction among the different systems. In fact, recent land-falling hurricanes in 2005 and later (Katrina, Rita, Gustav), the Deepwater Horizon oil disaster of 2010, and the Gulf Dead Zone all demonstrated the vulnerability of the region. It is clear that wetlands restoration, improvements to existing man-made coastal defense structures, and new defense structures have been and will be, for the foreseeable future, implemented to enhance resilience (CPRA, 2013; Fischbach et al., 2016). Informing the process of enhanced coastal resiliency with system-of-systems approaches (Hagen et al., in press 2017; Kidwell et al., 2016) that produce transdisciplinary research outcomes (DeLorme et al., 2016) form the vision of the CCR.

Due largely to greater competition, financial pressures, and the need for more diversity in human capital to address increasingly complex scientific problems, universities around the globe have been changing how they organized and managed their research (Boardman and Ponomariov, 2014; Santoro and Chakrabarti, 1999; Tash, 2006). One of these approaches has been to develop research centers within the university's core structure (Gray and Walters, 1998). "Research centers are organizational adaptations within the university which evolved in order to allow universities to increase their responsiveness to societal needs (as reflected by sponsors' funding interests), to enhance the university's research vitality through interdisciplinary collaboration, and to provide an institutional locale specifically geared to attract external funding for large projects that are sometimes difficult to secure and manage in academic departments" (Stahler and Tash, 1994).

Though definitions of a center vary considerably, a center is commonly considered a boundary-spanning organizational entity or unit outside of an academic department in an institute of higher education with the intention to foster collaboration and has primary functions focused on research and training in a specialized area (Boardman and Corley, 2008; Geiger, 1990; Hall, 2011; Stahler and Tash, 1994; Tornatzky et al., 1998). The types and characteristics of research centers range widely across many dimensions (*e.g.*, size, organizational structure, funding, degree of multidisciplinarity, types of researchers and external stakeholders, role within university system) (Bozeman and Boardman, 2003; Hall, 2011; Stahler and Tash, 1994; Tash, 2006). Typologies to help classify and better understand distinguishing characteristics of centers (generally based on finances, human resources, and physical resources) have been proposed (Ikenberry and Friedman, 1972) and examined (Hall, 2011) to improve research, planning, and evaluation of such endeavors.

The number of centers on U.S. campuses has been growing since the 1950s (Hall, 2011). According to the *Gale Directory of Research Centers*, there were more than 13,000 centers in the U.S. and 26,000 centers in the world as of 2003 (Tash, 2006). While centers are playing an increasingly important role in how research is conducted at academic institutions (Stahler and Tash, 1994) and a number of benefits of successful centers have been identified and discussed in the literature, it is an uphill battle for a new center (*e.g.*, the CCR) to make an international impact. For example, centers can provide a structure to harness capacity (*e.g.*, expertise, social networks, funds, equipment) and facilitate synergistic collaboration of participants (*e.g.*, faculty researchers from different fields, student assistants, external stakeholders) in order to achieve scientific and technical goals efficiently and effectively (Boardman and Corley, 2008). In addition, successful centers can complement and enhance the academic function of traditional departments (Stahler and Tash, 1994) and can accelerate the quantity and quality of productivity and disciplinary diversity of traditional academic activities such as publishing in scholarly journals (Boardman and Corley, 2008; Ponomariov and Boardman, 2010) and other aspirations such as acquiring patents on technological inventions (Santoro and Chakrabarti, 1999). There are also marketing-related and reputation-enhancing advantages associated with centers in terms of their potential to offer “additional visibility to a defined area of study important to the university” (Friedman and Friedman, 1984; Hall, 2011). Yet challenges associated with managing centers (*e.g.*, faculty role strain, supervising researchers, complex accountability pressures) have also been recognized (Bozeman and Boardman, 2003; Boardman and Bozeman, 2007).

Though the body of literature on research centers is not large (Bozeman and Boardman, 2003), the subject has received some scholarly attention over the years (Hall, 2011; Ikenberry and Friedman, 1972; Stahler and Tash, 1994; Walters and Gray, 1998). Prominent in the literature have been discussions of the history of centers; efforts to categorize and describe different types of centers including their structural and functional advantages and disadvantages; studies of the collaboration characteristics, industrial relations and technology transfer; processes and effects of center participants; identification of center administrative issues; and recommended strategies for planning, leading, and managing centers successfully, including how to navigate within the center’s home institution as well as externally at different levels (Bozeman and Boardman, 2003; Hall, 2011; Ikenberry and Friedman, 1972; Santoro and Chakrabarti, 1999; Tash, 2006). Likely due to the heterogeneity of the centers investigated and different methodological procedures used, past studies of research centers have produced mixed results (Boardman and Corley, 2008). There is still much to be learned about the emergence, operation, and influences of university research centers from both micro- and macro-orientations and with respect to short- and long-term time frames. Particularly needed is better understanding of the processes and activities involved in establishing and in promoting research centers from the firsthand experiences and perspectives of those directly involved. Documenting and sharing insights and lessons learned from actual case studies of new centers such as the CCR can provide useful and valuable information to advance scholarly knowledge in this domain as well as for comparative analysis and future practical application in other contexts. Thus, the purpose of this paper is to help address this need, raise attention to the topic, and inspire and guide others wishing to embark on similar endeavors.

The CCR can be classified as a “standard” type of university research center (Hall, 2011; Ikenberry and Friedman, 1972). Standard centers are generally characterized as having stable goals and financial resources from diverse sources (*e.g.*, institutional and federal) in order to employ and support full-time faculty, research, clerical, and student assistant personnel; their own policies, procedures, and standing advisory boards; and are recognized not only as part of their affiliated home institutions but also as separate viable organizational entities (Hall, 2011). Since the CCR has been authorized by the Louisiana Board of Regents to report directly to the LSU Office of Research and Economic Development, it has the autonomy to reach across the colleges to bring faculty, students and resources together for a common purpose. Types of “non-standard” centers include adaptive centers and shadow centers (Hall, 2011). Adaptive centers coordinate and configure existing faculty and staff from different departments of an institution to work on particular contracted projects as needed depending on the projects. Although adaptive centers do not have permanent resources or personnel, they offer the structural advantage of flexibility to respond to changing social and market conditions (Hall, 2011). Shadow centers, sometimes known as “paper centers,” also have no permanent resources or personnel but can provide a forum for cross-disciplinary faculty teams or foster opportunities for specialized research services (Hall, 2011).

The CCR focuses on advancing and applying computational hydrodynamic and hydrologic models to include overland flow, river discharge, tides, wind-waves, and hurricane storm surge. Particular focus is placed on the development of such models to be used for real-time forecasting throughout the northern Gulf of Mexico. The CCR is also developing advanced systems-based models for assessment of the effects of climate change and associated sea level rise at the coastal land margin. In addition, the center plans to further similar modeling approaches to oil transport and fate, and the Gulf dead zone. CCR scholars collaborate with natural and social scientists, engineers, government agencies, and stakeholders to produce transdisciplinary research outcomes that provide accessible and useful decision-support tools capable of enhancing coastal resiliency. Present research and outreach is targeting the northern Gulf of Mexico, including Louisiana, Mississippi, Alabama, and the Florida panhandle, with additional efforts on the east coast of the United States. This path forward was initiated with regard for appropriate alignment with the broader mission of the university and with its other academic programs (Stahler and Tash, 1994). Like many other centers, "research results are disseminated to a diverse market of industry, federal, and state government agencies" (Walters and Gray, 1998).

2 ESTABLISHING THE CCR

Establishing the CCR at the LSU campus can be conceptualized as involving ten distinct yet interrelated steps, each of which is specified and elaborated in this section. It is important to note that this process was not linear. As noted by Walters and Gray (1998), "creating a new center is best understood as a process which is articulated over time, involves a series of steps, feedback loops, and periodic follow through" and by Mintzberg (1994), "managers don't always need to program their strategies formally, sometimes they must leave their strategies flexible, as broad visions, to adapt to a changing environment." The CCR has greatly benefited by taking an open-ended approach such as this.

A first step in establishing the CCR was acquiring institutional support. "A center must have the support of the central administration in terms of adequate resources as well as the cognizant academic departments, if it is to flourish" (Stahler and Tash, 1994). This support was necessary to provide solid infrastructure for CCR-related operations including employment of center leadership and personnel; permanent allocation of functional space in a centrally-located building on campus that provides offices and meeting rooms for faculty researchers, graduate student assistants and post-doctoral personnel, professional clerical staff, and guests/visiting scholars; and access to state-of-the-art technological equipment such as high-performance computing systems; and a high-resolution audio/visual device. Stated succinctly by Hall (2011), "Centers need university support in terms of mission, money, and space." The importance of rewarding the director for the extensive and intensive leadership roles and responsibilities (described below) cannot be understated. For example, the CCR director received an endowed Chair, a three-year startup package, a suite of offices, and ample salary support upon employment which motivated and enabled him to take immediate actions with center-related initiatives.

A second step in establishing the CCR was hiring a founding director who is responsible for all activities of the center including its proper management and continued development through cultivation of diverse professional relationships and successful research funding support. The literature indicates that a center's success depends substantially on having a competent director (Bozeman and Boardman, 2003; Gray and Walters, 1998) and that for effective leadership, a research center director should have a broad vision for the future of the center and passion and dedication for its purpose; scientific expertise, entrepreneurial and communication skills to actively promote the center, and managerial knowledge and experience; respect and trust among colleagues; ability to create a cooperative work environment and collaborate effectively with other faculty, other departments, and higher administration and carefully navigate the work of the center within the institution (Boardman and Ponomariov, 2014; Hall, 2011; Walters and Gray, 1998). The capability of balancing multiple roles is also essential, as "center leaders must be able to delegate, provide a strong sense of direction, and focus on the task at hand while still being willing to shift gears" (Hall, 2011). Further, "center directors must devote considerable effort to preparing solid, professional presentations for they are a continuous aspect of center life" (Walters and Gray, 1998). Recruiting and hiring a trained, experienced, highly-competent, and efficient administrative assistant was another key task in this step and required significant time and consideration. It is typical for centers to employ an administrative assistant who reports to the director (Gray and Walters, 1998). However, the types of tasks and extent of responsibilities associated with this position can vary widely and have a major impact on the director's daily workload as well as the center's overall success (Gray and Walters, 1998).

A third step in establishing the CCR involved completing and meeting all of the procedures required to gain official Louisiana Board of Regents approval. Final approval of the CCR was achieved on April 27, 2016. Among the crucial tasks in this step was development of a written statement that outlined the description, need, activities, and future for the CCR. A clear, succinct statement helps ensure all research and operational activities of the center are focused on its niche and fosters communication about the CCR's identity to internal and external stakeholders.

A fourth step in establishing the CCR involved identifying and recruiting scholars in the natural sciences, social sciences, and engineering at the institution who have strong research backgrounds in and capacity for coastal resiliency-related work to serve voluntarily on a standing CCR Faculty Advisory Board. The CCR Faculty Advisory Board is comprised of five scholars from the departments of civil and environmental engineering, oceanography and coastal sciences, computer science, geography and anthropology, and environmental sciences. The Board meets regularly with the center director for strategic planning purposes and for consultation on various research, institutional, professional, and operational issues. As articulated by Hall (2011), advisory boards are "useful for testing project ideas" and can help centers "plan their work and work their plan."

A fifth step in establishing the CCR involved conducting a situation analysis and needs assessment in order to identify and prioritize community-specific and region-wide resiliency-related scientific research problems to be addressed as well as to explore opportunities within the diverse socioeconomic and cultural contexts of the geographic area. This task involved extensive information gathering on the latest science and practical needs especially regarding vulnerabilities to coastal hazards. An array of methods was used for this data collection which included emails, phone calls, face-to-face meetings, site visits, informal interviewing, and mining a myriad of secondary sources such as articles, reports, and databases (Tornatzky et al., 1998). A sixth step in establishing the CCR involved identifying, prioritizing, and engaging with key professional and community stakeholders and potential partners and determining and examining available resources. Ongoing outreach and interaction with the local community is vital for developing center familiarity, credibility, and support (Hall, 2011). For example, the CCR benefits from its close affiliation with the Louisiana Sea Grant College Program and its Marine Extension Program agents, which serves as a mechanism of direct communication with stakeholders and provides immediate feedback on projects and the overall vision of the CCR.

A crucial role for center directors is obtaining stable funding streams (Hall, 2011). In that regard, a seventh step in establishing the CCR was comprised of aggressively seeking and securing sustainable research funding from a variety of U.S. federal and state government agencies (*e.g.* Louisiana Sea Grant, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, National Science Foundation, U.S. Department of Homeland Security) and other sources. “Establishing relationships is important to most aspects of a center’s success, especially in the realm of funding” (Hall, 2011). Thus, this task involved finding appropriate requests for proposals, meeting and building personal relations with representatives from funding agencies, and writing numerous grant proposals (Hall, 2011) that involved multidisciplinary faculty spanning LSU colleges. The CCR placed particular emphasis on reaching out to early-career faculty who are motivated to pursue interdisciplinary research.

Certainly, a center must be perceived as credible and trustworthy by funding sources and other stakeholders for solidifying favorable relationships and positive results (Stahler and Tash, 1994). “According to previous academic literature, the identity of an organization has an inseparable link with the organization’s reputation” (Alessandri et al., 2006). To help build a credible and trustworthy reputation, an eighth step in establishing the new CCR involved developing a strong brand for the center (Aaker, 1991; Aaker, 1996; Alessandri et al., 2006; Melewar and Akel, 2005; Stride and Lee, 2007; Wheeler, 2003). This task required collaboration with stakeholders and consultation with appropriate parties at the university (*e.g.*, central administration, personnel in marketing and strategic communication) for guidance on the proper procedures for naming, branding, and positioning the center so that it has a relevant, memorable, and distinct but related organizational identity both within and external to the academic institution. Upon approval and participatory decision-making, the center was named the Center for Coastal Resiliency with intention to frequently reference its acronym, CCR. As a fun means of promoting “CCR” the music of the American rock band Creedence Clearwater Revival, which was active in the late 1960s and early 1970s, is played at CCR events. An appropriate color palette, font style, logo, and visual images were also carefully considered, strategically selected, and professionally designed with assistance from university and outside consulting personnel with marketing communication and graphic design expertise. The CCR branding (*i.e.*, name and acronym for the center, logo, color palette, visual images) was purposefully developed to be used prominently and consistently across all center activities and communications. Initially, the CCR branding was placed and distributed in multiple relevant locations on campus (*e.g.*, signage in the foyer of the designated CCR building as well as on office doors, letterhead stationary, business cards, etc.). Branding is an essential foundation for promoting the CCR, which is discussed in the section below.

A ninth step in establishing the CCR was development of a research agenda and conducting intensive cross-disciplinary collaboration on multiple present and future extramurally-funded research projects relevant to the CCR. The literature (Stahler and Tash, 1994; Walters and Gray, 1998) emphasizes the value of cross-disciplinary research teams of faculty and graduate students for optimal research productivity and quality within centers. Bozeman and Boardman (2003) encouraged center directors to “nurture collaboration among center members with regular meetings and multiple avenues of communication.” Effective communication in relationships requires ongoing dialogue and feedback (Santoro and Chakrabarti, 1999). A related task in this step pertained to effective and efficient allocation of the center’s budget as well as careful time management associated with these projects. Two current strategic initiatives for the CCR that are funded by federal agencies include: advancing and applying computational hydrodynamic and hydrologic models to include overland flow, river discharge, tides, wind-waves, and hurricane storm surge; and developing advanced systems-based models for assessment of the effects of climate change and associated sea level rise at the coastal land margin. A tenth step in establishing the CCR involved beginning the training of the next generation of transdisciplinary resiliency experts through supporting and mentoring several talented Ph.D. students and Post-Doctoral Associates. It has been well recognized that centers can “provide valuable research training sites and experiences for graduate students and postdoctoral fellows” (Stahler and Tash, 1994) and that “student workers can play an important role in centers” (Hall, 2011).

3 PROMOTING THE CCR

In conjunction with establishing the CCR operations, promoting the new center is an essential and ongoing endeavor. As centers must communicate with and influence various stakeholders (Hall, 2011; Tornatzky et al., 1998), "outreach, engagement, and raising the visibility of the center and its programs is of the utmost importance" (Beck et al., 2012). One general promotion-oriented goal for most centers is to achieve awareness and recognition for expertise in a certain scientific and/or technological research area within professional scientific communities. A center director who actively promotes the center and effectively communicates its mission and strengths to constituents both within the institution (Judson et al., 2009; Whisman, 2009) and externally plays a key role in achieving this goal. It is recommended that the director create a center culture in which promoting the center is genuinely valued and ensures that all internal participants (*i.e.*, employees) understand and contribute fully to these activities as champions for the center brand (Ind, 2004; Whisman, 2009).

Centers vary widely in terms of how much and the manner in which they are promoted. The CCR is aiming for maximum brand exposure across a range of stakeholders institutionally, locally, nationally, and abroad and strives overall to be viewed as a "tightly-knit, focused enterprise with a unified vision and programs" (Beck et al., 2012). Collaborative development of a long-term comprehensive and cohesive promotional plan for the CCR is currently being considered and the CCR intends to involve a Post-Doctoral Associate or Ph.D. student in this process. The plan will be based on traditional marketing principles and techniques from the commercial sector (Aaker, 1991; Aaker, 1996) as applied in the context of higher education. The literature streams on corporate identity and university branding (Alessandri et al., 2006; Chapleo, 2015; Melewar and Akel, 2005; Stride and Lee, 2007; Wheeler, 2003; Whisman, 2009) also provided useful information for guidance and justification for decision making. The fundamental components of the CCR promotion plan stemming from traditional marketing are expected to include social science research; clear behavioral and communication objectives; specific targeted audiences; branding; a coordinated strategic combination of promotional activities, tools, and messaging techniques; and procedures for evaluation. The strategy included use of personal contact as well as traditional and social media for message distribution. At this point, implementation of promotional activities is focused on two major objectives including raising awareness of the CCR brand name and understanding of the CCR vision and research-related services and accomplishments (*e.g.*, grants, publications, awards, and student achievements). Promotion of the CCR also aimed to build credibility and trust to foster supportive relationships and present and future collaborative projects.

Once the branding for the center was solidified (as described in the section above), it required purposeful execution and ongoing management. Seven major interrelated priority activities have been and continue to be implemented to promote the CCR with a focus on stakeholders. A first activity in promoting the new CCR was developing and managing a CCR website (www.lsu.edu/ccr). A website can be a powerful promotional tool that deserves careful development and monitoring as it is often external stakeholders' first encounter with the center (Beck et al., 2012). Websites offer many promotion-related strengths such as significant flexibility for creative information presentation and interactive capabilities (Beck et al., 2012). The CCR website was launched in August 2016. Currently, the CCR website content includes a Home page with introductory information about the center, the director, and Faculty Advisory Board; a description of Active Research Projects and funding sources; a News section that highlights recent publications and awards; announcements of Relevant Courses offered at the home institution; and access to Tools used in association with work of the center that offer research-driven coastal resiliency decision-support (MIRA: Mapping Interface for Research Applications and CERA: Coastal Emergency Risks Assessment). Center staff have the time-consuming but vital task of keeping the CCR website content updated. The format of the website adheres to common best practices for effective communication such as using accessible language and being well-organized and easy to navigate. The website design has an uncluttered professional look, with typography and color scheme congruent with that of the home institution, yet also distinctive with a prominent display of graphic illustrations of spatial maps representing research-relevant geographical domains in the Gulf coast. Additionally, the website showcases logos of partnering organizations and agencies (*e.g.*, Louisiana Sea Grant). As the CCR continues to evolve, the website will serve as a central archive (or at least direct where materials and data can be found) for its ongoing research, resources, institutional events, and community outreach activities and materials.

A second promotional activity involved creating and producing tangible and visually-cohesive CCR branded outreach and communication materials. As these materials should reflect the high standards of the center (Beck et al., 2012), this task required consultation with and assistance from university personnel who have marketing communication and graphic design expertise. The messaging was carefully written with editorial assistance for accurate, accessible, relevant, and consistent language. The visuals selected to correspond with the text were captivating, pertinent, and professionally prepared. Thus far, the CCR branded outreach and communication materials included printed brochures (*i.e.*, rack cards), pop-up banners (several designs), and useful promotional products (*i.e.*, "swag") (*e.g.*, insulated tote bags and small flashlights with the CCR logo and website address). These materials are being distributed to internal and external stakeholders via multiple venues (*e.g.*, CCR visits, postal mail, meetings, and conferences).

Many would agree that for optimal influence and relationship building there are no substitutes for interpersonal interaction (Beck et al., 2012). Thus, a third activity in promoting the new CCR involved significant presence at and participation in relevant professional events such as conferences (*e.g.*, American Geophysical Union, IAHR World Congress, Louisiana State of the Coast Conference). Participation was multifaceted and included co-sponsoring information booths, delivering research posters and oral PowerPoint presentations that include CCR mentions and associated visual images, serving on discussion panels, and coordinating special topic sessions. For example, CCR faculty, students, and staff showcased the new CCR by co-sponsoring an LSU information booth at the 2016 State of the Coast conference exhibit hall in New Orleans. The booth was large, welcoming and professionally-prepared and included CCR one-pagers, brochures, postcards of the CCR "Kickoff Symposium" (described below), promotional products, pop-up banners, comfortable seating, and slide shows of the center's research activities on video display monitors. Photos were taken at these events for future promotion-related use as appropriate (*e.g.*, added to CCR website). These professional event venues provide an opportunity for meaningful face-to-face interaction with different stakeholders (*e.g.*, funding agencies, practitioners, scholars, community leaders) regarding the formulation of a mission statement and research projects of the CCR. This promotional activity is in line with the literature that advises that "sponsoring booths at major conferences, supporting organizing committees for major industry events, and active high-level participation in professional associations can help raise the visibility of the center" (Beck et al., 2012).

A fourth activity in promoting the new CCR involved coordinating and hosting a CCR "Kickoff Symposium." This event was convened on August 16, 2016 at the main campus of Louisiana State University in Baton Rouge. Postcards announcing the CCR "Kickoff Symposium" were professionally designed and mailed as well as distributed interpersonally and posted in relevant buildings on campus. A list of invitees was compiled from the CCR local, national, and international faculty professional networks. In addition, postcards were given to visitors of the 2016 State of the Coast LSU information booth, they filled in their addresses, and then the postcards were mailed to them. Thus, the CCR developed a future contacts list and mailed the postcards to those interested parties as a reminder of the upcoming kickoff event. Electronic versions of the postcard were also produced and sent via email to key faculty and personnel at the home institution. The structure of the one-day CCR "Kickoff Symposium" was intended to consist of an introductory overview of the CCR, site tours of the CCR facility, several presentations by keynote speakers nationally and internationally renowned for their resiliency-related research, a panel discussion by experts on the topic from U.S. federal agencies, and a regional panel discussion. Throughout the day there would also be opportunities for informal dialogue about the latest scientific research and applied knowledge on various ecological and social dimensions of coastal resiliency. CCR brochures and branded promotional products (described above) were also produced for distribution to all "Kickoff" participants. Unfortunately (and ironically) due to the historic Louisiana flood of 2016 during this time, the larger symposium with an expected turnout of 240 attendees was cancelled by university officials. However, with prompt coordination and cooperation, the symposium was transformed into a smaller workshop consisting of a subset of 40 participants including all of the original planned speakers except for three local leaders who were assisting with flood recovery efforts. See HydroLink (2016) for further details. Others have acknowledged that educational events in various formats (conferences, symposiums, training workshops) are a common and effective method for a research center to brand itself relevant to its affiliate institution (Hall, 2011).

A fifth activity in promoting the new CCR involved hosting individual visiting scholars. These sponsored visits included tours of the CCR facility and university campus; interactions with administrators, faculty, staff, and students at the CCR and other units at the institution; and formal presentations on resiliency-related research topics. The CCR-sponsored guest speakers' presentations were publicized internally which involved creation and distribution of electronic and printed flyers as well as email and word-of-mouth announcements. The CCR pop-up banners were placed in high-visibility locations in the presentation auditoriums and photos were taken for possible further publicity opportunities. As appropriate, the visiting scholars represented different disciplines. For example, one scholar who spoke on "Risk, Rhetoric, and Communicating about Coastal Hazards" is from a humanities department at a Florida institution while another who spoke on "Why We Might Want Coastal Resilience" is a coastal engineering professor from the United Kingdom.

A sixth activity in promoting the new CCR involved media relations and generating news publicity about the center's research and events. Media relations involved working closely with university personnel and local and national print and broadcast reporters on developing interesting and relevant stories to bring favorable attention to the center and interest in its pursuits among internal and external stakeholders. An array of formats and venues for these publicity efforts were considered and pursued including news articles in various institutional and professional newsletters (HydroLink, 2016), press releases, CCR director interviews with local and national media, press conferences (AGU, 2016), and links to relevant websites. This activity follows the recommendation that research centers "connect with individuals from the news office" (Beck et al., 2012).

4 CONCLUSIONS AND RECOMMENDATIONS

In sum, launching the new interdisciplinary CCR has required considerable time and effort yet has been an exciting and productive endeavor. With effective leadership, support, planning, teamwork, stakeholder engagement, and two-way communication, there have been stellar accomplishments even in the CCR's short time span and all parties involved are confident about continued achievements and future significant impacts. Further, the self-reflection and examination of the literature involved in the process of writing this paper has helped in crystalizing the conceptualization of CCR's emergence and development. These realizations are particularly true for the CCR director. Those interested in creating coastal resiliency-related research centers would be well served by first reading the literature for information on potential challenges and opportunities and guidance on how to prepare accordingly. It is hoped that this paper directs the reader to some of the resources that are available while providing an example with the establishment and promotion of the CCR.

While the existing literature on university research centers and on university-related branding is certainly worthwhile, it is relatively limited. More detailed and systematic further study of this area is needed. The present paper offers a preliminary framework of interdisciplinary research center establishment steps and promotion activities stemming from firsthand experiences in an actual case and has research and practical implications. Regarding research, this framework might be used as a starting point for constructing social science survey instruments for future empirical studies and comparative analyses of the unfolding processes of other centers of various types and from different stakeholders' perspectives. Larger and longitudinal studies on the experiences of center participants, especially directors, would also advance knowledge in this domain. From a practical standpoint, the collective findings should help support, refine, or produce new formulations of best practices for planning and promoting interdisciplinary centers, specifically those aimed at improving coastal resiliency in increasingly vulnerable systems around the globe.

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REFERENCES

Aaker, D.A. (1991). *Managing Brand Equity: Capitalizing on the Value of a Brand Name*. Free Press, New York.

Aaker, D. A. (1996). *Building Strong Brands*. Free Press, New York.

American Geophysical Union (AGU). (2016). *Water World: Historic Floods, Sea Level Rise, Storm Surge and Climate Change,* San Francisco, see https://www.youtube.com/watch?v=LFDNelTPKx4.

Alessandri, S.W., Yang, S.U. & Kinsey, D.F. (2006). An Integrative Approach to University Visual Identity and Reputation. *Corporate Reputation Review*, 9(4), 258-270.

Beck, D. (2012). *Best Practices Manual*, Engineering Research Centers Program (prepared for but not published by the National Science Foundation). Available online (http://erc-assoc.org).

Boardman, C. & Ponomariov, B. (2014). Management Knowledge and the Organization of Team Science in University Research Centers. *The Journal of Technology Transfer*, 39(1), 75-92.

Boardman, C. & Corley, E.A. (2008). University Research Centers and the Composition of Research Collaborations. *Research Policy*, 37(5), 900-913.

Boardman, C. & Bozeman, B. (2007). Role Strain in University Research Centers. *The Journal of Higher Education*, 78(4), 430-463.

Bozeman, B. & Boardman, C. (2003). *Managing the New Multipurpose, Multidiscipline University Research Center: Institutional Innovation in the Academic Community*. IBM Endowment for the Business of Government, Washington, D.C.

Chapleo, C. (2015). An Exploration of Branding Approaches in UK Universities. *International Journal of Nonprofit and Voluntary Sector Marketing*, 20(1), 1-11.

Coastal Protection and Restoration Authority (CPRA). (2013). *2017 Coastal Master Plan: Model Improvement Plan, Version II*, The Water Institute of the Gulf, Baton Rouge, Louisiana, 52.

Delorme, D.E., Kidwell, D., Hagen, S.C. & Stephens, S.H. (2016). Developing and Managing Transdisciplinary and Transformative Research on the Coastal Dynamics of Sea Level Rise: Experiences and Lessons Learned. *Earth's Future*, 4(5), 194-209.

Fischbach, J.R., Johnson, D.R., Kuhn, K., Pollard, M., Stelzner, C. & Costello, R. (2016). *2017 Coastal Master Plan Modeling: Attachment C3-25 – Storm Surge and Risk Assessment, Version II*, Coastal Protection and Restoration Authority, Baton Rouge, Louisiana, 216.

Friedman, R.S. & Friedman, R.C. (1984). Managing the Organized Research Unit. *Education Record*, 65(1), 27-30.

Geiger, R.L. (1990). Organized Research Units: Their Role in the Development of University Research. *The Journal of Higher Education*, 61(1), 1-19.

Gray, D.O. & Walters, S.G. (1998). *Managing the Industry/University Cooperative Research Center: A Guide for Directors and Other Stakeholders.* Batelle Press, Columbus, OH, Chapter C3, 59-85.

Hagen, S.C., Bilskie, M.V., Passeri, D.L., DeLorme, D.E. & Yoskowitz, D. (2017). Systems Approaches for Coastal Hazard Assessment and Resilience. *Oxford Research Encyclopedias: Natural Hazard Science*. Edited by Susan Cutter. In press.

Hall, K. (2011). University Research Centers: Heuristic Categories, Issues, and Administrative Strategies. *Journal of Research Administration*, 42(2), 25-41.
HydroLink (2016), *The Louisiana State University Center for Coastal Resiliency Kickoff Symposium*, IAHR, 4, 122-123.
Ikenberry, S. & Friedman, R.C. (1972). *Beyond Academic Departments: The Story of Institutes and Centers*. Jossey-Bass, San Francisco, CA.
Ind, N. (2004). *Living the Brand: How to Transform Every Member of Your Organization into a Brand Champion*. Kogan Page, Sterling, VA.
Judson, K.M., Aurand, T.W., Gorchels, L. & Gordon, G.L. (2008). Building a University Brand from within: University Administrators' Perspectives of Internal Branding. *Services Marketing Quarterly*, 30(1), 54-68.
Kidwell, D.M., Dietrich, J.C., Hagen, S.C. & Medeiros, S.C. (2017). An Earth's Future Special Collection: Impacts of the Coastal Dynamics of Sea Level Rise on Low Gradient Coastal Landscapes. *Earth's Future*, 5(1), 2–9.
Melewar, T.C. & Akel, S. (2005). The Role of Corporate Identity in the Higher Education Sector: A Case Study. *Corporate Communications: An International Journal*, 10(1), 41-57.
Mintzberg, H. (1994). The Fall and Rise of Strategic Planning. *Harvard Business Review*, 72(1), 107-115.
Ponomariov, B. & Boardman, C. (2010). Influencing Scientists' Collaboration and Productivity Patterns through New Institutions: University Research Centers and Scientific and Technical Human Capital. *Research Policy*, 39(5), 613-624.
Santoro, M. & Chakrabarti, A.K. (1999). Building Industry-University Research Centers: Some Strategic Considerations. *International Journal of Management Reviews*, 1(3), 225-244.
Stahler, G.J. & Tash, W.R. (1994). Centers and Institutes in the Research University: Issues, Problems, and Prospects. *Journal of Higher Education*, 65(5), 540-554.
Stride, H. & Lee, S. (2007). No Logo? No Way. Branding in the Non-Profit Sector. *Journal of Marketing Management*, 23(1-2), 107-122.
Tash, W.R. (2006). *Evaluating Research Centers and Institutes for Success*. WT and Associates, Fredericksburg, VA.
Tornatzky, L., Gray, D.O. & Geisler, E. (1998). *Managing the Industry/University Cooperative Research Center: A Guide for Directors and Other Stakeholders*. Batelle Press, Columbus, OH, Chapter C5, 105-128.
Twilley, R.R., Bentley Sr, S.J., Chen, Q., Edmonds, D.A., Hagen, S.C., Lam, N.S.N., Willson, C.S., Xu, K., Braud, D., Peele, R.H. & McCall, A. (2016). Co-Evolution of Wetland Landscapes, Flooding, and Human Settlement in the Mississippi River Delta Plain. *Sustainability Science,* 11(4), 711-731.
Walters, S.G. & Gray, D.O. (1998). *Managing the Industry/University Cooperative Research Center: A Guide for Directors and Other Stakeholders*. Batelle Press, Columbus, OH, Chapter C2, 21-57.
Wheeler, A. (2003). *Designing Brand Identity: A Complete Guide to Creating, Building, and Maintaining Strong Brands*. John Wiley & Sons, Hoboken, NJ.
Whisman, R. (2009). Internal branding: A University's Most Valuable Intangible Asset. *Journal of Product and Brand Management*, 18(5), 367-370.

THE IOWA WATERSHED APPROACH

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ABSTRACT

Conventional disaster recovery has focused on the repair and replacement of housing and infrastructure; hazard mitigation efforts have focused geographically within the immediate impacted areas. The state of Iowa, USA has started to take steps to increase preparedness and resiliency through a watershed-based approach. This science-based strategy increases community resiliency through integrated planning and implementation of projects that reduce peak flows, thus reducing flooding and improving water quality across entire watersheds.

Keywords: flood, nutrient, mitigation, resilience, management

1 INTRODUCTION

Following historic flooding in 2008, Iowa laid the groundwork for successful short- and long-term disaster recovery and resilience through the establishment of the Iowa Flood Center (IFC), the nation’s first university-based center devoted solely to addressing long-term flood-related issues, establishing Iowa as a forward-looking state committed to recovering from past events and mitigating future flood-related damage. In 2010, Iowa passed legislation enabling the creation of Watershed Management Authorities (WMA) in the state. A WMA is a mechanism for cities, counties, soil and water conservation districts (SWCDs), and other stakeholders to cooperatively engage in watershed planning and management. WMAs bring stakeholders together within a single watershed (HUC-8 scale) to develop multi-faceted solutions to water quantity and quality concerns that span traditional jurisdictional boundaries. WMAs develop watershed plans, assess flood risk, improve water quality, and educate residents on watershed management, stakeholder engagement, and securing funding for implementation of projects.

2 WATERSHED SCALE MITIGATION PLANNING

The IFC took advantage of this new legislation, and received US Department of Housing and Urban Development (HUD) funding to initiate the Iowa Watersheds Project (IWP). Led by the IFC and WMA partners, the project seeks to reduce flood damages by implementing multiple projects designed to have significant localized impacts across sub-watersheds (HUC-12 scale). When combined, these practices—ponds, wetlands, grassed waterways—reduce streamflow and flood damages for the entire watershed as well as downstream communities. Although it primarily targets flooding, the Iowa Watersheds Project also seeks to maximize soil water holding capacity from precipitation, minimize severe scour erosion, manage water runoff under saturated soil moisture conditions, reduce mobilization and transport of agricultural nutrients, and reduce and mitigate structural and nonstructural flood damages.

3 PROGRAM EXPANSION AND FUTURE DIRECTION

A new IFC-led initiative called the Iowa Watershed Approach continues to address factors that contribute to floods and nutrient flows. With the framework established by the IWP, Iowa can move forward with additional projects specifically designed to reduce downstream flooding and improve water quality in targeted vulnerable areas. This framework includes: 1) improved statewide recognition and support for water quantity and quality improvement projects at the watershed scale; 2) a legal process for the formation of WMAs to help guide watershed-scale solutions; and 3) the scientific foundation and experience, data collection protocol, and hydrologic models to guide the selection, placement, and design of targeted watershed projects. This adaptive model, supported by HUD dollars, will leverage the principles of Iowa’s innovative Nutrient Reduction Strategy to make our communities more resilient to flooding and help improve water quality. The IWA will accomplish six specific goals: 1) reduce flood risk; 2) improve water quality; 3) increase resilience; 4) engage stakeholders through collaboration and outreach/education; 5) improve quality of life and health, especially for vulnerable populations; and 6) develop a program that is scalable and replicable throughout the US.

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THE RESILIENCE OF COASTAL DELTAIC FLOODPLAINS IN CARBON AND NITROGEN MITIGATION AT CONTINENTAL MARGINS

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ABSTRACT

Coastal deltaic floodplains actively receive water from river systems and play an important ecological role of trapping sediment, sequestering carbon during net ecosystem productivity, and removing or retaining riverine nitrate to improve water quality. Hydrogeomorphic zones reflect the vertical position in the floodplain that is subject to different inundation periods and biological and geophysical feedback mechanisms. It determines the vegetative composition and production and thus the soil texture, moisture, and nutrient content of an area, typically delineated by tidal zone in a coastal deltaic floodplain. We propose that these hydrogeomorphic zones have the potential to be biogeochemical “hotspots” that remove nitrate at high rates. As newly emergent systems, these depositional environments are actively building new land and in the process, developing the ecosystem function of processing and removing excess nitrate from river water before it reaches the coastal ocean. This landscape self-organization patterns also result in biogeochemical processes of carbon sequestration. These patterns will help to create a conceptual model to describe changes in soil biogeochemistry, nitrogen and carbon storage during deltaic land development which is relevant to present and future Mississippi River delta restoration efforts.

Keywords: Coastal deltaic floodplains; nutrient biogeochemistry; ecosystem development; denitrification; carbon sequestration**.**

1 INTRODUCTION

Deltas are globally important locations of diverse ecosystems, human settlement and economic activity that are threatened by reductions in sediment delivery, accelerated sea level rise, and increased subsidence (Syvitski et al., 2009; Vorosmarty et al., 2009; Twilley et al., 2016). Coastal deltaic floodplains occur at the mouth of many rivers, the terminal end of a fluvial system (catchment basin, river channel, depositional basin). Wetlands within these coastal floodplains actively receive water from river systems and play an important ecological role of trapping sediment, sequestering carbon during net ecosystem productivity, and removing or retaining riverine nitrate to improve water quality. Coastal deltaic ecosystems are responsible for ~40-50% of global coastal and oceanic carbon burial globally as they are the main depocenters for terrestrial sediments in addition to high in situ production (Blair and Aller, 2012). It is therefore important to study how the soil organic carbons dynamics vary within a deltaic wetland as it has direct implications on coastal land development and its effects on the global carbon cycle. Organic carbon burial and land building are a function of the relationship between organic matter accumulation and hydrogeomorphology in these mineral-rich high depositional zones. Hydrogeomorphic position is the vertical position in the floodplain that is subject to different inundation periods and biological and geophysical feedback mechanisms. It determines the vegetative composition and production and thus the soil texture, moisture, and nutrient content of an area, typically delineated by tidal zone in a coastal deltaic floodplain. Changes in the organic fraction both spatially on the delta top and in the stratigraphic record provide information about environmental conditions and ecological succession in the landscape and carbon sequestration through time.

2 ECOSYSTEM SERVICES

Intensifying and widespread use of fertilizers in agriculture has resulted in the riverine export of high levels of reactive nitrogen, which has drastically and negatively impacted coastal systems. In Mississippi River system, nitrate concentrations have increased fourfold over the last half century leading to formation of the hypoxic zone in the Gulf of Mexico off the Louisiana coast (Scavia et al., 2003; Turner et al., 2005). Coastal deltas are the last point of interception of riverine nitrate before river water reaches the ocean. Similar to other wetland systems, deltaic wetlands have the potential to be biogeochemical “hotspots” that remove nitrate at high rates. As newly emergent systems, these depositional environments are actively building new land and in the process, developing the ecosystem function of processing and removing excess nitrate from river water before it reaches the coastal ocean. With the high N flux from agriculture in Mississippi River watershed, newly created wetlands as part of deltaic processes may intercept and remove nitrate from river water via denitrification, serving as a

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mitigating factor to the nutrient enrichment responsible for the growing hypoxic zone in the Gulf of Mexico (Henry and Twilley, 2014). The Wax Lake Delta is one of the few coastal deltaic floodplains in the Lower Mississippi River Delta complex that, in recent years, has been built by riverine processes. This presents the opportunity to define the biogeochemical development of soil processes that drive denitrification, and ultimately, river nitrate removal.

3 PROJECT OUTCOMES

We will describe how the newly emergent coastal deltaic floodplains of Wax Lake Delta provide the unique opportunity to test conceptual ecologic models on primary successional ecosystem development and landscape self-organization patterns resulting in biogeochemical processes of carbon sequestration and nitrate removal. The flood pulse concept improves upon the river continuum concept for alluvial-floodplain systems. It argues that the lateral gradient of river channel to floodplain connectivity is more influential on the landscape features that the upstream-downstream longitudinal gradient. Additionally, over time flood frequency and duration becomes more predictable as the hydrogeomorphic system develops and biota adapt to the emergent landscape. In coastal deltaic floodplains, patterns in soil nutrient content and nutrient stoichiometry are a result of both landscape morphology and vegetation distribution and increasing biological influences over time. We will describe these spatial patterns of ecological development in the soils and sediments of the emergent coastal floodplain, the Wax Lake Delta. In addition, studies of nitrogen fluxes along a chronosequence, which has a gradient in organic matter content in soils, demonstrates differential fate of nitrate removed from river flood waters. These patterns will help to create a conceptual model to describe changes in soil biogeochemistry, nitrogen and carbon storage during deltaic land development which is relevant to present and future Mississippi River delta restoration efforts.

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REFERENCES

Blair, N. E. & Aller, R. C. (2012) The Fate Of Terrestrial Organic Carbon in The Marine Environment. *Annual Review of Marine Science*, 4, 401-423.

Henry, K. M. & Twilley, R. R. (2014). Nutrient biogeochemistry During the Early Stages of Delta Development in the Mississippi River Deltaic Plain. *Ecosystems*, 17(2), 327-343.

Scavia, D., Rabalais, N. N., Turner, R. E., Justic, D. & Wiseman Jr, W. J. (2003). Predicting the response of Gulf of Mexico hypoxia to variations in Mississippi River nitrogen load. *Limnology and Oceanography*, 48(3), 951-956.

Syvitski, J.P., Kettner, A.J., Overeem, I., Hutton, E.W., Hannon, M.T., Brakenridge, G.R., Day, J., Vörösmarty, C., Saito, Y., Giosan, L. & Nicholls, R.J. (2009). Sinking Deltas due to Human Activities. *Nature Geoscience*, 2(10), 681-686.

Turner, R. E., Rabalais, N. N., Swenson, E. M., Kasprzak, M., & Romaire, T. (2005). Summer hypoxia in the northern Gulf of Mexico and its prediction from 1978 to 1995. *Marine Environmental Research*, 59(1), 65-77.

Twilley, R.R., Bentley, S.J., Chen, Q., Edmonds, D.A., Hagen, S.C., Lam, N.S.N., Willson, C.S., Xu, K., Braud, D., Peele, R.H. & McCall, A. (2016). Co-evolution of Wetland Landscapes, Flooding, and Human Settlement in the Mississippi River Delta Plain. *Sustainability Science*, *11*(4), 711-731.

Vörösmarty, C. J., Syvitski, J., Day, J., de Sherbinin, A., Giosan, L. & Paola, C. (2009). Battling to Save the World's River Deltas. *Bulletin of the Atomic Scientists*, 65(2), 31-43.

MANGROVES FOR COASTAL RESILIENCE: OPTIMAL GREEN BELT WIDTH AND RESTORATION METHODS

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ABSTRACT

Mangroves are receiving massive attention for their ability to mitigate coastal flood risk. However, these protective properties are hardly ever included in coastal protection schemes and engineering designs by coastal managers and engineers. This may be due to a lack of standardized design values and management methods. Here, we review the state-of-the-art for design, construction and management of mangroves for their coastal protection benefits. We evaluate and combine knowledge on their wave attenuation properties and on their ecology to make recommendations on desirable mangrove widths. We also give an overview of possible methods for restoration and management of mangroves and although multiple methods are available, most projects revert to mangrove planting which is often done in unsuitable places with unsuitable species. It seems that restoration of mangroves on the ground is mostly approached from a forestry perspective and does not make use of principles of available knowledge on ecological restoration. As a consequence, mangrove restoration efforts have very low success rates. We conclude that the width of mangrove forests for coastal protection purposes and their restoration and protection needs to be strongly informed by both physical and ecological knowledge for creation of effective and resilient mangrove green belts.

Keywords: mangroves, flood risk reduction, wave attenuation, restoration, green belt width

1 INTRODUCTION

Since the Asian Tsunami, mangroves have been in the spotlight for their flood risk reduction properties. It was said that coastal communities behind extensive mangrove forests were less impacted by tsunami waves (Danielsen et al. 2005). Although this is only backed up by anecdotic evidence, mangroves do provide valuable services, such as fisheries and firewood, and are beyond doubt to be able to reduce impact of more benign waves and to reduce erosion (Alongi 2008). Nevertheless, mangroves are severely threatened by construction of infrastructure, urban development and clear cutting for aquaculture practices (Alongi 2002; van Wesenbeeck et al. 2015). Removal of mangroves and development of infrastructure close to the coast are increasing the need for large investments in coastal protection structures. Making mangroves an intrinsic part of coastal protection schemes may save mangrove forests and reduce costs for coastal protection infrastructure. However, there is little guidance on how to design, protect, restore and manage mangroves for coastal protection purposes.

Many countries in South East Asia have a greenbelt policy that appoints a protected mangrove zone between land and water. For example, in Indonesia, there is a decree that a mangrove belt should be at least the width of 1.3 times the tidal range, with a minimum of 100 meters. In the Philippines, similar regulation has just been approved by congress, in which it is stated that mangrove stands should be at least 100 meters wide. Width of these greenbelts is mainly determined by wave reducing capacities of mangroves under benign conditions. However, in conventional flood risk reduction, structures are designed for more extreme conditions to prevent failure. Furthermore, ecological and other physical factors that determine mangrove stability, resilience and persistence have not yet been taken into account to determine greenbelt width.

Whereas mangrove greenbelt width is only informed from a single perspective, restoration of mangroves is also making little use of the diversity of methods and of available knowledge in scientific literature. Mostly, mangrove restoration is done by single species planting of *Rhizophora mucronata*. This seems mainly driven by convenience as this species has a stick formed propagule and is easy to be planted. However, proper restoration strongly leans on system understanding and would start with an assessment of limiting factors. As a consequence, most planting efforts in the region fail. For example, during the last decade, USAID spent 7,1 million on planting mangroves in the Philippines and only 5-10% of these plantings survived. These low rates of success are mostly explained by very simple factors, such as planting too low in the intertidal, where mangroves do not grow well, or planting in zones that are wave exposed, whereas mangroves typically occur under sheltered conditions.

To improve the effectiveness of mangrove green belts for flood risk reduction, we present a first exploration of factors determining mangrove width here. Furthermore, we outline different mangrove restoration methods by focusing on interference in the abiotic system to improve conditions for natural mangrove settlement. By doing this, we hope to challenge interdisciplinary collaboration and to strengthen the link between science and practice to advance the field of using ecosystems for increasing resilience of coastal communities against flood hazards.

2 GREENBELT WIDTH

There are multiple field studies that show wave attenuation by mangroves under differing hydrodynamic conditions and with different mangrove species present (Mazda et al. 2006; Quartel et al. 2007; Bao 2011; Horstman et al. 2012). These measurements are used to validate numerical models such as SWAN and XBeach and thereby predictive power is increased, as these models allow for assessing functionality of mangroves in dampening waves under a range of hydraulic boundary conditions and vegetation characteristics. The most common way for capturing wave reduction by vegetation in numerical models is through the Mendez and Losada equation (Mendez & Losada 2004). This equation is also suitable for mangroves and it illustrates that wave attenuation by vegetation is influenced both by the hydraulic input parameters, such as water level, wave height and wave period, but also by the specific vegetation characteristics, such as, width of the vegetation field, stem diameter, stem density, stem height (as a function of the water level) and stem flexibility. For vegetation fields, the latter is captured in the bulk drag coefficient (Cd).

The effective drag coefficient is often empirically related to the Reynolds (Re) number or the Keulegan Carpenter number (KC) (for instance in Mendez & Losada 2004). This type of relationships has proven to provide reliable estimates for individual rigid cylinders. However, drag forces depend on blade bending. Re and KC only represent the strength of the flow. Variations of the mechanical properties of the plants (for instance of the Young modulus or moment of inertia) between different species or over different parts of the same individual (for instance between the trunk and the branches), will result in different behaviours under the same flow conditions. As a consequence, the fitting parameters will also vary (Zeller et al. 2014). Changes in the elastic properties of the plant may be of special importance for younger and shorter trees, where the more flexible canopy will play a larger role attenuating waves under mild conditions. In mature trees, the canopy may play a significant role under more extreme water levels and larger waves (McIvor et al. 2012).

Current numerical models facilitate the making of combined designs that integrate mangroves functionality with design of levees or seawalls (Figure 1). As mangroves mostly influence wave height, they will reduce wave impact on levees and reduce wave run up and set up. This can result in levee design with a reduced crest height (Figure 1). However, most models have only been validated with mild conditions, e.g. low water levels and wave heights, thus their predictive capacity becomes less under extreme conditions. Model analyses with different types of mangroves in SWAN showed that mangrove belts of 100 meter only reduce waves significantly when vegetation is dense and has a high biomass. For forests with less biomass per square meter, a belt with a width between 500-900 meters is needed to obtain significant reduction of incoming waves (waves at toe of levee smaller than 0,2 meters).

Relying only on the capacity of mangroves to reduce waves would lead to small greenbelts that are likely to be ecologically unstable and that do not allow for any natural dynamics with respect to erosion and accretion. In South East Asia, greenbelt policies enforce greenbelts that are often between 50 and 100 meters wide. Even only from the perspective of wave attenuation, this may be rather small for attenuation of waves that are higher and longer. If forest are older and have low densities, waves will penetrate deep in these forests. In addition, a forest of such a limited width may not be resilient and robust to withstand natural and anthropogenic variation in abiotic conditions such as sediment availability and sea level rise. In addition, mangrove forests are dynamic and may exhibit periods of accretion and erosion. Greenbelts should be wide enough to accommodate these dynamics. Optimal greenbelt width should be informed by functional requirements from different perspectives:

1. Ability to dampen waves;
2. Ability to hold sediments and to accommodate erosion and accretion dynamics
3. Harboring biodiversity and natural zonation;
4. Long-term stability and persistence.

The last two criteria are more related to long-time performance. The last factor is influenced by several of the factors above and the stability and persistence of a forest is influenced by species diversity for example. Different species of mangroves may be more efficient in reducing waves at different ranges of water level and wave height, depending on their geometry and mechanical properties. For example, pneumatophores of *Avicennia marina* are denser than the aerial roots of *Rhizophora*, which enhances energy dissipation closer to the bottom. However, *Rhizophora* may be more rigid and efficient for higher waves. This will also affect their ability to trap and hold sediment. As a consequence, an optimal mangrove belt may depend on the combination of different species and their functions, not only for the stability of the ecosystem, but from a physical perspective.

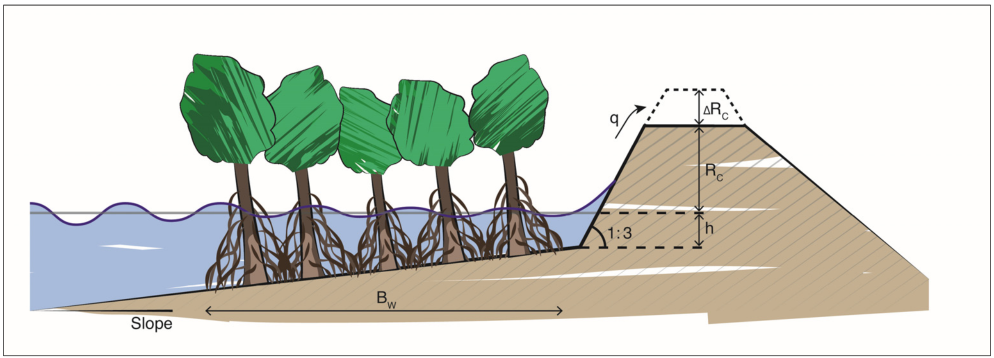

Figure 1. A mangrove forest levee combination where Bw is width of the mangrove forest, h is water level, q is the allowed overtopping discharge and Rc is crest height.

3 MANGROVE RESTORATION

Besides assessing functionality of mangroves, guaranteeing their long term performance under repetitive hazards is another essential step towards mainstreaming. Therefore, proper conservation and restoration techniques should be in place. Thus far, restoration has focused largely on mangrove planting, often without prior system assessment and without definition of proper metrics for success. A restoration project in China, for example, achieved a mangrove survival rate of 57%, but this could not be translated into ecological functioning of the system, as no appropriate baseline assessment was made (Chen et al. 2012). As a consequence, these planting practices have not advanced our knowledge on how to sustainably manage and restore mangrove ecosystems. Moreover, most of these practices have failed due to planting in locations that were too exposed to impact of waves or too low in the intertidal frame (Primavera & Esteban 2008). Species have specific optimum ranges within the intertidal gradient which often results in distinct species zonation in naturally recruiting areas (Imbert et al. 2000). Factors that determine zonation patterns such as soil aeration, salinity and propagule distribution should be considered in restoration projects (Imbert et al. 2000). Another reason for failure of mangrove plantations is inappropriate timing. A restoration experiment in the Caribbean encountered this problem, as all planted seedlings of *Avicennia* seedlings died after planting effort in the dry season. The planting experiment had to be repeated at the start of the wet season (Imbert et al. 2000). Additionally, planting often occurs in and destroys other habitats such as sea grass beds and the introduction of alien species may result in unbalanced mangrove stands that are mainly occupied by a single species (Chen et al. 2012). So, besides turning out to be a waste of money, planting itself becomes a threat for ecosystem health and persistence. Proper system analyses start with an assessment if mangroves used to be present in the systems and what are the main causes for their disappearance (Lewis Iii 2005). Only then, successful restoration can occur. There are multiple techniques that can be used for mangrove restoration and those focus on restoring the abiotic conditions for mangrove re-establishment. Measures can consists of the following:

- Hydrology and drainage by creek digging (Lewis Iii 2009)
- Increase elevation and sediment input (Winterwerp et al. 2005)
- Decrease hydrodynamic impact (Winterwerp et al. 2005)
- Make space for mangroves in the back (realign)
- Check seed availability

4 CONCLUSIONS

Optimal width of mangrove greenbelts should be informed by both biological and physical factors. Further investigation to effects of different species on wave attenuation and sediment retention will allow for more insight in desirable widths for stable and functional mangrove greenbelts. In addition, restoration and conservation of mangrove greenbelts should be informed by both ecology and physics and go beyond mangrove planting. This will allow for more diverse and tailor-made restoration techniques and advance our knowledge on best practices for restoration, conservation and management of mangroves.

REFERENCES

Alongi D.M. (2002). Present State and Future of the World's Mangrove Forests. *Environmental Conservation*, 29, 331-349.

Alongi D.M. (2008). Mangrove Forests: Resilience, Protection from Tsunamis, And Responses to Global Climate Change. *Estuarine, Coastal and Shelf Science*, 76, 1-13.

Bao T.Q. (2011). Effect of Mangrove Forest Structures on Wave Attenuation in Coastal Vietnam. *Oceanologia*, 53.

Chen, B., W. Yu, W. Liu, And Z. Liu. 2012. An Assessment on Restoration of Typical Marine Ecosystems in China - Achievements and Lessons. *Ocean and Coastal Management*, 57, 53–61.

Danielsen F., Sørensen M.K., Olw Ig M.F., Selvam V., Parish F., Burgess N.D., Hiraishi T., Karunagaran V.M., Rasmussen M.S., Hansen L.B., Quarto A. & Suryadiputra N. (2005). The Asian Tsunami: A Protective Role for Coastal Vegetation. *Science*, 310, 643-643.

Horstman E., Dohmen-Janssen M., Narra P., Van Den Berg N.J., Siemerink M., Balke T., Bouma T. & Hulscher S. (2012). Wave Attenuation in Mangrove Forests; Field Data Obtained In Trang, Thailand. *33rd International Conference on Coastal Engineering (ICCE)*, Santander, Spain, 1-15

Imbert, D., A. Rousteau, & P. Scherrer. 2000. Ecology of Mangrove Growth and Recovery in the Lesser Antilles: State Of Knowledge and Basis for Restoration Projects. *Restoration Ecology* 8, 230–236.

Lewis Iii R.R. (2005). Ecological Engineering for Successful Management and Restoration of Mangrove Forests. *Ecological Engineering*, 24, 403-418.

Lewis Iii R.R. (2009). Knowledge Overload, Wisdom Underload. *Ecological Engineering*, 35, 341-342.

Mazda Y., Magi M., Ikeda Y., Kurokawa T. & Asano T. (2006). Wave Reduction in a Mangrove Forest Dominated By Sonneratia Sp. *Wetlands Ecology and Management*, 14, 365-378.

Mcivor, A., et al. (2012). Reduction of Wind and Swell Waves by Mangroves. *Natural Coastal Protection Series*, pp.1–27.

Mendez F.J. & Losada I.J. (2004). An Empirical Model to Estimate the Propagation of Random Breaking and Nonbreaking Waves over Vegetation Fields. *Coastal Engineering*, 51, 103-118.

Primavera J.H. & Esteban J.M.A. (2008). A Review of Mangrove Rehabilitation in the Philippines: Successes, Failures and Future Prospects. *Wetlands Ecology and Management*, 16, 345-358.

Quartel S., Kroon A., Augustinus P., Van Santen P. & Tri N.H. (2007). Wave Attenuation in Coastal Mangroves in the Red River Delta, Vietnam. *Journal of Asian Earth Sciences*, 29, 576-584.

Van Wesenbeeck B., Balke T., Van Eijk P., Tonneijck F., Siry H., Rudianto M. & Winterwerp J. (2015). Aquaculture Induced Erosion Of Tropical Coastlines Throws Coastal Communities Back Into Poverty. *Ocean & Coastal Management*, 116, 466-469.

Winterwerp J.C., Borst W.G. & De Vries M.B. (2005). Pilot Study on the Erosion and Rehabilitation of a Mangrove Mud Coast. *Journal of Coastal Research*, 21, 223-230.

Zeller, R.B., et al., (2014). Improved Parameterization Of Seagrass Blade Dynamics And Wave Attenuation Based On Numerical And Laboratory Experiments. *Limnology and Oceanography*, 59(1), 251–266.

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INTEGRATED ASSESSMENT OF COASTAL AREAS

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ABSTRACT

This paper considers the requirements and benefits of integrated assessment of coastal areas, drawing on recent experience from a variety of cases.

Keywords: Coastal flooding; coastal erosion; coastal impacts; coastal adaptation; integrated assessment.

1 INTRODUCTION

Coastal areas are a microcosm of global change issues because of the intensity and multiplicity of human interventions and significant and interacting environmental processes often operating over sharp gradients. These drivers are various and include factors such as increasing population pressures, changing land use, management conflicts, and significant/diverse stakeholder concerns, various hazards such as hurricanes, relative sea-level rise, tsunamis, changing marine ecosystems, invasive species, etc. In addition, the ecological, socio-economic and cultural contexts within which the different coastal study areas are embedded must be considered. Due to these drivers, coastal areas widely experiencing profound change and with the multiple and interacting drivers, solutions to these issues are not clear.

An Integrated Assessment approach can address these problems and it has been argued that there are numerous coastal locations around the world that would benefit from such an approach (Nicholls et al., 2015). Integrated Assessment (IA) is a systemic approach that rather than taking a mechanistic approach, conceptualizes the system and all the relevant drivers, and then moves to a more quantitative analysis of the problem. The analysis needs to consider all the drivers and their interaction and hence is focused on the system level. This includes representing issues that are well understood and issues that are more poorly understood. Hence, hybrid approaches are often necessary. The details of any IA are defined by the system of interest, and the concerns that are raised. Hence, each IA model may tend to be bespoke, although there are general principles that might be applied. An IA approach provides a proactive method to assess present and future problems, as well as considering the range of possible responses to both and following episodic extreme events and longer term trends

Of particular concern for coastal areas is climate change, particularly sea-level rise (SLR). In low gradient coastal areas, small changes in water levels can have profound consequences. Hence, SLR is rightly considered to be a major threat. However, how will SLR interact with the other drivers that are occurring on the coast? These will vary from place to place and need to be considered on a place by place basis. To properly diagnose this type of problem and find appropriate and sustainable solutions, an IA approach needs to be considered. Human adaptation also needs to be considered as this can also have major direct and indirect effects beyond the immediate goal of the adaptation.

This paper will consider these issues from a multidisciplinary perspective drawing on examples from around the world. These issues are widely apparent, although there are limited examples of Integrated Assessment being applied to coastal areas. Important examples include East Anglia which was studied as part of the Tyndall Coastal Simulator (Dawson et al., 2009; Nicholls et al., 2015), the Delta Dynamic Integrated Emulator Model applied in coastal Bangladesh (Nicholls et al., 2016; 2017), the river and coastal component of the Regional Integrated Simulator, which considered two English Regions (Mokrech et al., 2008; Richards et al., 2008) and the river and coastal component of the CLIMSAVE Integrated Assessment Platform for Europe (Mokrech et al., 2014). This presentation will focus on key results and insights across these analysis. This will include when an Integrated Assessment approach might be appropriate and when not, as well as transferability to other coastal areas.

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REFERENCES

Dawson R.J., Dickson M, Nicholls R. J., Hall J, Walkden M, Stansby P K, Mokrech M., Richards J., Zhou J., Milligan J, Jordan A, Pearson S, Rees J, Bates P.D., Koukoulas S & Watkinson A. (2009). Integrated Analysis of Risks of Coastal Flooding and Cliff Erosion Under Scenarios of Long Term Change. *Climatic Change*, 95, 249-288.

Nicholls, R.J., Dawson, R. & Day, S. (Eds.) (2015). *Broad Scale Coastal Simulation: New Techniques to Understand and Manage Shorelines in The Third Millennium*. Springer.

Nicholls, R.J., Hutton, C.W., Lazar, A.N., Allan, A., Adger, W.N., Adams, H., Wolf, J., Rahman, M., Salehin, M. (2016). Integrated Assessment of Social and Environmental Sustainability Dynamics in The Ganges-Brahmaputra-Meghna Delta, Bangladesh, *Estuarine, Coastal and Shelf Science*, 183, 370-381, doi:10.1016/j.ecss.2016.08.017.

Nicholls, R.J., Lazar, A.N., Hutton, C.W., Adams, H.J., Salehin, M., Haque, A., Rahman, M. & Clarke, D.C. (2017). The Changing Hydro-Environment and Ecosystem-Based Livelihoods in Coastal Bangladesh. *E-proceedings of the 37th IAHR World Congress*, August 13 – 18, 2017, Kuala Lumpur, Malaysia.

Mokrech M., Nicholls R. J., Richards J. A., Henriques C, Holman I.P. & Shackley S., (2008). Regional Impact Assessment of Flooding Under Future Climate and Socio-Economic Scenarios for East Anglia and North West England. *Climatic Change*, 90, 31-55.

Mokrech, M., Kebede, A. S., Nicholls, R. J., Wimmer, F. & Feyen, L. (2015). An Integrated Approach for Assessing Flood Impacts Due to Future Climate and Socio-Economic Conditions and The Scope of Adaptation in Europe. *Climatic Change*, 128(3-4), 245-260.

Richards, J. A., Mokrech, M., Berry, P. M. & Nicholls, R. J. (2008). Regional Assessment of Climate Change Impacts on Coastal and Fluvial Ecosystems and The Scope for Adaptation. *Climatic Change*, 90(1), 141-167.

