Event and decadal-scale modeling of barrier island restoration designs for decision support

By

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ABSTRACT

An interdisciplinary project team was convened to develop a modeling framework that simulates the potential impacts of storms and sea level-rise to habitat availability at Breton Island, Louisiana, for existing conditions and potential future restoration designs. The model framework was iteratively developed through evaluation of model results at multiple checkpoints. A methodology was developed for characterizing regional wave and water levels, and the numerical model XBeach was used to simulate the potential impacts from a wide range of storm events. Simulations quantified the potential for erosion, overwash, and inundation of the pre- and post-restoration beach and dune system and were used as a preliminary screening of restoration designs. The model framework also incorporated a computationally efficient method to evaluate the impacts of storms, long-term shoreline changes, and relative sea level rise over a 15-year time period, in order to evaluate the effect of the preferred restoration alternative on habitat distribution. Results directly informed engineering design decisions and expedited later project stages including the construction permitting process.

KEYWORDS: Island restoration, numerical modeling, coastal habitat, decision-support.

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North Breton Island (Breton), located in the northern Gulf of Mexico off the mainland coast of Louisiana (Figure 1), is managed by the U.S. Fish and Wildlife Service (USFWS). Breton is one of several barrier islands that comprise the Breton National Wildlife Refuge (BNWR). This area is prone to storms, with 32 documented tropical storms passing within 150 km since 1872 (Terrano *et al.* 2016). Erosion caused by storms, combined with other processes like subsidence, sea level-rise and reduced sediment supply reduced the subaerial island footprint from 3.3 km^2 in 1869 to 0.15 km^2 in 2007. Breton is also relatively low-lying, with 85% less than 60 cm above NAVD88 (EMC 2015). Following the 2010 Deepwater Horizon oil spill, USFWS proposed restoration of Breton Island's beach, dune, and back-barrier marsh to create and sustain nesting habitat for bird species injured by the spill. In 2014, the Deepwater Horizon Natural Resource Damage Assessment Trustee Council allocated funding to complete the project.

In support of this restoration, the project manager convened an interdisciplinary team of wildlife biologists, consulting engineers, research oceanographers, and geomorphologists to develop and apply a science-based approach for informing what financially feasible project design would maximize the longevity and ecosystem services of the island. This multidisciplinary team 1) provided a range of technical expertise for expert elicitation, 2) enabled iterative project feedback and development of tools to meet evolving management questions, and 3) developed techniques that expanded on existing approaches that were insufficient to provide information needed to guide decisions for this project. A two-stage modeling framework was developed to simulate the evolution of an existing and restored Breton over different temporal scales to aid in restoration decisions and to provide stakeholders with a realistic expectation of the performance of the selected design. The model framework, hereinafter referred to as BIREM (Breton Island Restoration Evolution Modeling), provided robust and actionable information while also providing timely results for decision-making.

In its first stage, BIREM simulated the potential impacts of individual storms to the existing island topography and to the island following three proposed restoration designs. The approach accounted for the impacts of winter storms that occur in the area frequently but typically have less erosional impact, and tropical storm events (e.g. named storms) that occur less often but are typically larger and cause significant storm surge and waves, which can drive substantial morphological change including island breaching. Evaluation of these results informed the selection of a preferred restoration design that combined different features from several potential designs. The second stage simulated the decadal evolution of the preferred restoration design to better evaluate its performance. This approach provided information about impacts from multiple storms combined with longer-term processes like relative sea level rise and convergences/divergences in alongshore sediment transport. This stage provided information that was used to provide stakeholders with realistic expectations of the benefits and longevity of a restored island.

MODEL FRAMEWORK, COMPONENTS, AND INPUTS

The model framework was developed to maximize information available for decision support while constraining the computational expense to the timeline required for project development. The fol-

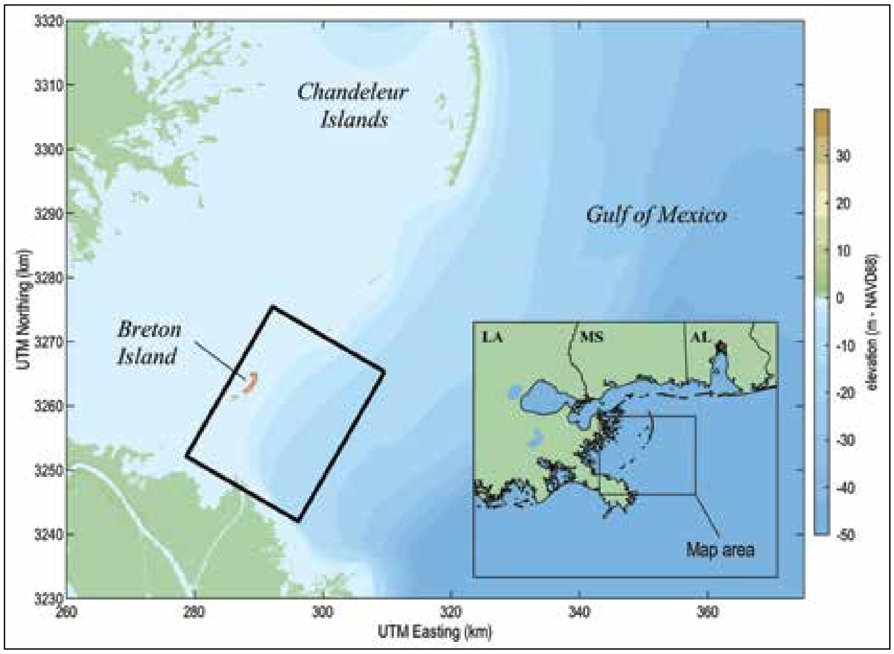

Figure 1. Location of Breton Island off the southeast coast of Louisiana. Black box represents the extent of the XBeach model grid. Red line indicates the shoreline contour which includes one of the proposed restoration templates.

lowing steps, with additional explanation below, detail the framework components:

1) Develop a discretized, regional characterization of wave and water level conditions.

2) Develop potential restoration designs (e.g., vertical and horizontal sediment-nourishment templates).

3) Simulate a subset of storm scenarios from step 1.

4) Evaluate the simulated island response for each restoration design.

5) Identify a preferred restoration design.

6) Simulate the 15-year island evolution including storms, long-term shoreline change, and relative sea level rise under the preferred restoration design.

7) Quantify changes to individual habitat regions.

Numerical model to simulate storm-induced morphological impacts

Storm-induced impacts to the existing and restored island for both stages were simulated using the process-based model XBeach (Roelvink *et al.* 2009). Hence, inputs to simulate hydro- and morphological event-scale processes included a digital elevation model (DEM) and time-series of offshore wave parameters and water levels associated with each storm event. The two-dimensional model setup used for this project accounted for the transformation of waves as they propagate across the inner continental shelf to the island. Dissipation of wave energy occurs in shallow water depths creating cross-shore and alongshore currents and driving wave run-up, a dominant process leading to dune erosion and overwash. Changes in topographic and bathymetric elevations that result from wave-driven cross-shore and alongshore sediment transport are also computed throughout the duration of each simulation.

The model grid spanned approximately 20 km and 27 km in the cross- and alongshore directions, respectively (Figure 1). Alongshore grid spacing covering the island was 25 m and increased to 100 m at the lateral boundaries. The cross-shore grid spacing was variable, increasing from 3 m over the island to 100 m offshore. Default parameter values (version 4926) were used, similar to previous studies (Lindemer e*t al.* 2010 and McCall *et al.* 2010, Sherwood *et al.* 2014, Mickey *et al.* 2018).

Digital elevation model and restoration designs

A DEM representing the existing island and nearshore areas (Figure 1) was developed using multiple datasets including the NOAA Southern Louisiana DEM (Love *et al.* 2010), bathymetric surveys collected in 2007 and 2014 (Kindinger *et al.* 2013 and Dewitt *et al.* 2016, respectively), and a 2014 topographic-bathymetric Lidar survey (Terrano *et al.* 2016). In places where overlapping data were present, preference was given to the most recent data using the spatial and temporal interpolation routines described by Plant *et al.* (2002).

Three potential restoration templates were then used to replace the existing island elevations within the design footprint using ESRI ArcGIS® software. These templates provided proposed island configurations that varied in beach width, berm and dune width and height, island width, and total volume of sand placement (Table 1). The design beach slope (1:30) started at the seaward edge of each design berm and extended offshore to the point of intersection with the bathymetry in the existing island DEM. All of the designs were backed on the mainland side of the island by a 1.5 m NAVD88 high containment dike along the back-barrier marsh. Some designs included a "feeder beach" on the northern end of the island, which was a feature designed to capitalize on net southerly alongshore transport directions and aid in nourishing the southern portion of the island and transport sand around the northwestern side.

Methodology for developing individual storm scenarios

To simulate island response to individual storms, representative storm scenarios of varying intensity (tropical and extratropical) were developed by analyzing historical records of wave and water level data in the region, namely from a 10-year (1996-2006) record from the National Data Buoy Center's directional wave buoy 42007, previously located just northeast of the northern section of the Chandeleur Islands in 15 m water depth (Figure 1). Storms were identified as time periods when significant wave heights (Hs) were at or above 2 m for at least six continuous hours. The definition of a storm was intentionally based on wave height rather than water level to ensure that the range of storms included those characterized by high waves with small surge (e.g. winter storms) and tropical events where large waves coincide with large surge. This definition resulted in a total of 52 individual storm events identified in the 10-year record. A coincident time series of peak wave period (Tp) during each event was also extracted from the buoy time series. The time series of still water level (superposition of tides and surge) during each of the identified storm events was taken from two NOAA tide stations located in the northern Gulf of Mexico: The Dauphin Island tide gauge (station # 8735180) or, when this station was unavailable, the Pensacola tide gauge (station # 8729840); previous work has shown that these two gauges are well correlated (Wahl and Plant 2015). Tide gauges closer to the study site are located in interior marshes and less representative of open ocean conditions needed to drive the modeling framework. Wave height, wave period, and mean water level data were interpolated to an hourly time series over the duration of each storm and the maximum water level, maximum Hs, Tp, and storm duration (D, defined as the duration when Hs exceeded 2m) were recorded to characterize each storm event. Wave direction was not used in the characterization but could be incorporated in future applications.

Table 1.

Summary of potential restoration designs.

	1A	2C	3B	4A
Beach berm width [m]	61	61	152 + feeder beach	61 + feeder beach
Beach berm elevation [m]	0.9	1.4	1.1	1.4
Dune crest width [m]	30.5	30.5	N/A	30.5
Dune crest elevation [m]	2.7	2.0	N/A	2.0
Back beach width [m]	N/A	30.5	N/A	30.5
Back beach elevation [m]	N/A	1.4	N/A	1.4
Total added volume [m^3]	2,993,119	3,244,648	3,246,177	3,806,575

Table 2.

Mean and maximum wave, still water level (SWL), and duration (D) conditions for storm scenarios. Shaded rows indicate simulated scenarios.

Bin	# of events	Mean Hs (m)	Max Hs (m)	Mean Tp (s)	Max Tp (s)	Mean SWL (m)	Max SWL (m)	Mean D (h)	Max D (h)
1	18	2.44	2.80	8.60	11.11	0.46	0.64	8	10
2	10	2.62	2.94	9.21	12.50	0.50	0.70	14	18
3	1	2.75	2.75	9.09	9.09	0.50	0.50	25	25
4	2	2.68	2.74	9.09	9.09	0.52	0.54	44	45
5	8	3.37	3.86	10.20	14.29	0.63	0.93	17	22
6	7	3.32	3.80	9.89	12.50	0.63	0.74	29	35
7	1	3.69	3.69	10.00	10.00	0.80	0.80	48	48
8	1	5.26	5.26	11.11	11.11	0.66	0.66	14	14
9	4	6.13	9.09	14.44	16.67	1.61	1.96	46	50

All storm events were assigned to one of 12 discrete classification bins according to the maximum Hs and total duration of each event. Storms were divided by wave height (2-3m, 3-4m, > 4m) and duration (6-12h, 12-24h, 24-36h, > 36h) intervals. The 52 storm events populated nine of the 12 bins, with the other three containing no observed events matching the wave height/duration criteria (Table 2). Within each of the bins, average and maximum Hs, Tp, and water level for all storms were calculated (Table 2). These average and maximum values were used to define the characteristics of one scenario that would be representative of all the observed storms within an individual bin. This methodology resulted in nine storm scenarios ranging from low magnitude winter storm events to high magnitude tropical storms. Note that wave buoys and water level gauges occasionally become inoperable during extreme events and may not capture the absolute peak conditions during some of the identified storms. From this set of storm scenarios, three (scenarios 1, 5, and 8) were initially chosen to simulate impacts to the existing island and proposed restoration templates. These scenarios represent low, medium, and high magnitude storm events. This approach, unlike common practice that focuses on tropical events with large waves and surge, includes the impacts of a wide range of storms on restoration designs.

Equation 1 was calibrated to generate storm wave time series for each storm scenario using the following criteria: 1) the amplitude of the time series was equal to the mean wave height, and 2) the length of time the wave time series exceeded Hs was equal to mean duration that waves exceeded Hs.

$$H(t) = Hs\,(Dn-t)/b^2\, e^{(-(Dn-t)/2b^2)} \tag{1}$$

In equation 1, t is a vector (hourly time steps), b is the scale parameter (0.17, 0.155, 0.107 for scenarios 1, 5, 8 respectively), Dn is the normalized mean duration, and Hs is the mean significant wave height for the particular scenario. Curves were made to characterize the gradual ramp up and steep decline of wave height at the beginning and end of a storm, respectively. Once the time-series of significant wave heights were created, idealized hourly spectra were generated assuming a JONSWAP spectra (Hasselmann *et al.* 1973). Wave direction was set to 90 degrees relative to the model grid; i.e. scenario waves at the offshore boundary of the model domain were normally incident to the shoreline. This is due, in part, to limitations of the model in applying non-periodic lateral wave boundary conditions and in an effort to simulate the maximum wave run-up conditions for a given wave height and period. While specific changes in direction for each storm scenario were not included, implementing an approach that uses normally incident waves for all scenarios provides relative comparisons of island response given a range of storm scenarios and restoration designs that can aid in decision-making needs. Other spectral inputs also remained constant ($\gamma = 3.3$, directional spreading coefficient = 20 degrees, and Nyquist frequency = 0.5 Hz).

Water level time series used to drive the model were developed as Gaussian curves characterized by the mean water level elevation and mean duration values in Table 2. The same requirements used for the wave height time series were necessary for the water level curves, in which the water level must be at or above the mean water level for a period equal to the mean duration.

Methodology for 15-year simulation

The second stage of BIREM evaluated the potential resiliency and evolution of the preferred design alternative over a 15-year time period. The timeline of the

Table 3.
Comparison of the European Centre for Medium-Range Weather Forecast Interim model (ERA), to wave data from NOAA buoys 42007, 42012, and 42040 in the northern Gulf of Mexico for all available observational data in the period of 1980-2009.

	Bias			R2			RMSE		
Buoy	42007	42012	42040	42007	42012	42040	42007	42012	42040
Hs (m)	-0.13	0.68	0.16	-0.09	0.81	0.17	-0.17	0.88	0.19
Tp (s)	-0.04	0.54	0.48	0.75	0.47	0.63	0.27	0.63	0.54

Table 4.
Frequency of storms that exceed the dune crest, based on maximum water level and duration of dune crest exceedance.

	Maximum TWL	Duration	Number of events (1979-2015)	Recurrence interval (yrs/event)	Average number of events in 15 years
SClass1	< 3 m	< 35 hours	14	2.6	5-6
SClass2	> 3 m	< 35 hours	2	18.5	1
SClass3	any	>35 hours	8	4.6	3-4

project did not allow for a relatively comprehensive suite of environmental forcing combinations (e.g. storm sequences, sea level rise scenarios) to be evaluated with the model framework. Instead, the objective was to project island evolution under a set of storms that represent a realistic sequence of tropical storm events for an "average" (in terms of storm magnitude, duration, and frequency) 15-year period for the island. Average storminess was chosen based on feedback from project stakeholders and refuge managers, who indicated that information on the potential evolution of the island under these conditions was more informative for evaluating and communicating realistic expectations for the project than an extremely stormy period, when the island was likely to be significantly eroded regardless of restoration action, or a quiescent period, when the restoration project would be minimally impacted by erosion.

The storm sequence was generated by using empirical model approaches to gauge the relative potential impact of storms independently of factors (tides, sea level rise) assumed to be independent of storm duration and intensity. To generate an "average" storm sequence, total water level (TWL) was estimated using the Stockdon *et al.* (2006) parameterization for wave run-up to quantify the magnitude and duration of individual storm events. This approach required wave parameters (height, period) at the 20-m bathymetric contour, still water level (surge, in this case), and beach slope. The European Centre for Medium-Range Weather Forecast Interim model (ERA; 1979-present; Dee *et al.* 2011) was used to provide wave characteristics (available at six-hour intervals) because a longer, more continuous, decadal-scale record is available compared to observational data. Because ERA provides mean wave period (Tm) and the run-up parameterization requires peak wave period (Tp), peak wave period was calculated from model output using an assumed relationship of Tp = 1.4*Tm (Moskowitz 1964). Significant wave height and calculated peak wave period output over the period of 1980-2009 were compared to available data from NOAA buoys 42007 (in service 1981-2009), 42012 (in service 1983-1984 and 2009-2016) and 42040 (in service 1995-2016) in the northern Gulf of Mexico (Table 3). Storms analysis was conducted over the period of 1980-2015, corresponding to the time of model output available at the time of this study.

Still water level data was from the composite Dauphin Island-Pensacola water level record. The tidal signal was removed from the data prior to merging the data sets by subtracting the predicted tide from the observed water level. The sea level rise signal over the time period of interest (1979-2016) was also removed by fitting and subtracting a linear trend in the water level data (slope and intercept of 0.12 m/year, -10.37m for Dauphin and 0.08 m/year, -6.37m for Pensacola respectively). A single, constant value was then added to adjust the de-trended, de-tided time-series to high tide at mean sea level for 2016 (0.10m for Dauphin, 0.08m for Pensacola). This time-series of water level was then interpolated to the times of the ERA wave model output.

Beach slope for the parameterization of run-up was taken as 0.0333, the slope of the intertidal region in the selected restoration design. The threshold for defining storm events was based on the TWL exceeding the restored dune (1.98 m elevation of the crest) in the preferred restoration design, indicating prediction of overwash, inundation, potential dune elevation loss, and/or breaching (Sallenger 2000). The maximum water level and duration were recorded for each continuous event that exceeded the dune crest. These storms were divided into three classes (referred to as SClass1, SClass 2, and SClass 3) based on their duration and maximum water level (Table 4).

A relatively long record of storms (1851-2015) was used to determine if the period of analysis considered in characterizing events was representative of the project area. For tropical events associated with dune crest water level exceedance, the maximum wind speed at the location in its track nearest to Breton was extracted from the National Hurricane Center's North Atlantic hurricane database (HURDAT2; Landsea *et al.* 2004; Landsea and Franklin 2013). These data were used to approximate the characteristics of storms resulting in overtopping of restored dune crest: those passing within 200 kilometers (km) with a maximum wind speed of greater than 50 m/s, and those passing between 200-400 km of Breton with a maximum wind speed of greater than 70 m/s. These thresholds were used to identify events likely to result in dune crest exceedance in the HURDAT2 database. This analysis suggested that 1979-2015 encompasses a transition from a relatively quiescent period to a relative active period for storms, and thus recurrence intervals from this period were assumed to be representative of an approximately average period of storminess for the island (Figure 2).

The primary objective was to select a sequence of storms that were consistent with the recurrence interval of storms at Breton (Table 4). Other factors considered were that events predicted to reach the dune base but not the crest were not included in the SClasses (i.e. smaller storms are not included); island and dune recovery through accretion and aeolian transport was not considered; and the

BIREM framework method for evaluating and incorporating shoreline change was based on observational data that includes storm impacts. In addition, storms representing across a range of intensities and distance to Breton were preferred. Based on these considerations, a 15-year simulation containing three storm events was chosen: year 2, Rita (a 2005 far-field Category 5 hurricane in SClass3); year 7, Isaac (a 2012 near-field Category 1 hurricane in SClass3); and year 12, Gustav (a 2002 near-field Category 3 hurricane in SClass2).

For the three chosen storm events (Rita, Isaac, and Gustav), wave height, period, and direction were extracted from the closest points to Breton in the ERA model grid. Boundary conditions for the still water levels were taken from the merged Dauphin Island/Pensacola data set. Water level time series were adjusted to 2015 base sea level, but the tidal oscillation was not removed.

To more accurately model a 15-year evolution of the island, island change associated with quiescent conditions must be included. For instance, convergences/divergences in littoral sediment transport that cause erosion/accretion and the impacts of relative sea-level rise should be considered. Model elevations between XBeach simulations were therefore adjusted by including gulf side erosion, bayside erosion, and relative sea level rise (RLSR; consisting of subsidence and sea level rise) observed at Breton or other islands in coastal Louisiana. The island template was manually eroded at each cross-shore profile over the non-storm time segments using AutoCAD® to capture these longer-term processes.

The average Gulfside shoreline change at Breton from 1922-2004 was used in the model framework. Shoreline change after 2004 was not included because the period between 2004-2010 represented a particularly stormy period in the Gulf of Mexico (Figure 2), including major events such as Ivan, Katrina, and Rita; shoreline change due to storms is explicitly modeled in the BIREM framework with XBeach and including this time period in the analysis would overestimate the total landward migration of the island. Alongshore variable shoreline change rates recorded at Breton were also applied at each cross-shore transect (e.g. Terrano *et al.* 2016). Rates varied from -10.1 m/yr to -6.2 m/yr; generally with higher change rates on the northern end of the island. The back-barrier shoreline change rate was set to -1 m/yr following the Louisiana Coastal Protection and Restoration Authority (CPRA) Barrier Island Modeling study and assumed uniform. This rate was similar to that reported by McBride and Byrnes (1997) for North Breton Island from 1978-1989.

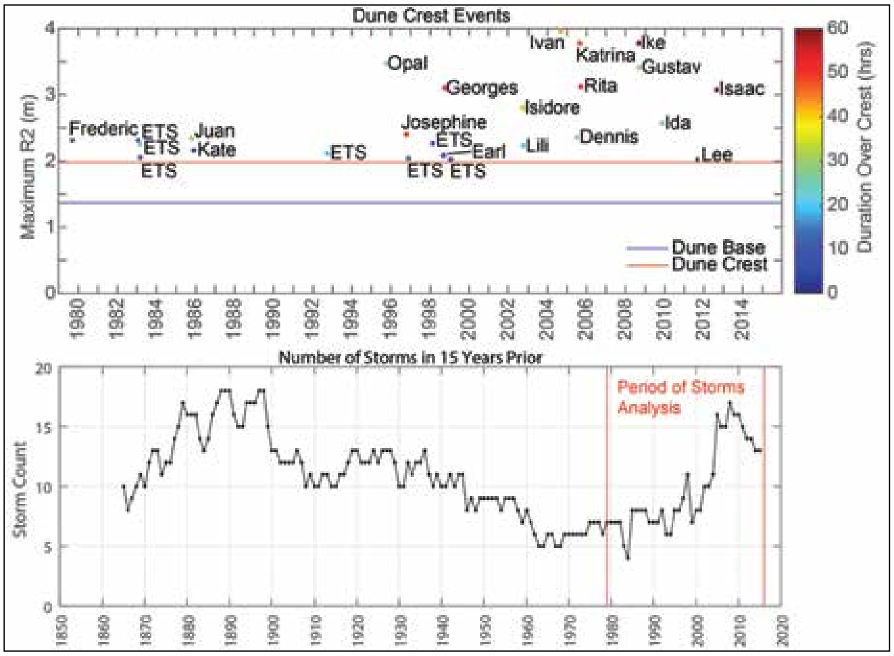

Figure 2. Duration (in hours, hrs) of storm events identified through exceedance of total water level (R2, m) above the dune crest. Tropical storms for the dune crest exceedance events were manually identified through evaluation of the presence of tropical systems in the northern Gulf of Mexico at the time period of the event. The remaining extratropical storms are identified with "ETS."

A subsidence rate estimate of 0.009 m/yr, a conservatively high estimate based on the CPRA 2012 Coastal Master Plan, was selected and combined with a eustatic sea level rise (ESLR) rate of 0.003 m/yr based on the same report. Combining subsidence and sea-level rise gave a RSLR rate of 0.012 m/yr, which was implemented into the modeling framework.

RESULTS

Individual storm scenarios

The magnitudes of modeled morphologic change associated with different storm scenarios and island configurations are provided in Figure 3. The planform response of the existing island and the three restoration designs for storm scenario 5 (Hs_max = 3.86m; Ds = 17 hours; mean SWL = 0.63m) was primarily confined to the northern and southern flanks of the island consistent with the historical evolution of the curvilinear island and erosion along the front of the feeder beach in design 3B (Table 1). Comparisons along an elevation profile extending across the southern flank of the island (Figure 3 E-H) demonstrated primarily erosion of sediment from the shoreface and some overwash to the back-barrier, which was in agreement with a review of historic aerial photography of Breton. Compared to design 3B, designs 1A and 2C retained maximum island elevations that would support greater bird nesting habitat diversity.

The results from storm bin 1 exhibited similar patterns but with only minor beach erosion along the northern and central part of the island (not shown). However, during the simulation, wave run-up did exceed the berm crest at the southern profile in design 3B. This indicated that a portion of the island could be vulnerable to even winter storm events if restored to design 3B, which was characterized by a low elevation berm and lack of high dune feature.

Increases in wave height and duration associated with storm bin 8 resulted in increased erosion of the beach but the restored dunes remained intact, particularly in the northern and central region of the island. Transects along the southern end of the island depicted that

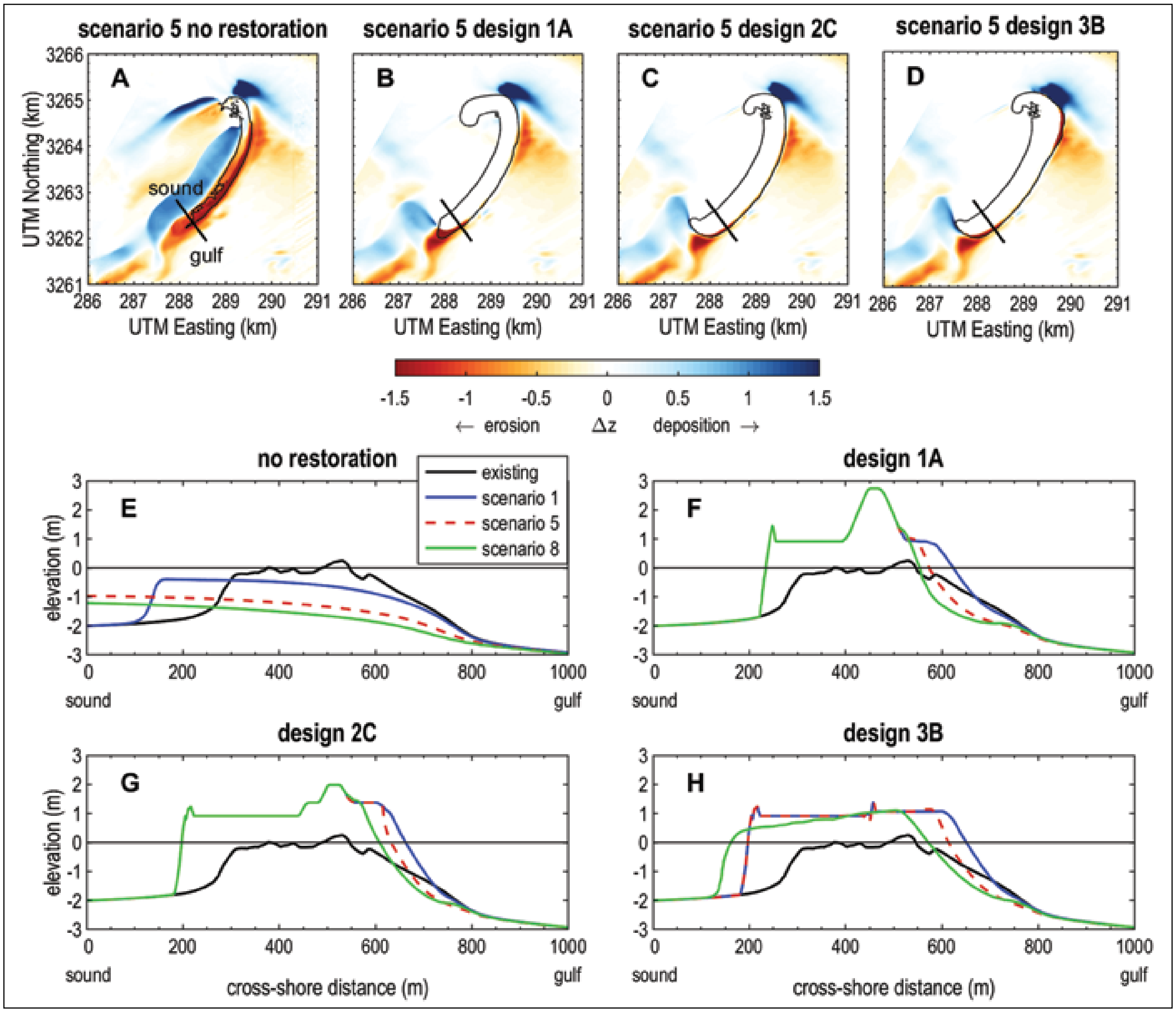

Figure 3. Modeled elevation change for storm scenario 5 using the (A) existing island elevations, (B) design 1A, (C) design 2C, and (D) design 3B. Modeled elevation change along a single cross-shore transect for storm scenarios 1,5, and 8 using the (E) existing island elevations, (F) design 1A, (G) design 2C, and (H) design 3B.

this part of the island was overwashed during this scenario causing the island to rollover landward, mimicking the natural processes that have dominated the historical evolution of the island. In general, the simulations indicated that overwash was less likely in the northern and central portion of the island for all three storm scenarios and for any of the restoration designs. The southern portion of the island was more vulnerable to storm impacts and the low elevations of design 3B can overwash in all three storm scenarios. Also note that for all storm scenarios there was significant overwash on the existing island (Figure 3E), which resulted in topographic change of more than 1m along most of its length, leaving only the northernmost part of the island above sea level. This is consistent with observed historical storm impacts such as after Hurricane Katrina.

15-year simulation

The results of these storm scenarios led the group to identify a preferred restoration design, 4A, which was a hybrid that included different features from the original designs including the presence of a feeder beach but with moderately high dunes to prevent overwash. The pre- and post-storm DEM for each storm included in the 15-year modeling sequence with design 4A is shown in Figure 4. Between storms, the influence of RSLR and shoreline erosion lowered and reduced the area of the island template. The temporal evolution of the island at a transect on the northern portion of the island illustrates the combined effects of the processes included in the modeling framework, including the background shoreline retreat and the erosion/overwash during each storm event (Figure 4; bottom).

The majority of the island remained intact during the first storm in year 2 with no overwash or breaching observed. Despite both storms falling in SClass3, the storm in year 7 caused significant overwash along much of the island due to the degradation caused by the first storm and the subsequent annual shoreline change and RSLR. Major breaching of the island occurred in the third storm in year 12, which was characterized as a weaker SClass2 but impacted a more degraded island due to its timing within the 15-year period.

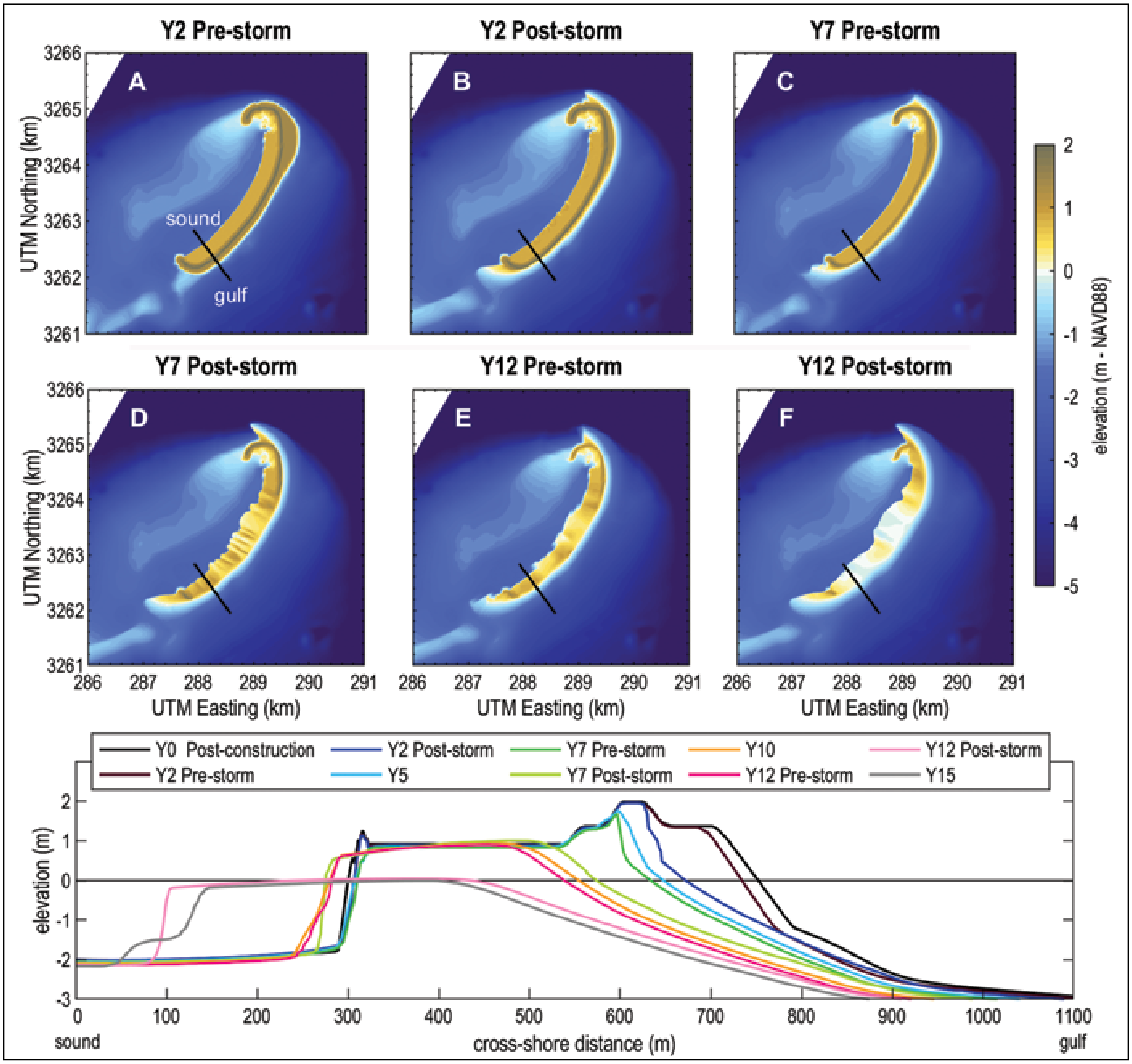

Figure 4. Pre- and post-storm DEMs at years 2 (A, B), 7 (C,D), and 12 (E,F) using XBeach simulations and (bottom) southern cross-shore profile at annual intervals illustrating island evolution.

Habitat acres defined using the Wetland Value Assessment (WVA) classifications of intertidal acreage (0 to +2 ft NAVD88), supratidal acreage (+2 to +5 ft NAVD88) and dune acreage (+5ft NAVD88 and above) (CWPPRA 2012) were quantified at multiple steps in the modeling process. While the existing island is dominated by intertidal region (86% of total area), the restored island under design 4A would consist mainly of supratidal (78%) and dune (13%) habitat. The largest simulated changes in these habitat regions started to occur after the initial storm event in year 2 and the dune habitat is expected to be completely degraded by year 10. The complete evolution of habitat acres during the 15-year period can be found in Table 5. For context, the change in modeled total island acreage was also compared to the historical change from 1989-2014 indicating similar trends in total island acreage through time (Figure 5).

DISCUSSION

The model framework developed to perform a 15-year simulation of island evolution included a process-based model for storms and empirical parameterizations of relative sea level rise and shoreline erosion, considered to be the most relevant processes in this case for benchmarking restoration designs. However, certain processes of relevance to island evolution on decadal time scales were excluded. The influence of strong tidal currents at the northern end and the presence of a shipping channel to the north of the island (Mississippi River-Gulf Outlet Canal [MRGO]) that may have affected sediment supply were not explicitly included; while historical shoreline change rates used in the empirical model would include some of these effects, they cannot account for changes associated with, for example, infilling of MRGO since channel maintenance was deauthorized in 2008. Natural recovery between storms through onshore sediment transport (Flocks and Terrano 2016) and aeolian transport were also ex-

Table 5.
Modeled area by habitat type (in hectares).

Simulation year	Intertidal (0 - 0.6m)	Supratidal (0.6 – 1.5m)	Dune (> 1.5m)	Total
0 (post-construction)	17.0	145.0	24.2	186.1
2 pre-storm	17.6	136.1	24.0	177.7
2 post-storm	29.0	113.3	23.0	165.4
5	27.0	108.9	13.5	149.4
7 pre-storm	26.2	104.0	9.8	140.0
7 post-storm	74.7	60.3	5.4	140.4
10	62.9	59.5	1.3	123.7
12 pre-storm	62.7	52.4	0.1	115.2
12 post-storm	66.5	19.1	0	85.6
15	54.3	13.3	0	67.6

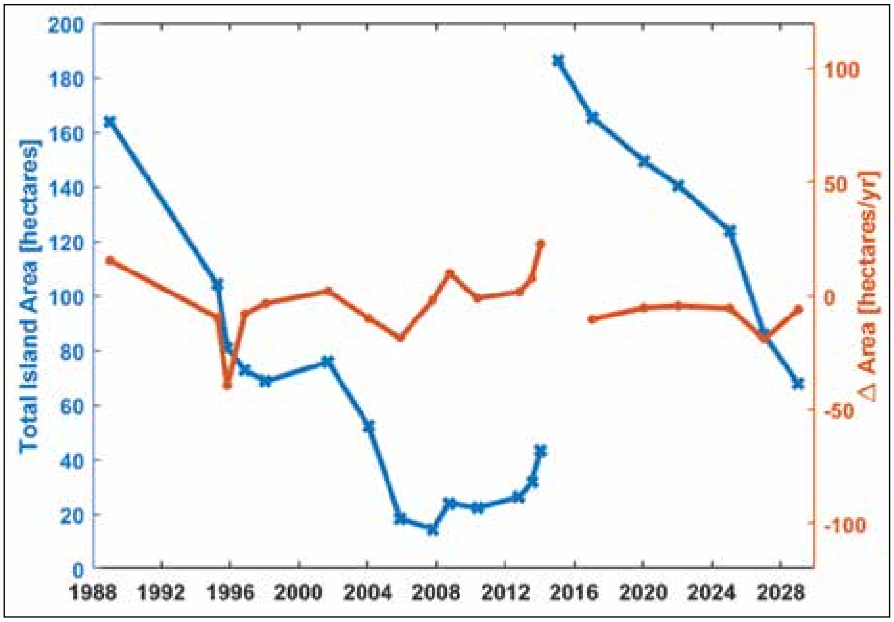

Figure 5. Observed (1989-2014) and predicted (2015-2030) total island acreage (blue) and change in acreage per year (red). Note the increase in island acreage in 2015 reflects the originally proposed island construction.

cluded, therefore acreage areas of habitat are a conservative estimate of restoration performance under the sequence of storms considered with the 15-year simulation.

As part of this project only one 15-year simulation corresponding to the occurrence of three storms was performed. This was determined to be the simulation that best addressed specific needs for project design (e.g. not focusing on the island response to the most extreme scenario) and addressing stakeholder expectations (e.g. how long will this restoration last if conditions are similar to the last 15 years?). Simulating multiple storm combinations would be informative and could be implemented into future projects. The simulation suggests that if restored, Breton Island may return to its existing state by the end of the 15-year period. While the focus here was on quantifying changes in island acreage, the results could be extended to consider the ecosystem or social value of a particular restoration.

SUMMARY

A model framework to simulate the evolution of a proposed barrier island restoration was developed by an interdisciplinary team to aid in management and engineering decisions and to assist with stakeholder expectations for design performance. The framework relied on combining a process-based model for storm impacts and empirical models of shoreline change and relative sea level rise. Model results were collectively evaluated at multiple checkpoints in order to elicit expert input and adapt the restoration design. This process eliminated time spent running simulations that provided little value to the decision-making process.

The first simulations in the model framework evaluated the response of multiple restoration designs to a wide range of potential storms ranging from wave-dominated winter storm events to tropical storm events with large surge. This approach extends common practice of focusing only on large tropical storms to evaluate potential designs. The results were used to evaluate the resilience of a preferred restoration design, which was simulated over a 15-year period using a new approach that combined impacts from conceptual storm events, relative sea level rise, and long-term shoreline change. The modeled trajectory of the proposed restoration was similar to the observed historical trajectory. The model provided information on the rate of island degradation, the predicted changes across different habitat types (intertidal, supratidal, dune), and the expected performance of the design template through time.

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