

ALABAMA BARRIER ISLAND RESTORATION ASSESSMENT

Dauphin Island Conceptual Ecological Model

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1.0 PURPOSE OF CONCEPTUAL ECOLOGICAL MODELS

Conceptual ecological models (CEMs) are generally simple, descriptive models, represented by a diagram, that describe general functional relationships among the essential components of an ecosystem. CEMs typically document and summarize current understanding of, and assumptions about, ecosystem function. Although they may be applied to numerous disciplines, when applied specifically to ecosystem restoration projects, CEMs also describe how restoration actions propose to alter ecosystem processes or components to improve system health (Fischenich 2008). To describe ecosystem function, a CEM usually diagrams relationships between major anthropogenic and natural stressors, biological indicators, and target ecosystem conditions. CEMs can be particularly helpful by providing assistance with four important tasks: ecosystem simplification; communication; plan formulation; and science, monitoring, and adaptive management.

1.1 Ecosystem Simplification

Because natural systems are inherently complex, resource managers must utilize tools that simplify ecosystem relationships and functions within the target ecosystem. An understanding of the target ecosystem is paramount to planning and constructing effective ecosystem restoration projects. During CEM development, known and unknown connections and causalities in ecosystems are identified and delineated (Fischenich 2008).

CEMs can promote ecosystem simplification by:

- Organizing existing scientific information;
- Clarifying system components and interactions;
- Promoting understanding of the ecosystem;
- Diagnosing underlying ecosystem problems;
- Isolating cause and effect relationships; and
- Identifying elements most likely to demonstrate an ecosystem response.

1.2 Communication

CEMs are an effective tool for the communication of complex ecosystem processes to a large diverse audience (Fischenich 2008). It is important for project teams to understand ecosystem function in order to reliably predict accomplishments to be achieved by restoration projects. CEMs can facilitate effective communication among project team members regarding ecosystem function, processes, and problems, and can assist in reaching consensus within the project team on goals and objectives.

Because CEMs summarize relationships among the important attributes of complex ecosystems, they can serve as the basis for sound scientific debate. Stakeholder groups, agency functions (e.g., planning and operations), and technical disciplines typically relate to system resource use and management independently, but CEMs can be used to link these perspectives.

The process of model development is at least as valuable as the model itself and affords an opportunity to draw fresh insight as well as address unique concerns or characteristics for a given project. Workshops to construct CEMs facilitate brainstorming sessions that explore alternative ways to compress a complex system into a small set of variables and functions. This interactive process of system model construction facilitates communication among project team members and almost always identifies inadequately understood or controversial model components.

CEMs can promote communication by facilitating the following:

- Integrating input from multiple sources and informing groups of the ideas, interactions, and involvement of other groups (Fischenich 2008);
- Assembling project/study managers with the project team and stakeholders to discuss ecosystem condition, problems, and potential solutions;
- Synthesizing current understanding of ecosystem structure and functions;
- Developing consensus on a working set of hypotheses that explain changes of studied ecosystem structure and functions, including ecosystem services provided such as habitat for critical fish and wildlife species;
- Developing consensus on system-wide monitoring variables and indicators that can reflect project specific ecological conditions; and
- Establishing a shared vocabulary among project participants.

1.3 Plan Formulation

Formulating a plan for an effective ecosystem restoration project requires an understanding of the following elements:

1. The underlying cause(s) of habitat degradation and ecosystem function change;
2. The manner in which causal mechanisms influence ecosystem components and dynamics; and
3. The manner in which intervening with a restoration project may reduce the effects of degradation.

These three elements should form the basis of any CEM applied to project formulation (Fischenich 2008).

CEMs can provide valuable assistance to the plan formulation process through the following:

- Supporting decision-making by assembling existing applicable science;
- Assisting with formulation of project goals and objectives, indicators, monitoring, management strategies, and results;
- Providing a common framework among team members from which to develop alternatives;
- Supplementing numerical models to assess project benefits and impacts; and
- Identifying biological attributes or indicators that should be monitored to best interpret ecosystem conditions, changes, and trends.

1.4 Science, Monitoring, and Adaptive Management

By recognizing important physical, chemical, and biological processes in an ecosystem, CEMs identify aspects of the ecosystem that should be measured. Hypotheses about uncertain relationships or interactions between components may be tested and the model may be revised through research and/or an adaptive management process. Indicators for this process may occur at any level of organization, including the landscape, community, population, or genetic levels; and may be compositional (i.e., referring to the variety of elements in a system), structural (i.e., referring to the organization or pattern of the system), or functional (i.e., referring to ecological processes) in nature.

CEMs can be helpful in restoration science, monitoring, and adaptive management through the following:

- Making qualitative predictions of ecosystem response;

- Identifying possible system thresholds that can warn when ecological responses may diverge from the desired effect;
- Outlining further restoration and research and/or development needs;
- Identifying appropriate monitoring indicators and metrics;
- Providing a basis for implementing adaptive management strategies;
- Interpreting and tracking changes in project targets;
- Summarizing the most important ecosystem descriptors, spatial and temporal scales, and current and potential threats to the system;
- Facilitating open discussion and debate about the nature of the system and important management issues;
- Determining indicators for monitoring;
- Interpreting monitoring results and exploring alternative courses of management as scenarios for ecosystem model simulations;
- Establishing institutional memory of the ideas that inspired the management and monitoring plan;
- Forecasting and evaluating effects on system integrity, stress, risks, and other changes;
- Identifying knowledge gaps and the prioritization of research;
- Interpreting and monitoring changes in target indicators; and
- Assisting in qualitative predictions and providing a key foundation for the development of benefits metrics, monitoring plans, and performance measures.

2.0 TYPES OF CONCEPTUAL ECOLOGICAL MODELS

CEMs can be classified according to their composition and presentation format. They can take the form of any combination of narratives, tables, matrices of factors, or box-and-arrow diagrams. The most common types of CEMs are narrative, tabular, matrix, and various forms of schematic representations. A comprehensive discussion of these types of CEMs is provided in Fischenich (2008). Despite the variety in types of CEMs, no single form will be useful in all circumstances (Fischenich 2008). Therefore, it is important to establish specific plan formulation needs to be addressed by the CEM and develop the CEM accordingly because “conceptual models . . . are most useful when they are adapted to solve specific problems” (Fischenich 2008).

2.1 Limitations of Conceptual Ecological Models

CEMs cannot identify the most important natural resources within a target ecosystem or prioritize project objectives. They do not directly contribute to negotiations and trade-offs common to ecosystem restoration projects. CEMs are not “the truth,” but are simplified depictions of reality. They are not “final,” but rather provide a flexible framework that evolves as understanding of the ecosystem increases. CEMs are not “comprehensive” because they focus only upon those components of an ecosystem deemed relevant while ignoring other important (but not immediately germane) elements. CEMs do not, in and of themselves, quantify restoration outcomes, but identify indicators that can be monitored to determine responses within the target ecosystem to restoration outputs.

Good conceptual models effectively communicate which aspects of the ecosystem are essential to the problem and distinguish those outside the control of the implementing agency. The best conceptual models focus on key ecosystem attributes; are relevant, reliable, and practical for the problem considered; and communicate the message to a wide audience.

3.0 APPLICATION OF CONCEPTUAL ECOLOGICAL MODELS TO DAUPHIN ISLAND

CEMs have been widely used in other regions of North America when planning large-scale restoration projects, including the Mississippi Coastal Improvements Program, the Louisiana Coastal Area Program, the Gulf Coast Ecosystem Restoration Task Force, the Everglades Restoration Program, and the Sacramento–San Joaquin Delta Regional Ecosystem Restoration Implementation Plan (DiGennaro et al., 2012, Healey et al., 2007, Barnes et al., 2005, Harwell et al., 2019). Under the Alabama Barrier Island Restoration Assessment, the Ogden model for development of a Dauphin Island CEM will be utilized (Ogden and Davis 1999). Conceptual ecological model development is an iterative process, and the CEM developed identifies the major drivers, stressors, effects, and attributes of Dauphin Island, and potential performance measures that could be used to assess various restoration measures considered under feasibility. The Dauphin Island CEM will be used as guidance when developing a detailed monitoring and adaptive management (MAM) plan during both planning and feasibility and upon selection of a restoration alternative, and may change as additional data, research and supporting information are gathered.

3.1 Background

Dauphin Island (Figure 1) is a strategically significant barrier island along the northern Gulf of Mexico and, more specifically, serves as the only barrier island providing protection to much of the state of Alabama’s coastal natural resources. The size of the system spans over 200 acres of barrier island habitat including, beach, dune, overwash fans, intertidal wetlands, maritime forest, and freshwater ponds. In addition, Dauphin Island provides protection to approximately 1/3 of the Mississippi Sound and much of the estuarine habitats in its lee including oyster reefs, mainland marshes, and seagrasses. The barrier islands fronting the Mississippi Sound have been losing surface area through time and their capacity to protect mainland natural resources and infrastructure is diminishing (Byrnes et al., 2010). Rising sea level, severe storms, and engineering activities all threaten the sustained subaerial presence (Twichell et al., 2011, Byrnes et al., 2012, Morton et al., 2008). Moreover, loss of barrier island area threatens the estuarine ecosystem of the Mississippi Sound and its resources and exposes the mainland coast and its associated wetlands and coastal habitats to increasing saltwater intrusion and damage from future storms and storm surges (USACE 2009). Hurricanes Ivan and Katrina caused some of the most substantial morphological changes on Dauphin Island since major residential development occurred on the island. Local concerns and efforts designed to protect the island led to anthropogenic actions such as redistribution of overwashed sand deposits and construction of seawalls. Furthermore, in response to the 2010 Deepwater Horizon (DWH) oil spill, a major breach in the island was closed with a temporary rubble mound structure to prevent oil migration into the Mississippi Sound. However, these actions could potentially influence sediment transport and island recovery. A comprehensive plan for restoration of Dauphin Island focusing on its importance to the state’s natural coastal resources has not been considered. Before substantial restoration of the island can proceed, many questions need to be answered utilizing scientifically defensible information. Questions that need to be considered include: 1) will beneficial use of dredged material and/or sand nourishment of the Gulf shoreline provide for long-term stability, and at what cost; 2) should Dauphin Island be restored for resilience to storm events, for support of beach and dune habitat, to have the longest island “lifespan” (i.e., be resilient and sustainable), and at what cost; and 3) would strategic conservation easements and/or land purchases meet the goals of habitat enhancement and sustainability, and at what cost?

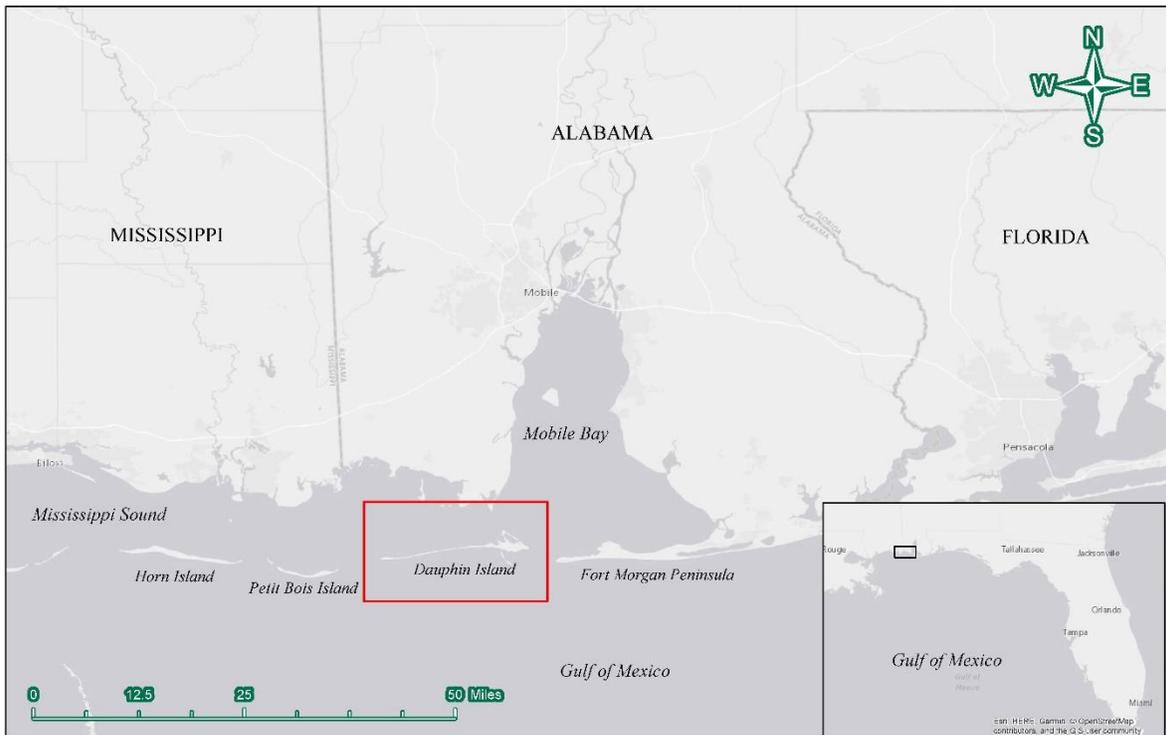


Figure 1. Dauphin Island Study Area.

3.1.1 Assessment Goals and Objectives

Restoration of Dauphin Island will help enhance, maintain, and protect ecologically important coastal habitat and living resources damaged by the DWH oil spill. Therefore, the goal of this assessment is to investigate viable options for the restoration of Dauphin Island as a sustainable barrier island to protect and restore island resources, including habitat and living coastal and marine resources, as well as protect the coastal resources of the Mississippi Sound/Mobile Bay and the southern portion of Mobile County, Alabama, including the expansive Heron Bay wetlands.

One of the main objectives to support the goal of this study is to evaluate all restoration alternatives based on sound science, allowing the science to guide the development of sustainable restoration alternatives, and being open to exploring a wide range of restoration possibilities. Strategic recommendations this study could help to advance include:

- 1) Protect all natural and cultural resources by determining their capacity in light of resource vulnerability;
- 2) Protective measures to preserve wetland and water surface ecosystems;
- 3) Understand the importance of and relationships between barrier island systems like Dauphin Island complex of Sand Island Shoals, Pelican Island, and Little Dauphin Island;

- 4) Develop a better island-wide understanding for the extent of what is called the “West End” of Dauphin Island and what it represents to the island in terms of resources; and
- 5) Identify best ways to seek beach stabilization.

Funding consideration was based on the importance of Dauphin Island to the resilience of coastal Alabama, impacts to species and habitats during the 2010 DWH oil spill, and the vulnerability of the island to natural and manmade forces.

3.1.2 Assessment Description

This study will provide the state of Alabama science-based information and tools to support restoration decisions on various engineering and ecological restoration designs. This scope of work covers seven tasks necessary to evaluate feasibility-level alternatives capable of increasing resiliency and sustainability of Dauphin Island:

1. *Update Baseline Conditions and Trends* - To help facilitate a broader understanding of the system as a whole, a search will be conducted to locate available literature and data pertaining to the geologic framework, coastal processes, and habitat on and surrounding Dauphin Island.
2. *Field Data Collection* - Habitat, nearshore sediment distribution, topographic and bathymetric, water quality, wave, and current measurements will be collected to update baseline conditions (Task 1) and provide a primary source of data for model development and validation.
3. *Data Analyses of Dauphin Island Shorelines and Habitats* - An updated analysis of historical and present-day Gulf-facing shoreline positions will provide the basis for assessing short-term and long-term shoreline change along the coast.
4. *Existing Volumetric Changes and Sediment Budget Analysis* - An updated sediment budget analysis will be performed to describe existing and potential changes in sediment transport pathways in the vicinity of the island.
5. *Modeling* - The development of the model is intended 1) to support evaluation of restoration alternatives based on a comprehensive analysis of nearshore wave transformation, tidal hydrodynamics, and sediment transport; 2) to analyze structural and functional performance of the breakwater structure as a function of time over the life cycle as well as computation of the wave transmission over and around the structure; 3) to understand the existing water quality within the Mississippi Sound and to quantify the relative changes in the water quality and flushing capacity resulting from proposed actions; and 4) to allow for assessment of habitat suitability and living resource benefits and/or impacts from proposed restoration alternatives into the future.
6. *Alternative Evaluations* - Alternatives to address island sustainability will be formulated and evaluated. To support this task, a tool designed to evaluate trade-offs among developed alternatives as related to overall project goals (e.g., habitat for at-risk populations, probability of persistence of migratory birds, protection of wetlands) will be developed. This tool will be used to inform decision-making and will also be useful to identify key uncertainties associated with alternative actions.
7. *Monitoring and Adaptive Management (MAM)* - The MAM will be formulated around the project objectives of the sustainable restoration actions identified during feasibility study development. The development of this CEM falls under this task.

4.0 CONCEPTUAL ECOLOGICAL MODEL DEVELOPMENT

4.1 Methodology

The CEM structure used for Dauphin Island follows the top-down hierarchy using the components established by Ogden and Davis (1999). The schematic organization of the CEM is depicted in Figure 2 and includes the following components:

Drivers - External driving forces that have large-scale influences on natural systems. Drivers may be natural (e.g., changing climate patterns) or anthropogenic (e.g., human development).

Ecological Stressors - Physical or chemical changes that occur within natural systems that are produced or affected by drivers and are directly responsible for significant changes in biological components, patterns, and relationships in natural systems.

Ecological Effects - Biological, physical, and chemical responses within a natural system that are produced or affected by stressors. CEMs propose linkages between one or more ecological stressors and ecological effects and attributes to explain changes that have occurred in ecosystems.

Attributes - Indicators or end points of a frugal subset of all potential elements or components of natural systems representative of overall ecological conditions. Attributes may include populations, species, communities, or chemical processes. Performance measures and restoration objectives are established for each attribute. Post-project status and trends among attributes are measured by a system-wide monitoring and assessment program as a means of determining success of a program in reducing or eliminating adverse effects of stressors.

Performance measures - Specific features of each attribute to be monitored to determine the degree to which an attribute is responding to projects designed to correct adverse effects of stressors (i.e., to determine success of the project).

A CEM serves as a guiding tool for the entire project; therefore, a CEM was developed by a subset of the project team at the beginning of the project to represent a current understanding of the Dauphin Island system (Figure 3). This CEM represents geomorphology, hydrology, water quality and habitat and was developed from the information contained and cited in the project proposal, conceptual models developed for similar projects (i.e., Barrier Island Restoration under the Mississippi Coastal Improvements Program), and information gained from a 2-day face-to-face meeting on Objectives Setting for the Dauphin Island project, followed by expert peer review. This CEM identifies stressors, working hypotheses, and key uncertainties and helps to identify problems and opportunities during the feasibility stage that will drive the development of restoration goals and objectives. This initial CEM identifies where the inventories and forecasting of conditions that will be conducted as a part of this project (described above) will fit into the new knowledge needed to ultimately formulate alternative plans. Any refinements to the CEM based on this new knowledge will be incorporated into the feasibility level Monitoring and Adaptive Management Plan (MAM).

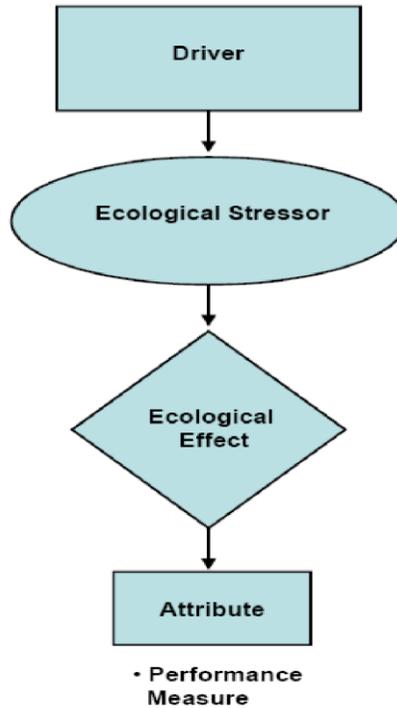


Figure 2. Conceptual Ecological Model Schematic Diagram.

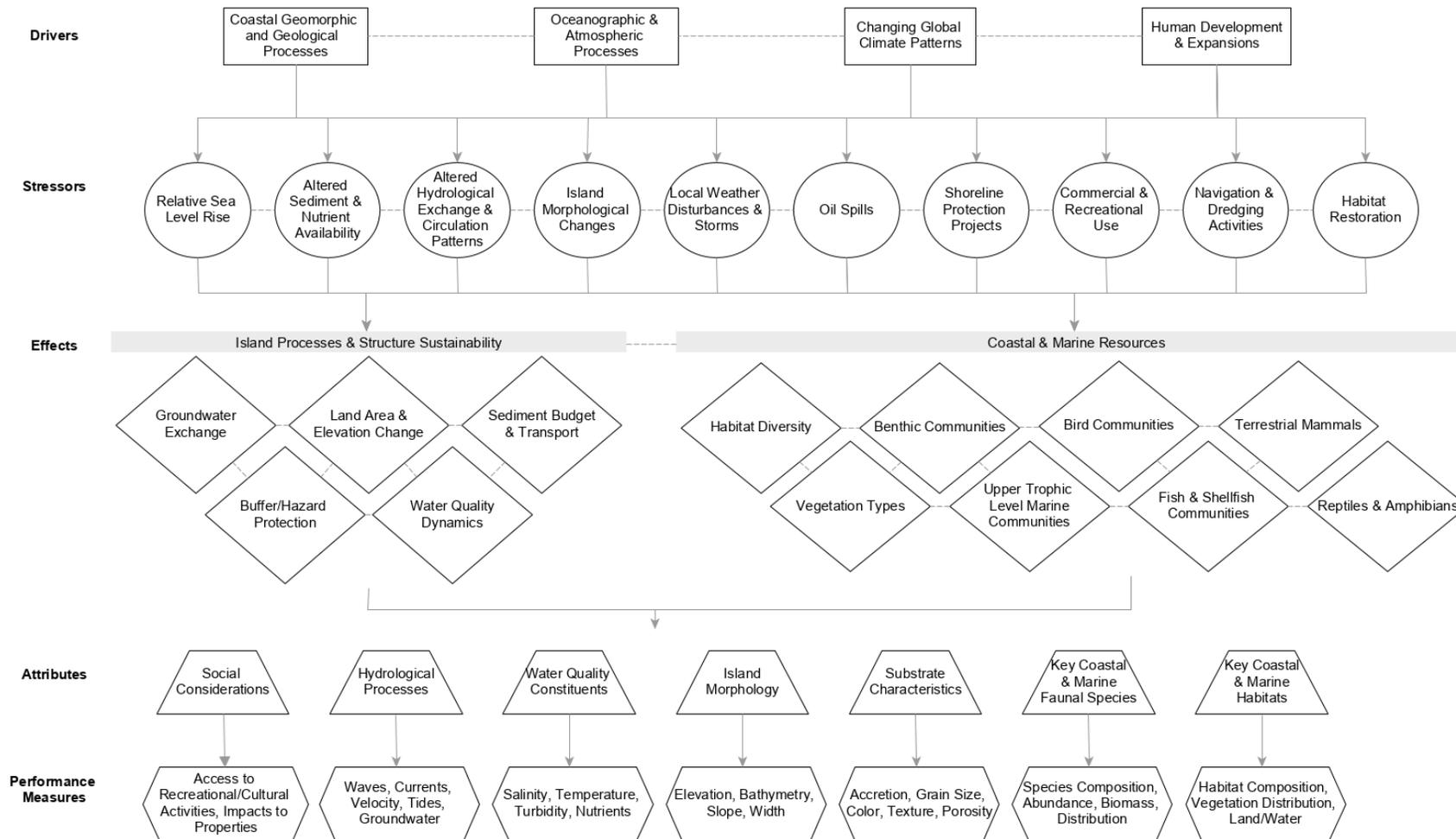
This CEM does not attempt to explain all possible relationships or include all possible factors influencing the performance measure targets within natural systems in the study area. Rather, the model attempts to simplify ecosystem function by containing only information deemed most relevant to ecosystem monitoring goals. Barrier island systems are inherently complex; illustrating the interconnectivity of ecological processes while categorizing elements into the CEM organizational structure (e.g., drivers, stressors, etc.) requires some simplification of island dynamics. Further, some processes may be described in multiple sections if they are relevant to multiple CEM elements. Model components are identified and discussed in the following subsections, and references for additional information are noted.

4.2 Drivers and Stressors

4.2.1 Coastal Geomorphic and Geological Processes

Dauphin Island consists of underlying geologic characteristics that have shaped the evolution of the island complex and have made it morphologically different from the other barrier islands of the Gulf coast (Nummedal et al., 1980). High elevations and active sand dunes characterize the eastern portion of Dauphin Island, which is positioned over the Pleistocene core, making it relatively stable (Nummedal et al., 1980, Morton 2008, Rosati and Stone 2009). The distal ebb-tidal shoals also shelter the eastern portion of the island from waves (Douglass 1994). Maintaining the morphology and integrity of the island is related to physical processes that control sediment availability and transport along the coast. A large volume of sand is stored in the ebb tidal delta shoals at the entrance to Mobile Bay as well as in the subaerial Pelican Island, which can serve to nourish the beaches of Dauphin Island through longshore transport (Morton 2008). There is an east

Figure 3. Dauphin Island CEM. Solid lines signify the connections across CEM components (e.g., drivers to stressors) while dashed lines are a simplification of interactions that occur among all of the elements within each of the components.



to west gradient in littoral transport of sand that allows the island to continue to evolve as sand is transported onshore (Passeri et al., 2015). Dauphin Island experiences low subsidence rates of approximately 1.2 to 1.7 mm/yr (Shinkle and Dokka 2004, Zervas et al., 2014, Wahl and Plant 2015).

4.2.2 Oceanographic and Atmospheric Processes

Dauphin Island is microtidal with a diurnal tidal range of approximately 0.5 m (Rucker and Snowden 1990) and experiences high energy waves and currents resulting from tropical cyclones in the summer and cold fronts in the winter (Morton 2008). The low-lying, coastal-plain topography makes the Mississippi Sound barrier islands particularly vulnerable to tropical storm forces. These atmospherically driven storm events can directly and indirectly contribute to coastal land loss through a variety of processes: (1) erosion and breaches from increased wave energies; (2) removal and/or scouring of vegetation from storm surges; and (3) storm-induced saltwater intrusion into interior wetlands and the Mississippi Sound. Severe storms can reconfigure the morphology of barrier islands by creating or widening existing breaches, accelerating erosion, and redistributing sediments (Flocks et al., 2015, Byrnes 2010, Fritz et al., 2007). Major hurricanes have substantially modified the morphology of the island (Morton 2008). Because the barrier island chains have exhibited similar impacts from multiple extreme-wave events, previous studies provide a basis for predicting and understanding future responses (Morton 2010).

The influence of winds on coastal currents and waves within the Sound and on the Gulf side of the barrier islands is well documented (Morton et al., 2004, Byrnes et al., 2013). Wind-driven waves and associated currents are the primary mechanisms for entraining and transporting nearshore sediments (Morton et al., 2004, Morton 2008, Byrnes et al., 2012). Wave energy is a key factor in sediment resuspension and promotion of lateral transport through longshore water movements. Wave-driven currents assist in maintaining the shoal orientation of ridges along the island (Flocks et al., 2015) and are a major driver in erosion and flooding risk (Wahl and Plant 2015). Large volumes of water move through the passes surrounding the barrier islands into the Mississippi Sound, generating strong tidal currents (Rucker and Snowden 1990) that are subsequently influenced by wind events, river discharge, and fluctuations in coastal sea levels (Noble et al., 1996, Cowan et al., 1996).

4.2.3 Changing Global Climate Patterns

The most recent report from the Intergovernmental Panel on Climate Change (IPCC 2014) provides several important findings that have the potential to impact the sustainability of Dauphin Island. Although the report suggests there is low confidence in the projections of tropical cyclone frequency and intensity for the mid-21st century, factors that have historically influenced the intensity and frequency of tropical cyclones (e.g., El Niño–Southern Oscillation) are likely to continue influencing tropical cyclone activity in the future (Kirtman et al., 2013). Thus, it is likely that the frequency, intensity, and spatial distribution of tropical cyclones in the North Atlantic will exhibit interannual and interdecadal variations (Kirtman et al., 2013) with the potential to contribute substantial morphological changes to barrier islands over short time periods. Over geological time frames, sea level rise is considered a major driver of coastal land loss (Morton 2008). Global mean sea level is predicted to rise 0.22 to 0.25 m by 2050 (median values across all scenarios with respect to 1986-2005; Church et al., 2013). As sea levels rise and islands evolve, it is anticipated that tidal hydrodynamics within the Mississippi Sound and estuaries will be further

altered (Passeri et al., 2015). Relative sea level rise—the combined effects of localized subsidence and sea level rise—is predicted to become the dominating driver for major changes in erosion risk for Dauphin Island and adjacent barrier islands in the northern Gulf of Mexico (Wahl and Plant 2015).

4.2.4 Human Development and Expansions

Although Dauphin Island has been continuously settled since 1701, low-quality beaches and frequent storms have kept recreational demand levels low on the island relative to the major tourist destinations found elsewhere along the Gulf of Mexico (Meyer-Arendt 1990). However, urbanization still has the potential to affect the behavior of storm surge in coastal communities by changing the roughness of the landscape, potentially resulting in amplified surge levels (Bilski et al., 2014). For instance, large sand deposits have disrupted residential areas on the northern end of the islands following hurricane events (e.g., Froede 2006), and the island was essentially flattened during Hurricane Frederic in 1979 (Meyer-Arendt 1990). Recreational and commercial activities on the island mainly are situated on its eastern end, and the construction of groins, riprap, and bulkheads has resulted in some stabilization and protection to this end of the island (Morton 2008). Offshore oil rig development is prevalent off the coast of Dauphin Island. As was apparent from the DWH oil spill, these rigs serve as a serious threat to coastal habitats. The beaches of Alabama, which included those along Dauphin Island, experienced over 120 km of light to heavy oiling conditions following the DWH spill (Michel et al., 2013). Small crabs, clams, shrimp, and snails inhabit sand beaches and dunes and serve as an important food base for birds and mammals (DWH NRDA 2016). These habitats also serve as nesting habitat for many federally listed threatened or endangered species, including sea turtles and beach mice (DWH NRDA 2016). As a result, oil spills, such as DWH, are critical stressors to Dauphin Island. In response to the DWH spill, several restoration projects have been proposed including beach and dune restoration, increasing sediment supply, sand bypassing, saltmarsh restoration, and land acquisition. These projects aim to restore the injuries from the oil spill on the island, return the island to historic conditions, and/or promote the ecological functions and services, among other objectives. Some small-scale restoration has previously occurred on the island, including the Gulf of Mexico Foundation project “Habitat Restoration in the Saw Grass Point Salt Marsh.” Completed in 2005, the project provided educational opportunities and fostered community participation through restoration activities that included the removal of derelict vessels, construction of wave attenuation devices to serve as oyster reefs, and replanting of marsh grasses and native woody plants (www.gulfmex.org).

Other human-related activities also serve as stressors to the island. Navigation channels and passes have modified the barrier island chain, including the Mobile Ship Channel, Fort Gains Harbor, Pascagoula Channel, and the Gulfport Ship Channel, while the Gulf Intracoastal Water Way extends east to west through the Mississippi Sound (Passeri et al., 2015). Commercial and recreational use of these waterways has required the use of dredging to maintain their navigability. The dredging of the Mobile Ship Channel began in 1826 at a depth of 3 m and is now dredged to a depth of 13.2 m and is 120 m wide (Morton 2008). Fort Gains Harbor serves as a primary access point for recreational and commercial boats, although dredging of the channel has resulted in marsh habitat loss and reduced naturally occurring sand overwash onto the marsh (Swann 2008).

4.3 Effects

4.3.1 Effects on Island Processes and Structure Sustainability

4.3.1.1 Groundwater Exchange

Coupled effects of future climate and human-use patterns have the potential to affect freshwater storage and groundwater resources on the island (Chang et al., 2016). Dauphin Island's shallow water-table aquifer and shallow sand aquifer serve as the main sources of freshwater for public supply. Precipitation recharges the shallow water-table aquifer, while losses occur through seepage to the ocean, evapotranspiration, and direct pumping activities (Kidd 1988). Increases in human development have the potential to affect the groundwater supply by increasing the demand for water from the aquifer. If the demand exceeds the aquifer's recharge rate, lateral movement of the saltwater wedge from the ocean into the aquifer can occur, resulting in saltwater intrusion into the aquifer and contamination of groundwater resources. Similarly, changes in land use and land cover (e.g., increase in impermeable surfaces) can reduce recharge rates by preventing precipitation from entering the aquifer.

4.3.1.2 Buffer/Hazard Protection

Barrier islands serve as a first line of defense for protecting adjacent coastal communities from storm-induced waves and surge. The geomorphology, topography, and roughness of the barrier islands influence the flow path of storm surge and the attenuation of wave energy. The western end of the island is particularly vulnerable to hurricanes as the barrier is narrow, dunes are uniformly low, and the shoreface is moderately steep (Morton and Sallenger 2003). On the eastern end, the ebb-tidal delta was observed to have reduced wave energy and minimized erosion during Hurricane Ivan (Froede 2006). Future changes in land area, island elevation, and habitat structures, as described below, have the potential to impact the hazard protection that barrier islands provide.

4.3.1.3 Land Area and Elevation Change

Dauphin Island has exhibited considerable morphological change over the past 160+ years, resulting in differential rates of land change over time (Table 1), with an overall net loss of 11% of its 1840s land area (Morton 2008). From 1996-2006, rates of land loss average 12.9 ha/yr, biased somewhat by Hurricane Katrina removing a 40-ha segment of the barrier island (Morton 2008). Elevation and land area change along the barrier islands are primarily caused by storm-related processes resulting in breaching and overwash (Byrnes et al., 2013). Large changes in elevation can occur following hurricanes as storms disrupt the east to west sediment transport, resulting in erosion on the shoreface and substantial deposition on the northern side of the islands (Fritz et al., 2007, Froede 2006, Flocks et al., 2015). During the 18th century, an unnamed hurricane created an inlet in Dauphin Island resulting in a new island called Petit Bois (Otvos 1979). Since then, storm-induced processes including wave refraction and overwash have widened the Petit Bois Pass from 2.4 to 7.5 km (Otvos and Carter 2008, Passeri et al., 2015) and have resulted in several additional breaches throughout the island (Froede 2008, Morton and Sallenger 2003). Storm surge heights of 3.5-5.5 m were observed over Dauphin Island during Hurricane Katrina, resulting in temporary flooding of the entire island chain and northern migration of the island (Fritz et al., 2007).

Table 1. Average long- and short-term historical rates of land area change for Dauphin Island (Morton 2008).

| Period of Record | 1847-1917 | 1847-1958 | 1958-1996 | 1996-2006 |
|-----------------------------|---|-----------|-----------|-----------|
| Average Rate (ha/yr) | Most of island submerged post-hurricane | +1.8 | -6.1 | -12.9 |

4.3.1.4 Water Quality Dynamics

Surface water quality in the bays and channels surrounding Dauphin Island are influenced by estuary-shelf exchanges as well as riverine runoff from terrestrial sources. Terrestrial sources include the Pearl River, which drains approximately 23,000 km² and transports chemical and biological pollutants before emptying into the western part of the Sound (Chigbu et al., 2004), and Mobile River, which drains approximately 114,000 km² and empties into the Gulf of Mexico at the eastern end of Dauphin Island. Changes in climate, land cover, and human activities have the potential to alter the volume and circulation of water, leading to subsequent effects to water quality constituent concentrations. Water quality constituents such as salinity, temperature, nutrients, organic pollutants, and dissolved oxygen play a critical role in the distribution and abundance of fish and shellfish in the bays and channels surrounding Dauphin Island, plant zonation, and soil biogeochemical processes, as well as the distribution of submerged aquatic vegetation (Enwright et al., 2020).

The U.S. Geological Survey Lower Mississippi-Gulf Water Science Center collected water quality and sediment data at four locations eight times from summer 2015 to summer 2016 in the Mobile Bay and Dauphin Island vicinity (<http://nwis.waterdata.usgs.gov/al/nwis/qwdata>). USGS personnel measured water quality parameters including pH, salinity, temperature, dissolved oxygen, and turbidity at 5-foot (1.5 m) intervals from the surface to the bottom of the water column at each sampling location during each visit. Water samples were also collected for nutrient and sediment analyses at bottom, mid-depth, and at the surface at each sampling location during each visit. These data indicated that river inflows had a strong influence on measured physical parameters. Salinity data collected from sampling points in the Mobile Bay estuary indicated that salinity gradients were often observed at locations affected by streamflow and were less common at sites closer to the Mississippi Sound and Gulf of Mexico. In addition, turbidity values were higher for periods of months following major river floods.

4.3.1.5 Sediment Budget and Transport

The east to west gradient in littoral transport has resulted in rapid growth on the western end at a rate of approximately 46 m/yr from 1847 to 2010 (Byrnes et al., 2013), and the development of a narrow Holocene sand spit that is frequently overwashed due to its low elevation (Nummedal et al., 1980, Morton 2008). The morphology of the western end of the island continues to evolve as sand is transported onshore, allowing the barrier island to maintain a minimum volume as it migrates landward (Passeri et al., 2015). Although dredging activities have disrupted sand transport, the large volume of sand stored in the Mobile ebb tidal delta is still an important source to the Gulf beaches of Dauphin Island (Douglass 1994, Morton 2008). Storms also rework and

disperse sands contributing to the post-storm regeneration of shoal areas adjacent to islands (Otvos and Carter 2013), as described under Land Area/Elevation Change.

The interaction of morphological island changes and relative sea level rise is predicted to impact tidal hydrodynamics within the bays behind the barrier island chain. Tidal amplitudes in the region are predicted to increase as much as 10 cm by 2100 under ‘high’ sea level rise scenarios and result in changes to current flood-ebb ratios and velocities (Passeri et al., 2016). The potential change in tides will impact the volume of water within the surrounding bays and channels and have implications on the transport of available sediment.

4.3.2 Effects on Coastal Marine Resources

4.3.2.1 Flora

The barrier island consists of diverse habitats supporting both emergent and submergent vegetation, including freshwater wetlands, longleaf pine, maritime forest, intertidal marshes and flats, beaches and dunes, submerged aquatic vegetation, and oyster reefs (Enwright et al., 2017). Subaerial and subaqueous vegetated and unvegetated habitats can be altered gradually in response to sea level rise and changes in littoral sediment transport, or they can be altered substantially in a short period of time due to acute events such as hurricanes and restoration activities that change the geomorphic profile and alter salinity and inundation regimes that are forcing functions in the distribution and diversity of coastal habitats. Alterations in the distribution and diversity of habitats could lead to increases in some critical habitat and decreases in others that would affect changes in biological community composition and utilization by species of concern. Additionally, the absence of dense vegetation increases the island’s vulnerability to erosion and storm-induced forces (Fritz et al., 2007).

Seagrasses including *Halodule wrightii* have previously been observed in small patches along the north face of the western tip of the island, although surveys following Hurricane Ivan in 2004 and Hurricane Katrina in 2005 found no evidence of seagrass in the area (Byron and Heck 2006). The disappearance of seagrasses has also been noted elsewhere in the Mississippi Sound and has been attributed to an overall decline in water quality linked to human influences and/or shifts in precipitation patterns affecting both salinity and turbidity (Moncreiff et al., 1998).

4.3.2.2 Fauna

The barrier islands and surrounding estuaries of the northern Gulf of Mexico support a diversity of birds and other terrestrial wildlife, marine mammals and predators, juvenile fish and shellfish, and benthic infauna. Dauphin Island has historically supported cattle egrets, snowy egrets, tri-colored herons, and great egrets (Dusi and Dusi 1987), but habitat loss and events such as hurricanes can destroy feeding sites or feeding efforts, such as with piping plovers (Johnson and Baldassarre 1988).

High densities of benthic macroinfauna taxa along with high species richness have been observed on the western end of Dauphin Island, while seasonal use of vegetated areas by postlarval and juvenile *Penaeid* shrimps were observed along the eastern end of Dauphin Island (Howe et al., 1999). Dauphin Island may also serve as an important nursery ground for large marine predators including sharks and bottlenose dolphins. Young of the year and juvenile shark populations have

been collected within the bays and sounds surrounding the island, including Atlantic sharpnose shark (*Rhizoprionodon terraenovae*), blacktip shark (*Carcharhinus limbatus*), finetooth shark (*C. isodon*), scalloped hammerheads (*Sphyrna lewini*), and bull sharks (*Carcharhinus leucas*) (Parsons and Hoffmayer 2007). Research studies of bottlenose dolphins have revealed increases in reproductive rates within the region following Hurricane Katrina, potentially due to increased prey density and declines in commercial fishing effort (Smith et al., 2013), but they were subsequently negatively impacted following an extreme cold and freshwater event that occurred less than a year after the DWH oil spill (Carmichael 2012). Ecological disturbances resulting from individual events or the interactions of multiple drivers and stressors will differentially impact fish and wildlife populations that utilize the barrier island chain.

Barrier islands also play an important role in estuary-shelf interactions. Access to nursery grounds behind barrier islands in the northern Gulf of Mexico is restricted to passes and inlets where fish and crustaceans move and disperse with tides and currents. Small benthic crustaceans and fish larvae have been found to seasonally disperse through tidal passes into the Mississippi Sound on the backside of Dauphin Island (Modlin and Dardeau 1987, Lyczkowski-Shultz et al., 1990). Disruptions to the natural exchange, including the creation of new cuts or widening of existing cuts can result in increased volume of water and subsequent changes in water quality constituents, such as salinity. Hurricane Katrina created a new pass in the center of Dauphin Island, and results from a biophysical model for hydrodynamics and oyster larval transport suggest that the cut increased salinities and reduced larval retention in the spawning area (Park et al., 2014). High salinities can increase the abundance of marine predators, such as oyster drills, and increase the mortality of post-settlement oysters (Lowe et al., 2017, Park et al., 2014).

4.4 Attributes and Performance Measures

A comprehensive monitoring program is needed to inform restoration planning and evaluate all restoration alternatives based on sound science. Monitoring of the hydrodynamic processes, water quality constituents, island morphology, substrate characteristics, key coastal and marine habitats, and key coastal and marine faunal species were identified as the important attributes for this system. For each of these attributes, a series of monitoring performance measures was identified.

4.4.1 Hydrological Processes

Hydrological processes that may be impacted by island restoration include waves and currents. These processes will predominantly be impacted by activities that modify the island footprint or the offshore bathymetry, which can alter wave attenuation, regional tides, and/or other oceanic circulation patterns. Performance measures associated with these attributes should be monitored pre- and post-restoration in this case (Table 2).

Table 2. Recommended monitoring of hydrologic processes for Dauphin Island.

| Attribute | Performance Measure | Location | Time/Duration |
|-----------|---|--|-------------------------------|
| Waves | Significant wave high, dominant wave period and direction | Gulf- and bay-side of restoration or sediment placement area | Baseline and post-restoration |

| | | | |
|----------------------|----------|--|--|
| Inlet tidal currents | Velocity | Petit Bois Pass, Pass Aux Herons, Mobile Bay Inlet | Baseline and post-restoration a full tidal cycle during spring and neap tide |
|----------------------|----------|--|--|

4.4.2 Water Quality Constituents

Back barrier and marsh restoration measures reduce the vulnerability of Dauphin Island to lowering and breaching. Water quality modeling showed that breaching of the island in the region of the Hurricane Katrina cut led to a reduction in seagrass and oyster habitat suitability in the leeward of Dauphin Island (Enwright et al. 2020). The primary water quality attributes associated with estuarine habitat suitability were salinity and water depth. If objectives are designed around maintaining or improving estuarine conditions leeward of Dauphin Island, in addition to salinity and water depth performance measures, temperature, turbidity, and nutrients should also be considered. These properties should be measured as baseline and post-construction for a duration of no less than 2 years and could require 3 to 5 years to capture potential change under a wider range of natural variability in the system.

4.4.3 Island Morphology

Restoration activities such as onshore or offshore sediment placement, modification of the island footprint, and vegetation planting may directly or indirectly impact island topography or offshore bathymetry. The primary attribute associated with morphology is the elevation of the island or surrounding bathymetry. Derived metrics such as shoreline location, beach width and slope, and dune elevations are also valuable in assessing restoration impacts (Table 3). Natural processes including oceanic and aeolian sediment transport also alter island characteristics. Therefore, the timing and duration of baseline and post-restoration monitoring should be designed and analyzed with consideration of relevant factors (seasonal variability, timing and strength of storm events, scale of restoration, etc.). For example, in the case of a large-scale restoration project that substantially alters the subaerial configuration of the island, monitoring should be conducted for 5+ years post-restoration to evaluate its evolution over time.

Table 3. Recommended monitoring of Dauphin Island morphology.

| Attribute | Performance Measure | Location | Time/Duration |
|---------------------------|--|---|--|
| Topography and bathymetry | Elevation and volume | Area of restoration, including cross-shore and longshore locations likely to be influenced through sediment transport | Baseline and post-restoration. Post-restoration duration should vary depending on the scale of the activity and may extend upward of 5+ years. |
| Beach configuration | Height, width and slope (derived from topographic elevation) | (see above) | (see above) |

| | | | |
|---------------------|---|-------------|-------------|
| Shoreline | Cross-shore position (derived from topographic elevation or from imagery) | (see above) | (see above) |
| Dune configuration | Height, width and volumes (derived from topographic elevation) | (see above) | (see above) |
| Marsh configuration | Height and width (derived from topographic elevation) | (see above) | (see above) |

4.4.4 Substrate Characteristics

Barrier islands are the result of continuous feedback between physical processes (waves, tides, winds) and morphology (width, length, height, slope). The physical processes that drive morphological change are circularly influenced by the morphological state of the island at any point in time. However, island morphology is also constrained by other geologic (sediment availability, sediment texture, antecedent (sub)surface architecture/framework) and ecologic (flora distribution, benthic habitats) variables that may or may not be related to current physical processes. For example, the texture of sediment available for both littoral and cross-shore/-island transport (grain size distribution) constrains beach and shoreface slope as well as dune height and width. Substantial deviations of the texture of available sediment, either through natural (transgression and erosion into a stratigraphic unit with differing sediment texture) or artificial (sediment placement and/or re-nourishment) means, can have perpetual impacts on the morphology of the island.

In addition to constraining the morphology, sediment texture and composition (e.g., organic matter content) often serves specific ecological influence. For example, birds (e.g. piping plover), reptiles (e.g., sea turtles) and small mammals (e.g., beach mouse) all favor sandy environments for various life habits such as nesting and corridors. Alternatively, fine-grained and/or muddy back-barrier and estuarine environments host various economical fisheries (e.g., oysters, mussels, shrimp) as well as serve ecologically important species (e.g. Gulf sturgeon, brown pelican). Therefore, both quantitative metrics (species-preferred substrate) and semi-quantitative characterizations (local to regional substrate distributions) are needed to better evaluate restoration scenarios or strategies and potential influences on the overall ecosystem.

Specific to the area on and around Dauphin Island, Ellis and others (2017) compiled sediment texture data for roughly 300 samples collected from various coastal environments (e.g., inlet tidal channels, ebb-tide delta, back-barrier wetlands, shoreface). Based on 10 major texture classes (i.e., coarse sand to clay), sediments from Dauphin Island and surrounding (submerged) environments group into the following five hierarchical clusters: C1 – poorly sorted, muddy sand; C2 - moderately well-sorted, medium to coarse sand; C3 - moderately well-sorted medium sand; C4 - moderately well-sorted medium sand with higher abundance of finer-grained size classes; and C5 - extremely poorly sorted, slightly sandy mud with $\geq 10\%$ organic matter. All clusters appear to have some spatial or physical relationship.

The textural classification provides simple performance measures for substrate characteristic attributes that can be used as baseline targets for restoration activities and/or used to develop long-term monitoring efforts that are required to determine the progress of prior or ongoing restoration. Substrate characteristics should be measured as baseline and post-construction approximately every 5 years over the project monitoring duration.

Back barrier and marsh restoration measure types should also consider measuring marsh sediment accretion rates to determine if sediment input and soil accretion is occurring in project areas in response to the project features, and whether accretion rates are sufficient to respond to sea level rise changes. Surface elevation table (SET) measurements and feldspar marker horizon measurements should be used to evaluate performance. Surface elevation table (SET) measurements provide a constant reference plane in space from which the distance to the sediment surface can be measured by means of pins lowered to the sediment surface. Repeated measurements of elevation can be made with high precision because the orientation of the table in space remains fixed for each sampling. Feldspar marker horizon measurements involve the placement of a cohesive layer of feldspar clay on the ground surface. Soil borings are extracted at the marker horizon location periodically to measure the amount of soil deposition and/or accretion that has occurred above the horizon since placement. Marsh accretion and sediment elevation should be measured pre- and post-construction to establish rates of change within the project area.

4.4.5 Key Coastal & Marine Habitats

Coastal and marine habitats will be affected by all the restoration measure types assessed at Dauphin Island. The habitats that should be evaluated include barrier flats, beach, dune, intertidal flats, intertidal beach, intertidal marsh, woody vegetation, and woody wetlands. If objectives are designed around improving habitat conditions for other designated critical habitats such as oyster reefs and submerged aquatic vegetation, those habitats should be evaluated also. Monitoring for the above habitats will include habitat composition, vegetation distribution (including invasive species), and land:water ratios.

High-resolution orthophotography and light detection and ranging (lidar) should be collected before, during, and two additional times during the 10-year monitoring effort. These data can be used to identify land:water ratios and to map habitat composition using the same methodology and classification scheme used to develop the 2015 habitat map (Enwright et al., 2017, Enwright et al., 2019) for Dauphin Island, Little Dauphin Island, and Pelican Island. Field investigations should be conducted to ground-truth various geomorphic and vegetation habitats in the field with corresponding signatures on orthophotography. Spatial analysis would involve comparative analysis of pre-project and post-project aerial or satellite imagery and may utilize Landsat Thematic Mapper analysis to determine relative changes in land cover within the Dauphin Island area.

Vegetation distribution should also be tracked pre-construction and post-construction to determine if plant communities change in response to project measures. Relative abundance is a measure of the abundance or dominance of each species present in a sample and can be measured using the Braun-Blanquet method (Mueller-Dombois and Ellenberg 1974) as described in Steyer et al. (1995).

4.4.6 Key Coastal & Marine Faunal Species

The coastal and marine habitats of Alabama depend on Dauphin Island for important habitat for trust species and at least 347 species of birds in the Southeast that either pass through or reside on

the island (eBird, 2020). Restoration measures that affect island habitats will have consequences for the conservation value of the island.

The key coastal and marine faunal species were selected from a list of 44 species that have affinities to the key coastal habitats identified in Section 4.4.5. These affinities were identified from the scientific literature and from a non-metric multi-dimensional scaling (NMDS) model developed as part of this study. The species identified are Loggerhead Sea Turtle, Bottlenose Dolphin, Gulf Sturgeon, Seaside Sparrow, Reddish Egret, Oyster Catcher, Least Tern, Swainson’s Warbler, Loggerhead Shrike, Brown Pelican and Piping Plover. The primary performance measures will be tied to the distribution and abundance of nesting birds and will be monitored before, during, and after project construction. If objectives are designed around improving habitat conditions for other species of concern, those species should be evaluated as well.

4.4.7 Social Considerations

Erosion of Dauphin Island is leading to increased risk to cultural resources sites. As a result, restoration of Dauphin Island form and structure is expected to provide beneficial effects to reduce threats to these cultural resources. If objectives are designed around reducing cultural impacts, shoreline/island response, including aerial extent and surveys, should be used to measure project performance in maintaining a land area (buffer zone) around cultural resources. However, restoration projects can carry social implications for communities located within, adjacent to, or beyond the project boundaries. These social implications or social effects include impacts to human well-being, including health and safety, social vulnerability and resilience, economic vitality, social connectedness, identity, participation, and leisure/recreation (Durden and Wegner-Johnson 2013, Kaplan-Hallman and Bennett 2018). Projects may result in positive impacts for local communities, such as preservation of cultural sites, while also negatively impacting other social or cultural considerations. Objectives designed to reduce negative social impacts will require a monitoring plan that evaluates direct and indirect impacts to public and private properties and the communities that utilize them.

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