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COASTAL BARRIER RESILIENCE AND RESISTANCE

Analysis and Metrics for Characterizing Coastal State

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PREFACE

The Deepwater Horizon (DWH) oil spill settlement in 2016 provided the Natural Resource Damage Assessment (NRDA) Trustees (Trustees) up to \$8.8 billion, distributed over 15 years, to restore natural resources and services injured by the spill. The Louisiana Trustee Implementation Group (LA TIG) Monitoring and Adaptive Management (MAM) Strategy (LA TIG, 2021) has identified a need for barrier island and headland creation, restoration, and maintenance (i.e., to preserve resilience over time), with the goal of reducing land and habitat loss as a high-level objective under the Wetland, Coastal, and Nearshore Habitats Restoration Type. Under this high-level goal is the objective to support natural processes of barrier island evolution (e.g., erosion, overwash that builds back-barrier platform; longshore sediment transport within the littoral zone, and barrier island rollover rate) through restoration projects.

As part of making this goal a Specific, Measurable, Achievable, Relevant, appropriate Timeline (SMART) objective, the LA TIG identified that a MAM effort is needed to develop and document an approach for assessing and characterizing restored barrier island and headland response to natural processes (e.g., resistance to individual storms and resilience to longer-term processes like sea-level rise and cumulative storm effects). Through a joint effort between The Water Institute and the U.S. Geological Survey, the authors conducted the effort described here to address that gap while being synergistic with and enabling other ongoing monitoring and restoration activities in the region, such as the Louisiana Coastal Protection and Restoration Authority's (CPRA) Barrier Island Comprehensive Monitoring (BICM) program and Barrier Island System Management (BISM) program.

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This project included input and review by a technical advisory group (TAG) comprised of representatives from agencies that comprise the Louisiana Trustee Implementation Group (LA TIG) as well as other subject matter experts (SMEs). The TAG evolved over time as new SMEs became available, and others left their respective agencies. These individuals provided valuable insights including identification of data sources, guidance on how to focus the effort, and insight into coastal dynamics. They included Darin Lee, Syed Khalil, Glen Curole, Michelle Felterman, and Matthew Vincent (CPRA); Patty Kelly and Dianne Ingram (U.S. Fish and Wildlife Service); Sarai Piazza, Richard Rebich, Dave Hewitt, and Greg Steyer (U.S. Geological Survey, USGS); David Reeves and Courtney Schupp (National Oceanic and Atmospheric Administration); Philip Lee (U.S. Environmental Protection Agency); and Benjamin Battle (U.S. Department of Agriculture). The authors thank Casey Stuht (Cherokee Nation System Solutions) for their assistance with data analyses and report graphics.

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EXECUTIVE SUMMARY

Barrier islands are shaped by a variety of short- and long-term environmental processes such as storms and relative sea-level rise. These islands, found along the estuarine-marine interface, provide ecosystem services including storm surge and wave attenuation, erosion protection to inland marshes, habitat for fish and wildlife, and recreation. Natural resource managers require actionable information on how barrier island resilience and resistance changes over time to understand how an island's current state relates to past conditions and to inform restoration prioritization and implementation.

The U.S. Geological Survey and The Water Institute collaborated on a study to develop indicators of resilience and resistance for barrier islands in Louisiana. Here, resilience captures island persistence on yearly to decadal time scales, and resistance captures persistence on event time scales of days to weeks. The indicators fall in two categories: Tier 1 Screening Metrics, that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and Tier 2 Analysis Metrics, which are detailed metrics that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

The research team derived Tier 1 resilience indicators from subaerial land and vegetation cover calculated from publicly available maps and products based on satellite imagery. By benchmarking the total land and vegetation extent against their respective historical maxima, this metric provides a snapshot of an island's current state in the context of its long-term trajectory. The research team developed Tier 1 resistance indicators based on subaerial island configuration and water level recurrence as a proxy for evaluating island resistance to storms, which are the primary driver of short-term change. These Tier 1 metrics can be analyzed over time to provide a high-level assessment of how an island's resistance decreases because of elevation loss or sea-level rise or increases due to restoration or natural recovery.

The research team developed Tier 2 resilience and resistance indicators and associated analyses to provide detailed information for specific time periods or applications (e.g., wildlife management). These metrics include habitat coverage from high-resolution maps, which show composition changes over time to capture the evolving resilience of specific habitat types; high tide flooding analysis, which evaluate island area relative to specified flooding thresholds to characterize resistance in the short-term or, if analyzed over time, indicate changes in resilience; and hypsometric curve analysis, which allows managers to evaluate island area changes above their own elevation benchmarks of interest and similarly characterize resistance in the short-term or indicate changes in resilience if assessed over time.

The research team calculated Tier 1 metrics of the barrier islands and headlands along the coast of Louisiana for the period of 1984 through 2021 and Tier 2 metrics for select times during that period depending on data available and quality. The results were captured in a report card for each barrier, which also includes an overview of the metrics and their interpretation; a restoration and storm history; and Tier 1 and Tier 2 metric analysis, including benchmarking against coastwide and regional values as well as to an island's pre-restoration trajectory. These report cards provide a readily digestible synthesis of barrier condition and trajectory that coastal managers can use to support restoration prioritization and other decisions.

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LIST OF ACRONYMS

Acronym	Term
BICM	Barrier Island Comprehensive Monitoring
BISM	Barrier Island System Management
C-CAP	National Oceanic and Atmospheric Administration's Coastal Change Analysis Program
CIMS	Louisiana Coastal Protection and Restoration Authority's Coastal Information Management System
CPRA	Coastal Protection and Restoration Authority
DEM	Digital Elevation Model
LA TIG	Louisiana Trustee Implementation Group
LCMAP	Land Change Monitoring, Assessment, and Projection
lidar	Light detection and ranging elevation data
MAM	Monitoring and Adaptive Management
MHHW	Mean Higher High Water
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NRDA	Natural Resource Damage Assessment
RSM	Regional Sediment Management
SLR	Sea-Level Rise
SVAR	Standardized Volume to Area Ratio
TAG	Technical Advisory Group

UNIT TABLE

Abbreviation	Term
ha	Hectares
km	Kilometers
km ²	Square Kilometer
m	Meters
m ²	Square Meter

INTRODUCTION

Barrier islands are thin strips of land located offshore of the mainland coast that provide habitat for species such as nesting sea turtles, shorebirds, and other coastal flora and fauna, along with ecosystem services, including protection of the main coast and recreational opportunities (Khalil et al., 2013; Oertel, 1985; Penland & Suter, 1988). Coastal deltaic headlands are similar narrow features that are connected to the mainland that provide similar ecosystem services, and hereafter “barrier” is used to encompass both barrier islands and deltaic headlands. Sea-level rise (SLR), storms, insufficient sediment supply, and other drivers can lead to barrier erosion and loss of these services (FitzGerald et al., 2007; Grzegorzewski et al., 2011; Passeri et al., 2020). In response, coastal managers often consider sediment placement, vegetation planting, and other measures to restore coastal barriers and the functions they provide (Dalyander et al., 2021; Khalil et al., 2013).

A key challenge facing coastal managers is prioritizing when and where to focus barrier restoration. These landforms are highly dynamic, eroding and accreting in response to waves, currents, and winds on spatiotemporal scales ranging from hours to days and localized breaches/erosion to full island changes (Lentz et al., 2013; Passeri et al., 2020; Zinnert et al., 2017). Managers sometimes lack meaningful metrics for characterizing the eco-geomorphology of barriers in the context of their natural trajectory and potential need for restoration. The effort described here focused on addressing that gap through the development of metrics for characterizing the state of Louisiana barriers, specifically their resilience and resistance to change drivers including SLR and storms.

ECOSYSTEM RESILIENCE AND RESISTANCE: BACKGROUND LITERATURE REVIEW

A brief background literature review of prior work on ecosystem resilience and resistance is provided here for context on decisions made in developing resistance and resilience metrics, and why they necessarily vary somewhat from those developed and applied to other barrier systems or ecosystems. Ecosystem resistance and resilience definitions typically rely on an assumption that the system occupies one of a set of relatively stable state spaces—combinations of geomorphic and ecological parameters—rather than existing on a continuum with infinite possible parameter combinations (Monge & Stallins, 2016a). The ecosystem occupies one of these stable states until a perturbation or disturbance leads to a temporary or permanent transition to a different state.

For example, a forest might consist of old-growth trees until being destroyed by wildfire, when either the former distribution of flora might start to grow or there could be a transition to an entirely different ecosystem with more grasses or smaller shrubs. Broadly speaking, “resistance” refers to the capacity to remain in a state despite a perturbation (e.g., an old growth forest retaining enough trees to remain forest despite a wildfire), while “resilience” refers to the capacity to return to a state after transitioning to a different state (e.g., a forest re-establishing after a wildfire rather than permanently transitioning to scrubland). The scientific community has specifically defined “resilience” and “resistance” in a variety of ways, however, leading to ambiguity (Kombiadou, 2019). For example, Timpane-Padgham et al. (2017) characterized resilience as encompassing both resistance to change or the capacity for recovery from disturbance. Engineering resilience typically refers to an ecosystem’s ability to recover to its original state

after a minor perturbation, while ecological resilience refers to the capacity of an ecosystem to recover to the same state after a major perturbation rather than transitioning to an entirely new state (Dakos & Kefi, 2022; Kombiadou, 2019). Ecological resilience has alternately been defined as “the capacity of a system to absorb disturbance and re-organize while undergoing change so as to still retain essentially the same functions, structure, identity, and feedbacks” (Kombiadou, 2019).

For low-lying barrier systems, the concept of “resilience” and “resistance”—and the definition of a “stable” state—is even more difficult to define given their highly dynamic nature. For example, a barrier island may transgress landward with SLR, leading to complete loss of the island in its original footprint (which could be characterized as a lack of resilience and/or resistance in that spatial area) while the landform itself migrates landward and retains or recovers some or all of its geologic form and ecological function (which could be characterized as resilience).

Monge (2014) and Monge & Stallins (2016a) developed a two-state model for barrier islands along the Atlantic coast based on dune elevation and associated vegetation, postulating that the islands tended to exist in either a higher dune state with limited overwash or a lower one with relatively frequent overwash. Kombiadou, (2019) and Kombiadou et al. (2020) defined state independently for the beach, dune, and marsh components of a barrier island, and characterizing the resistance and resilience of the barrier as a function of the change and transition of combinations of these geomorphic units (e.g., presence/absence/characteristics of those features with transitions between the states driven by storms, erosion, and accretion). Stallins (2005, 2006), Stallins & Corenblit (2018), Stallins & Parker (2003), and Zinnert et al. (2017) postulated that dune vegetation growth, sediment transport, and morphologic changes are interconnected processes that lead to the development of stability domains, which then control biotopographic resistance to storms and overwash. However, these ecosystem state approaches have not been applied to the Louisiana coast, where limited sediment supply and frequent storms lead to relatively homogenous, low-lying barriers that are even more dynamic than barriers along other coastlines.

Researchers have also sought to characterize the vulnerability and loss potential for barriers and sandy mainland coastal systems without explicitly considering ecosystem states or a formal definition for resilience and resistance. The Sallenger scale (Sallenger Jr., 2000) benchmarks total water level—the combined water level resulting from surge, tides, and wave effects (Stockdon et al., 2006)—against dune toe and crest elevations to define response regimes of increasing impact including beach erosion, dune collision/erosion, dune overwash, and complete inundation. Thieler & Hammar-Klose (2000) developed and applied a Coastal Vulnerability Index (CVI) that characterizes the relative likelihood of different coastal responses to SLR based on factors including geomorphology, coastal slope, and shoreline erosion rate. Rosati (2009) identified critical dimensions (elevation, width, alongshore length) that can be used in designing barrier island restoration to ensure restoration of function, including identifying a “stable design” for maintaining a barrier in place and a “retreat design” allowing for transgression.

These studies each provide insights into coastal barrier dynamics, but do not provide a scheme for characterizing their resilience and resistance to support management. The research team reviewed several of these approaches for potential incorporation within the scheme developed here (*Appendix A*), but ultimately found that these schemes could not adequately characterize Louisiana barrier resilience and resistance to inform management.

Advances in remote sensing have also provided a mechanism for the efficient assessment of changes on coastal barriers. The increased availability and technological advancements of remote sensing data, particularly satellite imagery, has revolutionized the study of coastal change patterns by providing data at various spatiotemporal scales that were previously not feasible or challenging to collect and study (Vitousek et al., 2023). Remote sensing imagery has been used to provide information about the response of coastal systems to stressors and can provide insights into barrier island resilience (Bernier et al., 2021; Enwright et al., 2025). Enwright et al. (2025) highlighted a two-tier hierarchical approach for using remote sensing data for assessing and understanding barrier island changes over time from Dauphin Island, Alabama to the Florida Panhandle. The approach used in that study, which included a framework with tiers for screening-level assessment utilizing high temporal resolution and moderate spatial resolution and metrics for more detailed, application-specific analyses, was adopted as a framework for this project.

LOUISIANA COASTAL BARRIER DYNAMICS AND MANAGEMENT

The study area for this effort encompasses coastal barriers found along the Louisiana deltaic coast (Figure 1). The Central Coast barrier chain stretches from Racoon Island in the west to Scofield Island in the east, whereas to the northwest of the Mississippi River Delta lies Breton Island, the Northern Chandeleur Islands, and the Grand Gosier/Curlew Islands complex, a set of formerly subaerial barrier islands that are now intermittently emergent shoals. Louisiana barriers are relics of historical lobes of the Mississippi River Delta and are generally sediment-limited since the original source, the river, is no longer providing sediment (FitzGerald et al., 2018; Otvos, 1985, 2022; Otvos & Carter, 2013; Penland et al., 1981). In contrast to barrier islands located along the Atlantic coast, Louisiana barriers are relatively low-lying and transgress (migrate inland through processes such as overwash) rapidly during periods of accelerating relative SLR (FitzGerald et al., 2007, 2018; Miner et al., 2009; Otvos & Carter, 2013).

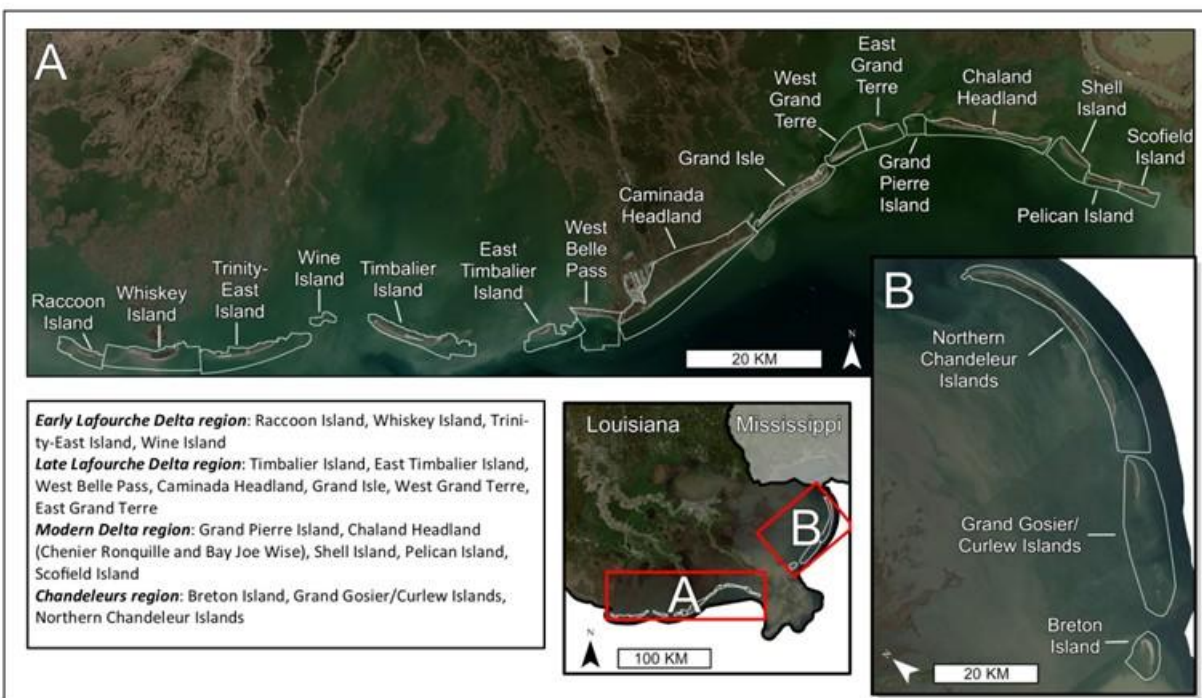


Figure 1. Spatial extent of the study area in southeast Louisiana. The Central Coast barrier chain includes barrier islands and headlands to the southwest of the modern Mississippi River Delta (A) while the Chandeleurs area is comprised of islands to the north of the delta (B). The study area includes four regions: Early Lafourche Delta (spans from Raccoon Island to Wine Island [submerged in this photo], Late Lafourche Delta (Timbalier Island to East Grand Terre), Modern Delta (Grand Pierre Island to Scofield Island), and Chandeleurs (Breton Island to Northern Chandeleur Islands) regions. Basemap is from Landsat 8–9 mostly acquired in April 2025.

Researchers and practitioners have applied a variety of data sources and analysis methods to characterize the Louisiana barriers and coastal system. A complete inventory of prior work is beyond the scope of this effort; however, examples of closely related work are presented here. Assessment often relies on light detection and ranging (lidar) data measuring Louisiana barrier elevation and analysis of geomorphic condition. For example, Johnson et al. (2020) used a 15-year time series of lidar for the Caminada Headland to assess its vulnerability, defined as “the degree to which a coast is likely to be affected by—or its incapability to withstand—the consequences of impact.” A follow-up assessment of these data determined that decreasing elevation and overwash threaten the capacity of a barrier to sustain itself in the face of SLR (Johnson et al., 2021). CPRA’s BICM program also uses lidar to monitor the geomorphic condition of the coastal system, along with shoreline change analysis, bathymetry, habitat mapping, and sediment samples (Kindinger et al., 2013). Elevation data derived from lidar combined with predictive modeling have also been used to characterize storm response through evaluation of sediment transport pathways, specifically in the Chandeleurs region, under the assumption that net inshore sediment transport can potentially support barrier resilience through transgression, whereas net offshore sediment transport is more likely to be associated with submergence (Miner et al., 2021).

Satellite and aerial imagery data have also been used to characterize habitat coverage and geomorphic state on Louisiana barriers. As part of BICM, for example, Enwright et al. (2020) built upon the work of

Fearnley et al. (2009) to develop a detailed habitat classification scheme, and used aerial imagery and lidar to create spatial maps delineating classes such as beach, unvegetated barrier flat, and meadow. Bernier et al. (2021) developed land cover maps of open water, sand, vegetated, submerged intertidal, and intertidal habitats for the Chandeleurs region for the period from 1984–2019, allowing long-term trends in habitat types, vegetation, and shoreline change to be assessed, while Goldstein & Moore (2016) analyzed the same area using four land cover classes of water, bare earth, vegetated, and intertidal using an automated threshold approach for classification. Fisher et al. (2023) documented morphodynamic changes at East Timbalier Island from 1953–2021 using a combination of aerial photos, satellite imagery, and the U.S. Geological Survey (USGS) Global Fiducials Library (USGS, accessed 2026).¹

Studies have also focused on methods for assessing the vulnerability of Louisiana barriers to becoming subaqueous and/or for other significant system changes. Coastal Engineering Consultants, Inc. (2015) derived metrics for characterizing the potential likelihood of a barrier to breach, such as ratio of minimum island width to total island length and ratio of minimum island width to updrift island length, using aerial photos of Raccoon Island, West Belle Pass, East Timbalier Island, Chaland Headland, and Scofield Island. Using a combination of data analysis and modeling, Moore et al. (2014) investigated factors contributing to threshold crossing (i.e., transition from a subaerial to a submerged barrier), including sediment availability, and loss or migration away from the marsh platform.

The Coastal Protection and Restoration Authority (CPRA) manage the Louisiana coast, including restoration of the Louisiana barriers. The State of Louisiana has conducted extensive restoration efforts over the past 25 years since Hurricane Andrew in 1992, restoring most of the barrier system through island-by-island restoration efforts. The centralized nature of coastal management for Louisiana creates unique perspectives and objectives for barrier management when compared to other locations where a management entity may only be concerned with a single barrier. This allows CPRA to manage finite sediment and financial resources to maximize overall benefits coast-wide. Recognizing that the barriers are an interconnected system and are ideally managed as such, CPRA more recently created the BISM program, which seeks to practically implement regional sediment management (RSM) on a coast-wide scale (i.e., managing sediment sources and placement to maximize benefit to the system as a whole; Dalyander et al., 2021). This management context closely guided the work of this effort to ensure the results were actionable and useful in informing restoration and management of the Louisiana barrier system.

Through a joint effort between The Water Institute and the USGS, the research team conducted four activities in support of management of Louisiana barriers: (1) identifying and consulting with a technical advisory group (TAG) (Appendix B); (2) conducting a detailed literature review of studies relevant to characterizing the resilience and resistance of coastal barriers, as well as assessing the condition of Louisiana barriers (summarized previously in the Introduction); (3) identifying and refining resilience and resistance metrics through analysis of data from a set of pilot sites (developed approaches and metrics

¹ <https://www.usgs.gov/global-fiducials-library-data-access-portal>

described in Methodology); and (4) applying the identified metrics coast-wide and documenting the results (presented in Results). The Discussion section of this report describes potential management interpretation and use of these results, as well as broader application beyond Louisiana. Lastly, a Lessons Learned section identifies factors contributing to the quality of the metrics, suggestions to consider for future monitoring, and high-value next steps.

METHODOLOGY

Given the ambiguity surrounding the definition of barrier island “states,” “resilience,” and “resistance,” the research team’s first step was to define those terms for this effort. In coordination with the TAG (*Appendix B*), the research team determined that defining discrete subaerial barrier states (following, e.g., Monge & Stallins, 2016) is less applicable and actionable for the Louisiana coast than for other, higher elevation barrier island systems. In contrast to the barrier islands on the Atlantic coast—where relatively high dune fields can shift height, width, and vegetation characteristics while remaining subaerial—Louisiana barriers are much lower in elevation, in many cases only maintaining their subaerial profile due to restoration. Engineering and design of barrier restoration is conducted to maximize the resulting ecosystem form and function, but the overarching management concern is maintaining the subaerial barrier. In other words, the two states of management concern for Louisiana barriers can be broadly characterized as subaerial and submerged/emergent, where subaerial is desired. The research team therefore focused on identifying continuous metrics or indicators that meaningfully capture a subaerial barrier’s resilience and resistance as defined above, rather than focusing on state definition.

Because restoration and maintenance of ecosystem services are the primary goals of coastal managers for Louisiana and there is an overarching concern that the low-lying barriers to remain subaerial (Campbell et al., 2005; Khalil et al., 2011), resilience is defined here as the capacity of barriers to maintain their subaerial geologic and geomorphic form and ecological function on time scales of years to decades. This definition was also based on working sessions with the TAG (*Appendix B*), during which there was extensive discussion of what “resilience” means for a dynamic and low-lying barrier system such as is found in coastal Louisiana. Resilience for Atlantic barriers with persistent and unique higher and lower elevation “states” (Stallins, 2005) can be defined as a barrier’s tendency to return to an original state after a perturbation, such as a barrier returning to a higher elevation state after a storm transitions it to a lower elevation state. For the Louisiana barriers, however, resilience can be more meaningfully defined on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is similarly defined as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. This definition has similarities to other standardized approaches widely used to characterize barrier vulnerability to storms. For example, Sallenger Jr. (2000) developed a storm impact scale based on comparing benchmark elevations such as dune toe and dune crest to a storm’s maximum total water level. Higher water levels relative to key elevations (i.e., overwash and inundation events) are associated with more permanent impacts to the coast (i.e., a more significant impact on coastal condition). The definition used here for resistance is similarly focused on characterizing the capacity of a barrier to maintain its form (i.e., resist inundation and associated landscape change) during storm events. The definitions used here refer to barrier landforms and not spatial location (i.e., a barrier that has transgressed but has the same geomorphic and ecological characteristics as in its original location would be considered the same form and function as prior to transgressing, and therefore a barrier can be resilient as long as it recovers to its former condition after transgression).

These definitions allow for a barrier to be resilient, resistant, or both: for example, a barrier may be able to resist the short-term effects of a single storm event (i.e., not be inundated in the short term) but may not be resilient to SLR and storms on longer time scales (i.e., long-term erosion from the shoreline to the deeper shoreface may inhibit barrier overwash and transgression). Similarly, a barrier may be resilient in the long run while being vulnerable to significant short-term impacts from storms (i.e., overwash occurs during storm events, but the volume of sediment flux into the bay is sufficient to allow for barrier transgression). It should also be noted that the focus of this effort was on characterizing subaerial barrier island state, which is influenced by subaqueous sediment volumes that are not explicitly considered here.

The second step was to consider the types of data and analysis that could most effectively support coastal restoration and management decisions. The research team determined that existing, readily available data may be a better input source than, for instance, proprietary data or new data collected for this purpose, thereby ensuring the methods developed were replicable and maintainable by coastal managers without significant investment in new data collection or monitoring. Because CPRA manages the entire barrier system, the analysis also needed to support assessing a barrier's resilience and resistance relative to other barriers in the Louisiana coastal system as well as over time (i.e., benchmarked to its own trajectory).

Based on that evaluation, the objectives of the study included: (1) development of a set of metrics that can be calculated from readily available data and used to benchmark coastal barrier resilience (capacity to maintain geologic form and ecological function on time scales of years to decades) and resistance (capacity to maintain geologic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms); (2) application of those metrics to data for the Louisiana barrier system; and (3) dissemination of that information in a format that is accessible and consumable by coastal managers.

DATA SOURCES AND DATA PREPROCESSING

The research team followed a similar approach for data sources and preprocessing as Enwright et al. (2025). Consequently, some content from Enwright et al. (2025) is repeated here for the convenience of the reader (i.e., description of subaerial land, vegetated area, and hurricane database data processing steps). Figure 2 provides a high-level overview of data and data processing the research team used in this study.

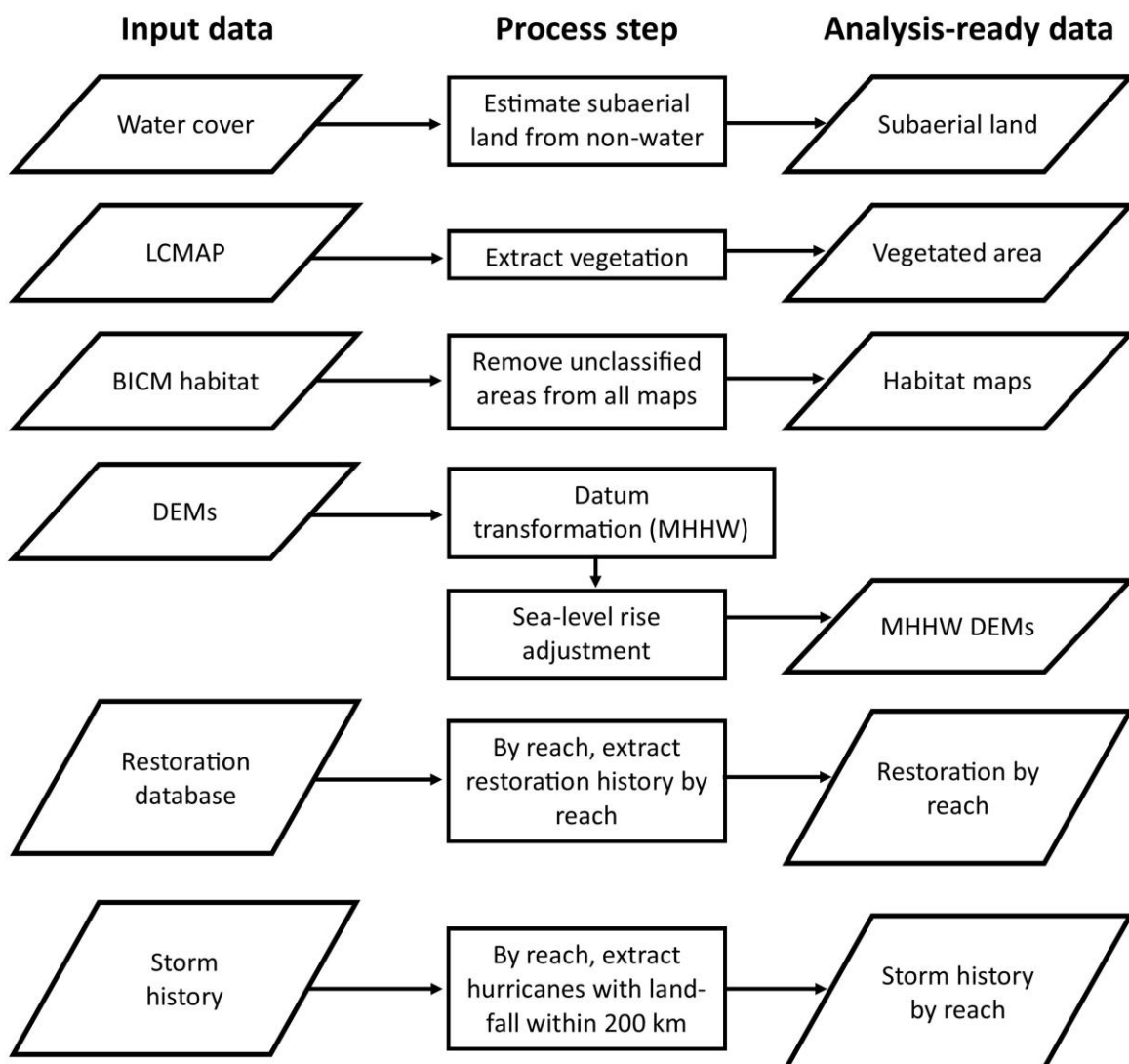


Figure 2. Overview of input data, data processing, and analysis-ready data used to assess the geomorphic state of coastal barriers. LCMAP, U.S. Geological Survey Land Change Monitoring, Assessment, and Projection Collection 1.3 (U.S. Geological Survey, 2021). DEMs, digital elevation models; MHHW, mean higher high water.

Coastal Reaches

A critical step was for the research team to determine how to subdivide the coast into reaches (i.e., spatial areas/units) to support analysis interpretation. Currently, the BISM and BICM programs utilize slightly different reach definitions for reporting and analyses due to their varying purposes and history. BICM was developed earlier, when some barriers were in different configurations compared to the modern landscape, and has the primary function of monitoring. In contrast, BISM was developed more recently and for the purpose of supporting management. In some cases, BICM divides a single barrier across multiple reaches; includes multiple islands in a single reach; or includes marsh islands on the leeside of

barriers (e.g., Enwright et al., 2020). BISM reaches are designed to include each barrier as a separate reach. The research team opted to use the BISM reaches with minor modifications to expand some reaches and thereby ensure that each reach includes the maximum subaerial land extent for each island from 1985–2021. The research team analyzed reaches individually as well as interpreting results through the lens of BICM regions (Figure 1). All data analyses were conducted using the NAD 1983 (2011) Universal Transverse Mercator Zone 15 or 16 North coordinate reference system, depending on the reach. Unless noted otherwise, the research team used Esri ArcGIS Pro 3.3 (Redlands, California, USA) for all spatial analyses.

Subaerial Land

Tracking subaerial land over time can provide information on the response of a coastal barrier to gradual change, extreme storms, SLR, and restoration that could result in land gain (Morton, 2008; Zinnert et al., 2019; Enwright et al., 2020). The research team used annual water history classification data (v1.4 from Pekel et al. 2016) to develop subaerial land maps with a spatial resolution of 30 m for the study area from 1984–2021 (Figure 3). These annual maps were developed from available cloud-free Landsat imagery with a decision tree approach based on multispectral feature-space hulls and ancillary data (e.g., digital elevation models [DEMs] and urban area maps). The classes included: (1) permanent water; (2) seasonal water (i.e., areas that are seasonally flooded); (3) not water; and (4) no data. Pekel et al. (2016) reported that maps had an overall producer's accuracy (i.e., lack of omission error) that was >95% and a user's accuracy (i.e., lack of commission error) that was >99%. The research team's next step was to identify which of the classes in the water maps to consider as subaerial land. The research team determined the most appropriate class for seasonal water to be land using visual inspection, given that these areas include estuarine marsh. Presence-only subaerial land maps were created by reclassifying the seasonal water, not water, and no data classes to 1 and setting permanent water to no data.

Vegetated Area

The research team extracted vegetation area from 30-m annual maps produced for the USGS Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 (U.S. Geological Survey, 2021). The relevant classes for the study area included: (1) developed; (2) cropland; (3) tree cover; (4) grass/shrub; (5) water; (6) wetland; and (7) barren. LCMAP products use the continuous change detection and classification algorithm and approximate the expected class of each pixel on 1 July of each year. The products include the primary class (i.e., the class with the highest probability of occurrence) and the secondary class (i.e., the class with the second highest probability of occurrence). Stehman et al. (2021) found LCMAP land cover data from 1985–2017 to have a temporally consistent accuracy of around 83%.

The research team inspected the primary LCMAP land cover maps for the study area and visually detected a high degree of commission error (i.e., pixels that are incorrectly mapped as a specific class) with the developed and cropland classes. These issues related to the incorrect classification of developed areas (i.e., areas that are not developed being classified as developed) and the research team addressed them by using 30-m land cover maps developed by the National Oceanic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program (C-CAP) from 1996, 2001, 2011, and

2016.² For each LCMAP dataset, the land cover type was set to be the secondary class for any pixel that was not called a developed class in the C-CAP dataset closest temporally to the LCMAP product. Since this study was focused on non-developed areas, developed pixels in the revised LCMAP products were set to be NoData. Secondly, due to the expected lack of cropland area on Louisiana barriers, cropland was set to be the value of the nearest neighbor. Using these refined datasets, the research team developed annual vegetation maps that included tree cover, grass/shrub, and wetland classes from the LCMAP products from 1996–2021 (Figure 3).

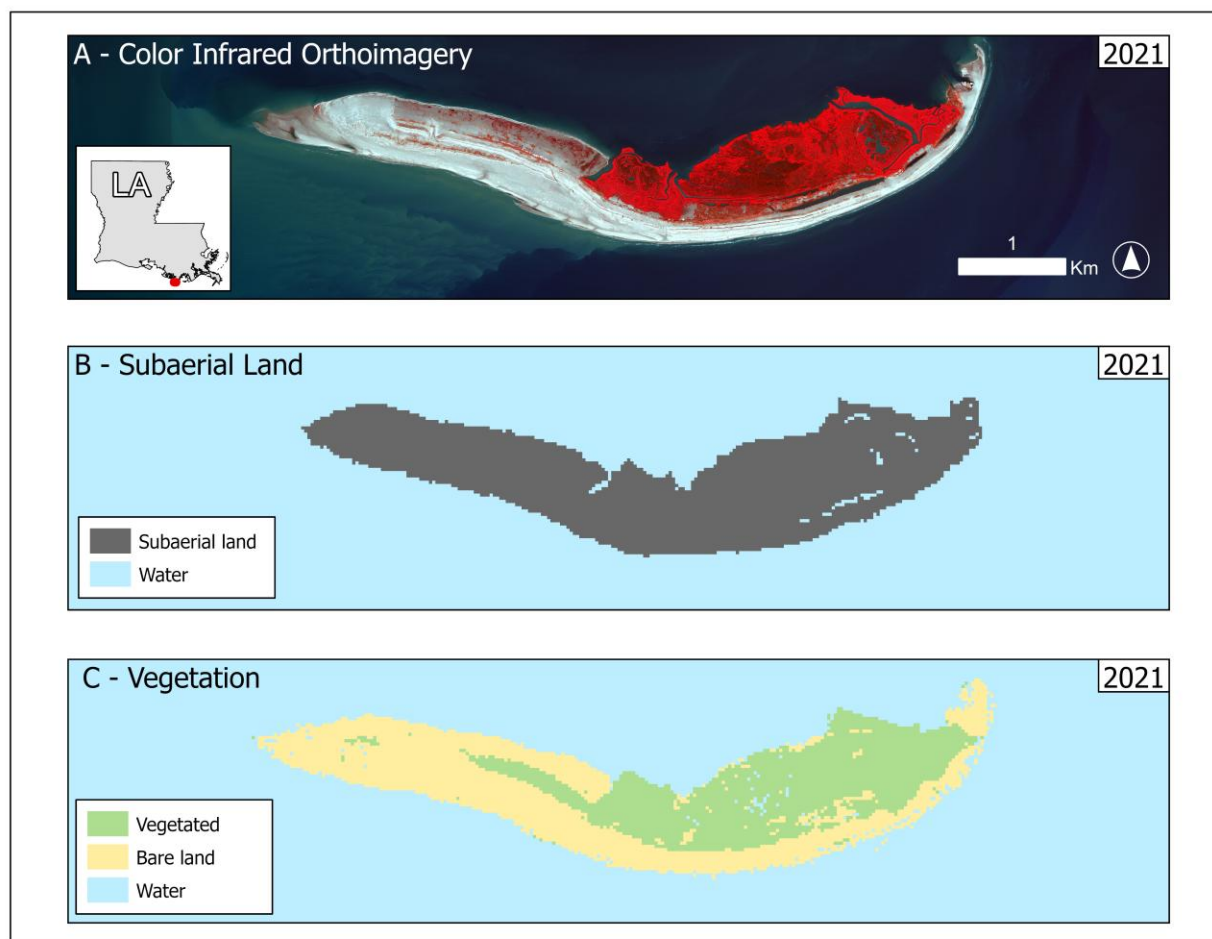


Figure 3. Example of subaerial land and vegetation maps for Whiskey Island for 2021. The color infrared orthoimagery (A) is from November 2021, the subaerial land map represents the subaerial land created from Landsat imagery throughout 2021, and the vegetation map (C) highlights vegetation cover estimated in July 2021.

² <https://coast.noaa.gov/digitalcoast/data/ccapregional.html>

High-resolution Habitat Maps

CPRA's BICM program has produced habitat maps from high-resolution (1-m to 2-m) orthoimagery and satellite imagery and the best available DEMs existing at the time of map development. Currently, maps have been developed for seven periods (1996, 2002, 2004, 2005, 2008, 2016, and 2021). The original habitat maps (maps produced for years before 2008) were produced with an 8-class general habitat scheme (Table 1) (Fearnley et al., 2009). Maps produced for 2008 and later include a 15-class detailed habitat scheme and additional habitats like unvegetated dune, vegetated dune, and mangrove (Enwright et al., 2020). While these more detailed classifications can provide valuable insight into coastal barrier resilience and resistance, the research team used the general habitat scheme to be able to compare habitat coverage for the entire period of 1996–2021.

All existing BICM maps were clipped to the reaches used in this study (Figure 1). However, the final extent of the BICM habitat maps do not align to the extent of the reaches used in this study for all barriers, including Caminada Headland. As a result, the analysis of these data allow identification of trends and spatial/temporal patterns are consistent with BICM, but specific values may not be identical. Maps developed prior to 2008 included some unclassified areas. For regional analyses, the research team omitted areas that were unclassified for any prior date. For regional and reach analyses, the research team omitted the 2005 BICM map for the Chandeleurs region due to large unclassified areas. While not included in this project, spatial change of habitats conducted by the BICM program for maps produced for 2008 and later (Enwright et al., 2020) could be assessed with the methods here and/or using a technique called change component analysis (Enwright et al., 2021).

Table 1. Habitat class and descriptions for the Louisiana Coastal Protection and Restoration Authority's Barrier Island Comprehensive Monitoring (BICM) program's 8-class general habitat classification scheme (Fearnley et al., 2009).

Habitat class	Description
Water	Water includes any area that is not land.
Intertidal	Intertidal includes shallow areas not supporting emergent vegetation and zones of deposition below normal high tide. Intertidal zones can support submersed aquatic vegetation and are frequently colonized by marsh vegetation over time, which changes the classification from intertidal to marsh.
Beach	Beach includes unvegetated area adjacent to open water that is subject to direct wave action at some time during the daily tidal cycle or during frequent storms. Beaches can sedimentologically consist of shell, sand, organic, or a mixture of clasts and grain sizes. Beach habitats do not support permanent vegetation because of frequent reworking by wave action. This class includes recent washover deposits that have not yet become vegetated.
Barrier vegetation	Barrier vegetation includes all elevated vegetated areas that are not subject to normal tidal action or inundation such that non-wetland species thrive. This class includes habitats such as dune, upland, swale, grassland, and shrub.
Bare land	Bare land includes areas that are unvegetated and not normally subject to direct wave action. This habitat type may develop as a result of freshly placed dredge material, sparse plant colonization or plant death, or from sediments stranded inland during extreme storm conditions.

Habitat class	Description
Estuarine vegetated wetland	Estuarine vegetated wetland includes vegetated area subject to regular inundation by marine waters or influenced by tidal action. Such areas are sufficient to support emergent wetland vegetation. Because all the study areas lie within saline waters, salt marsh is the only marsh class pertinent to this investigation, herein defined as marsh within in waters of high salinity (20–40 parts per thousand [ppt]) and dominated by the flora <i>Spartina alterniflora</i> (smooth cordgrass), <i>Juncus roemerianus</i> (needlegrass rush), and <i>Distichlis spicata</i> (saltgrass). Included are those areas dominated by <i>Avicennia germinans</i> (black mangrove), as this species also thrives in wetland environments subjected to tidal inundation, similar to marsh habitat.
Rip-rap	Rip-rap includes any material used to armor shorelines against erosion. Includes rocks, cement, debris, and sunken barges.
Structure	Structure includes any man-made object fixed to the land surface as a result of construction. Includes roads, industry, residential recreational structures, and residential areas.

Elevation Data

The research team used airborne lidar-based DEMs to assess subaerial volume, inundation at various water levels, and summarize elevation by reach. Data used for subaerial volume ranged from 1998–2022, whereas only the best available data were used for inundation and elevation summarization (Table 2). The research team included data from the late 1990s and early 2000s for completeness, but it is important to note that elevations from these earlier data may not always represent the bare earth elevation, especially in vegetated areas. Due to technological advancements, elevation data accuracy is considered to be higher from the early 2010s to present. The years included for inundation and elevation summarization were: 2015, for Raccoon Island to West Belle Pass; 2021 for Caminada Headland to Shell Island; and 2022 for Breton Island to the Northern Chandeleur Islands. The horizontal spatial resolution of these elevation data ranged from 0.5 to 5 m. All elevation data were referenced to the North American Vertical Datum of 1988.

Table 2. Year, resolution, and source of elevation data by region. ELD, Early Lafourche Delta; LLD, Late Lafourche Delta; MD, Modern Delta; CI, Chandeleurs regions; Lidar, light detection and ranging data. Asterisk after region indicates partial coverage for that region.

Year	Spatial Resolution (m)	Source	Regions
1998	3	National Aeronautics and Space Administration (NASA), National Oceanographic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS) Airborne Lidar Assessment of Coastal Erosion (ALACE)	All
2002	2	USGS/NASA Airborne Topographic Mapper (ATM) Lidar	ELD, LLD, MD, CI*
2002	3	NASA/USGS ATM Lidar	ELD, LLD, MD
2003	5	Louisiana Lidar Project	LLD, MD
2005	2	U.S. Army Corps of Engineers (USACE) National Coastal Mapping Program (NCMP)	LLD*, CI*
2007	2	USGS, National Park Service (NPS), NASA Experimental Advanced Airborne Research Lidar (EAARL)	CI*
2008	2	USGS/NASA EAARL	ELD*, LLD, MD
2010	1	USACE NCMP	ELD*, LLD, MD
2010	2	USGS/NASA EAARL	ELD*, LLD, MD
2011	1	USACE NCMP	CI*
2011	1	USGS	ELD, LLD*, MD*
2013	1	USGS	CI
2014	1	USGS	CI*
2015	1	USGS	ELD, LLD*, CI*
2018	1	USGS	CI*
2018	0.5	Coastal Protection and Restoration Authority/T. Baker Smith	ELD*
2021	1	USGS	LLD, MD
2022	0.5	USGS	CI

Transforming elevation data to mean higher high water

The research team transformed the vertical datum of the best available DEMs from the North American Vertical Datum of 1988 to mean higher high water (MHHW) level. National Oceanographic and Atmospheric Administration's (NOAA) VDatum 4.7.1 was used to create a 250-m transformation surface for changing the vertical datum of the DEMs. Areas that were outside VDatum's valid tidal transformation area were extrapolated from nearby data using inverse distance weighted interpolation. Typically, VDatum uses water levels from the most recent national tidal datum epoch (1983–2001);

however, tidal datums for Louisiana tide gauges are set using observations from 2012–2016. The research team used the long-term SLR trends from the NOAA Grand Isle tide gauge (Station ID: 8761724) to adjust the MHHW from a base year of 2014 (beginning of the epoch) to year of the lidar acquisition for the 2021 and 2022 DEMs:

$$\begin{aligned}
 &SLR = \text{estimated annual sea level rise rate (mm)}, \\
 &Years = \text{years between lidar acquisition and VDatum base year (2014)}, \\
 &MHHW_{adj} = \text{mean higher high water adjusted for estimated sea level rise (cm)}, \\
 &\text{where} \\
 &MHHW_{adj} = SLR * Years
 \end{aligned}$$

NOAA estimates the SLR rate for the Grand Isle tide gauge from 1947 to 2024 to be 9.16 mm (NOAA, 2025). To account for potential SLR, the research team lowered the elevation relative to MHHW by 64 mm for the 2021 DEM (i.e., $9.16 \text{ mm} \times 7 \text{ years}$) and 73 mm for the 2022 DEM (i.e., $9.16 \text{ mm} \times 8 \text{ years}$). The research team did not adjust the MHHW for the 2015 DEM since the acquisition fell within the tidal datum observation window for the Grand Isle tide gauge.

Hurricane Database

Information on when and where hurricanes occur can provide context for understanding the resistance and resilience of coastal barriers. The research team extracted information on hurricanes from NOAA’s Hurricane Database, commonly referred to as HURDAT2 (HURricane DATa 2nd generation; (Landsea & Franklin, 2013). HURDAT2 is a database of storms for the Atlantic Basin, including the Gulf of America, maintained by the National Hurricane Center that archives tropical storm track and characteristic data from the late 1800s to the most recent hurricane season. HURDAT2 data were loaded into Python using the publicly available `hurdat2parser`³ with custom scripts developed for extraction of storms and associated characteristics. For each reach (Figure 1), tropical storms were assigned to the reach if they were within 200 km of the reach centroid between 1985 and the end of 2021. The 200-km threshold was chosen based on prior research that identified that tropical storms passing closer than that distance were likely to result in overwash or inundation of a Louisiana barrier island (Long et al., 2020). Data extracted from HURDAT2 included storm name, date, and wind speed, which was converted to a categorical value.

Restoration Information

Louisiana barriers have been significantly altered by CPRA and its predecessor agencies through restoration projects of varying size and scale. The research team used the list of historical barrier island restoration projects in the 2027 CPRA Annual Plan to identify projects, project IDs, and placement

³ <https://github.com/davidstackio/hurdatreader>

volumes (CPRA, 2026), cross-checked against records of restoration information for each island available on the Louisiana CPRA’s Coastal Information Management System (CIMS).⁴

ANALYSES

One of the study objectives was to develop outcomes that are usable by coastal managers; however, different entities have different goals and objectives in monitoring the barriers. For example, the CPRA BISM program focuses on coast-wide management and would benefit from metrics that are readily calculable and can provide a high-level, easily interpretable snapshot of coast-wide barrier condition to inform where to focus restoration. However, managers may also benefit from a more detailed evaluation of the distribution of elevation and vegetation on a barrier, which—for example—are tightly linked to the type of species that will utilize the landform. The research team therefore established two types of metrics:

- Tier 1 Screening Metrics (refer to Tier 1 Screening Metrics below): metrics that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and
- Tier 2 Analysis Metrics (refer to Tier 2 Analysis Metrics, below): detailed metrics that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

The two tiers of metrics can also be used in conjunction with each other to inform management of the individual coastal barriers and the entire coast. For example, monitoring of Tier 1 metrics can indicate if a barrier is undergoing substantial erosion and landform loss, which could be further investigated through Tier 2 Analysis. Table 3 provides a highlight of the Tier 1 screening metrics and Tier 2 analysis metrics, metric type (i.e. resistance, resilience, both), information for interpretation, and questions managers might consider related to the metrics.

Table 3. Tier 1 and Tier 2 metrics, metric types (i.e., resistance and/or resilience), interpretation, and example questions managers might consider depending on their interests.

Tier	Metric	Metric type	Interpretation	Example Questions
1	Subaerial land	Resilience	Exploring trends in subaerial land coverage along with the deviation from the maximum coverage can provide information on resilience: an island with subaerial area significantly less than the historical maximum is not exhibiting resilience.	How is subaerial land coverage changing on time scales relevant to the management planning horizon (e.g., is the island likely to be lost prior to planned restoration)? How does subaerial land coverage post-restoration compare to the historical maximum value?

⁴ <https://cims.coastal.louisiana.gov/>

Tier	Metric	Metric type	Interpretation	Example Questions
1	Vegetation cover	Resilience	Exploring trends in vegetation coverage along with the deviation from the maximum coverage can provide information on resilience. As with subaerial area, an island with vegetated cover significantly less than the historical maximum is not exhibiting resilience.	How is vegetation coverage changing on time scales compared to the management planning horizon? How does subaerial land coverage compare to maximum value or period where restoration actions were completed?
1	Subaerial volume to area ratio (SVAR)	Resistance	SVAR provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). Higher SVAR relative to water levels indicates higher resistance. Changes in resistance over time can be obtained from exploring how SVAR compares to water levels over time (i.e., which includes relative sea-level rise [SLR]).	How does SVAR compare to water level recurrence intervals used in planned (e.g., 95 th percentile to benchmark current or post-restored resilience to storms)? Is the height above water levels keeping pace with relative SLR?
2	Habitat coverage from high-resolution maps	Resilience	Periodic high-resolution habitat maps can show the habitat composition changes for subaerial land, vegetated areas based on geomorphic position (i.e., estuarine vegetated wetland and higher [supratidal/upland] barrier vegetation), and intertidal non-vegetated areas. Exploring how these classes are changing over time can provide information on resilience.	How are subaerial land, vegetated areas (i.e., estuarine and supratidal/upland, collectively and respectively), beach, and intertidal areas changing over time? Is a specific type of habitat of interest for restoration/management being maintained over time?
2	High tide flooding (HTF) analysis	Resistance for snapshot; resilience when assessed over time	Resistance is relative to the proportion of area that is above each HTF water level. For example, area above the moderate HTF includes the classes “below major HTF” and “above major HTF.” If multiple dates are available, exploring how the areal coverage of these classes change over time can provide information on resilience. This metric is different from hypsometric curves in that it yields a map of HTF-related inundation classes.	How much (and which) area is below the minor HTF (i.e., low-lying area that is vulnerable to all extreme storm impacts)? How much area is above the moderate HTF and major HTF (i.e., higher areas that may be less prone to changes from extreme storms)? What is the spatial distribution of the HTF classes? When multiple maps have been developed, how is the proportion changing and where are the changes occurring?
2	Hypsometric curve	Resistance for snapshot; resilience when assessed over time	Hypsometry provides an intermediate metric between HTF analysis and the Tier 1 metrics in that it is not spatially resolved, but still provides detailed information on elevation distribution. Relative resilience between islands can be assessed by comparing the relative distribution of higher-elevation land. Exploring how curves change over time can indirectly provide information on resilience (e.g., is the form of the curve being maintained). This metric is different from HTF analysis because it shows elevation as a simple continuous plot and allows users to set their own elevation thresholds for analysis.	How much area is there above a user-defined threshold (i.e., 2 m NAVD88; the user might define this threshold based on a minimum elevation for a particular habitat type, for example)? How does the shape of the curve change over time — is higher elevation being transformed to lower elevation, reflecting overwash and a potential loss of resistance to individual storms even as the overall footprint of the island (i.e., resilience) is maintained?

Tier 1 Screening Metrics

The research team developed two Tier 1 metrics for characterizing the resilience of a barrier, each of which is calculated from satellite data: total subaerial land area and total vegetated land area. Each metric also has two variants: absolute metric calculated in spatial units of km^2 and a unitless metric calculated by dividing the absolute metric for each barrier by the maximum value observed over time for that barrier:

$$SA_{T,B}(t) = \text{total subaerial land area at time } t \text{ for barrier } B \text{ [km}^2\text{]},$$

$$VA_{T,B}(t) = \text{total vegetated land area at time } t \text{ for barrier } B \text{ [km}^2\text{]},$$

$$SA_{N,B}(t) = \text{normalized subaerial land area for barrier } B \text{ [unitless, scale of 0 to 1]},$$

$$VA_{N,B}(t) = \text{normalized vegetated land area for barrier } B \text{ [unitless, scale of 0 to 1]},$$

where

$$SA_{N,B}(t) = \frac{SA_{T,B}(t)}{\max(SA_{T,B}(t))}, \text{ and}$$

$$VA_{N,B}(t) = \frac{VA_{T,B}(t)}{\max(VA_{T,B}(t))}.$$

The absolute subaerial and vegetated land area metrics provide a mechanism for evaluating the state of a coastal barrier in spatial units to, for example, benchmark against established targets for barrier restoration (e.g., Figure 4). The normalized metrics allow for comparison between the resilience condition of each barrier to the other barriers making up the coastal system, each of which will have a different baseline area (e.g., Figure 5). The research team used satellite data for this calculation because it provides the longest and most complete record of barrier condition, with over 25 years of observations available at 30-m resolution. This record enables the normalized metric to be benchmarked against each barrier's largest observed value over a multi-decadal period. The natural trajectory of the islands and the relative impact of restoration can also be highlighted by conducting a linear regression of the normalized subaerial land metric for dates prior to the first restoration effort within the analysis window of 1985–2021 (Figure 6).

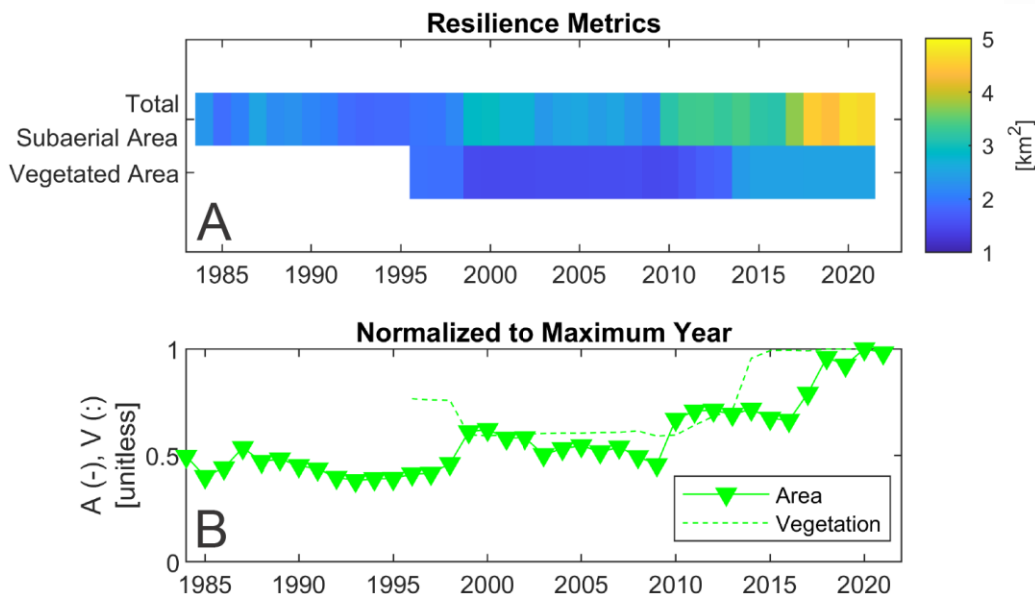


Figure 4. Example of resilience metrics calculated for a barrier, in this case Whiskey Island. The top panel (A) shows total subaerial land area and total vegetated area in square kilometers (km^2); the bottom panel (B) shows normalized subaerial land area and vegetated area (unitless).

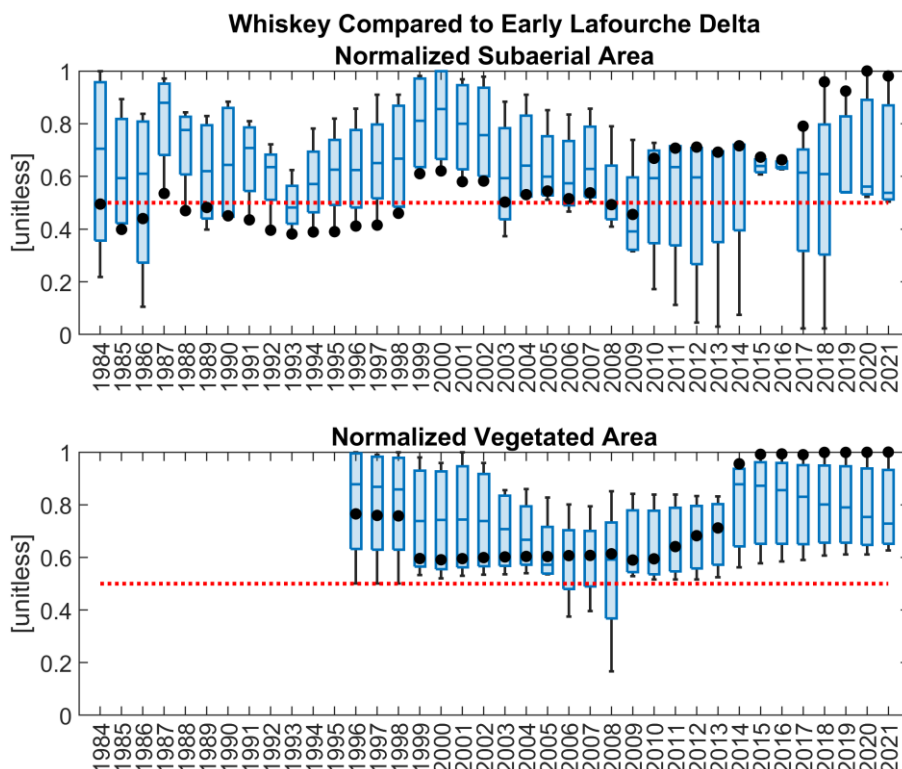


Figure 5. Box plot showing Whiskey Island resilience metrics (black dots) of normalized area (A) and normalized vegetation (B) benchmarked against coastwide statistics. The box plots illustrate the coastwide median values (blue lines), 25th-75th percentile (blue boxes), and overall range (black lines) excluding statistical outliers (blue circles). Also shown for reference is a value of 0.5, representing 50% of the historical maximum (red dashed line). Similar comparisons can be created by comparing individual barrier values to regional values for nearby barriers.

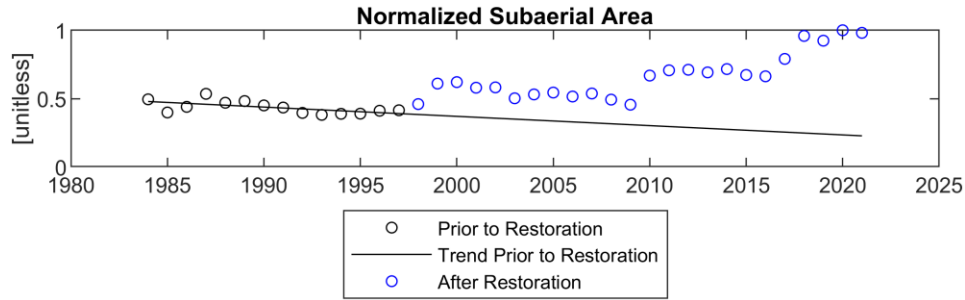


Figure 6. Example of a linear fit (black line) applied to the normalized resilience metric of subaerial land prior to the first restoration at Whiskey Island (black circles). The difference between the trajectory of this line and the observation of subaerial land after restoration (blue circles) highlights the impact of restoration on barrier condition and resistance.

The research team developed two Tier 1 screening metrics for assessing barrier resistance. Commonly used approaches for evaluating a barrier’s resistance to storms, such as the Sallenger scale (Sallenger Jr., 2000), compare the total water level (storm surge, tide, wave run-up, and wave setup; Stockdon et al., 2006) to key elevations in the profile including the dune toe and crest, given that significant island change (i.e., reduced island resilience to storms as defined here) is associated with inundation. The metrics developed here build on both that approach and the established relationship between total water level and the likelihood of significant barrier change during storms but avoid having to pre-determine what storm intensity and feature to use as a benchmark. The first Tier 1 resilience metric is “Standardized Volume to Area Ratio (SVAR)”, calculated by dividing the landform volume above a chosen threshold elevation to the area of land that exceeds that threshold:

$$SVAR_B(t) = \text{Standardized Volume to Area Ratio at time } t \text{ for barrier } B [m],$$

where

$$SVAR_B(t) = \frac{V_B(t, Th)}{S_B(t, Th)},$$

$$V_B(t, Th) = \text{landform volume of barrier } B \text{ above threshold elevation } Th \text{ at time } t [m^3],$$

$$S_B(t, Th) = \text{landform area of barrier } B \text{ at threshold elevation } Th \text{ at time } t [m^2], \text{ and}$$

$$Th = \text{threshold elevation } [m].$$

For example, if a threshold elevation of 0 m is chosen—as was done by the research team—SVAR would be calculated as the subaerial landform volume of the barrier divided by the subaerial area. SVAR relies on volume calculations, therefore lidar data are the inputs. The DEMs for this metric were sampled to 1-m resolution from their native resolution (Table 2) for consistency. This metric divides the sediment volume for a barrier against the area that volume is maintaining, resulting in a metric measured in meters, which can then be compared to statistics of water level over time (also in meters in the same vertical datum). SVAR and water level benchmarks for this effort were calculated from elevation measurements in North American Vertical Datum 88 (NAVD88). This comparison (Figure 7) benchmarks barrier resistance to frequency of occurrence of water levels representing tides, storms of different intensities, etc. In other words, a coastal manager can select what level of driver they wish to use as a benchmark: for example, a

manager primarily concerned with extreme storms might compare SVAR to the 90th percentile of water level, whereas one concerned with tidal impacts might compare SVAR to the 10th percentile of water level.

The SVAR metric is indicative of the spatial area of the barrier that the barrier volume has to maintain and can also be interpreted as the average height of the barrier above the chosen threshold (in this case, 0 m NAVD88). The water level recurrence intervals benchmark that value to the frequency at which water reaches that height. For example, if SVAR is approximately equivalent to the 50th percentile of water level, that means that still water level (i.e., water level excluding wave effects) is likely to reach the average height of the barrier approximately half the time (and conversely does not reach that elevation the other half of the time). A higher SVAR value—for instance, the 99th percentile—indicates water levels stay below the average height of the barrier 99% of the time, even during relatively large storms (or conversely that water levels only exceed the average height of the barrier 1% of the time). A lower SVAR value—for example, approximately equal to the 10th percentile—indicates that water levels stay below the average height of the barrier only 10% of the time (or conversely that water levels exceed the average height of the barrier 90% of the time). This lower SVAR value indicates a less resilient barrier given that frequent inundation is highly likely to impact the island and lead to significant short-term changes to the subaerial barrier.

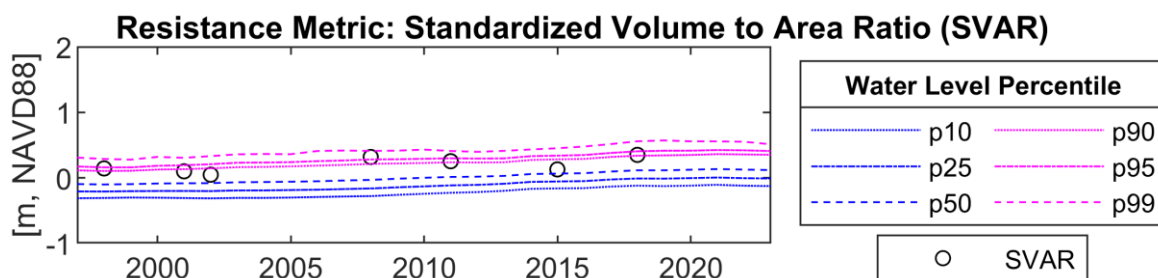


Figure 7. Example of the Standardized Volume to Area Ratio (SVAR; black circles) resistance metric calculated for a barrier, in this case Whiskey Island. Water level percentiles over time are calculated by year using data from the Grand Isle tide gage (<https://tidesandcurrents.noaa.gov/stationhome.html?id=8761724>), which is shown as a rolling year average. Water level benchmarks include those associated with relatively quiescent conditions (percentiles shown in blue: 10th, p10; 25th, p25, and 50th, p50) as well as more stormy conditions (percentiles shown in pink: 90th, p90; 95th, p95; and 99th, p99). Water levels increase over time due to sea-level rise.

The SVAR metric can also be compared to coastwide or regional statistics to evaluate the relative resistance of a given barrier (Figure 8). For example, Whiskey Island by the SVAR metric is one of the most resilient islands in 2018 (immediately post restoration), with an average height at approximately the 90th percentile of water level (i.e., water levels only exceed the average height of the island 10% of the time). Care should be taken in interpreting these regional and coastwide comparisons, however, given the often limited spatial and temporal coverage of lidar surveys (i.e., statistics calculated over 1–2 islands cannot be assumed to be wholly representative of the entire coast or region). Note, there is a companion Tier 2 resistance metric (described below) that provides additional, more spatially resolved resilience information by evaluating the extent of the island that would be inundated at different water levels.

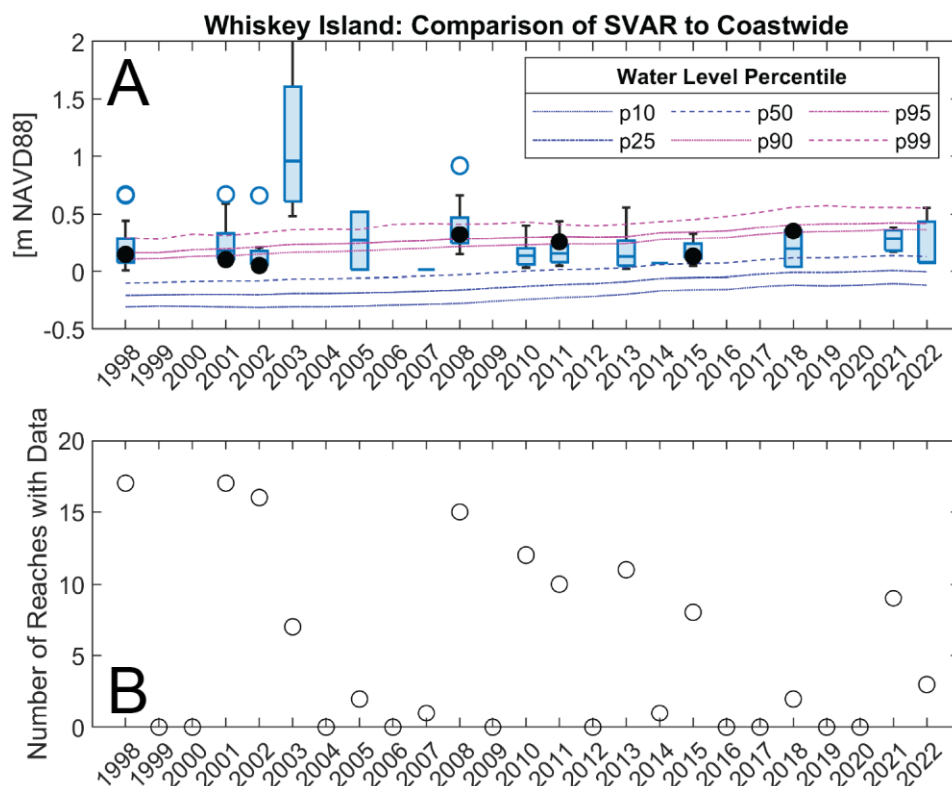


Figure 8. Comparison of Standardized Volume to Area Ratio (SVAR, black dots) for Whiskey Island to statistics of coastwide metrics (A). The box plots illustrate the coastwide median values (blue lines), 25th–75th percentile (blue boxes), and overall range (black lines) excluding statistical outliers (blue circles). Also shown for context are the number of barriers for which data are available in a given year (B).

The team also developed a second variation of the Tier 1 resistance screening metric by converting SVAR to a water level percentile using data from the closest tide gauge (Figure 9). Water level percentiles for each year of SVAR were calculated for a 5-year window centered around the SVAR observation time so that changes in water level due to SLR were accounted for. This resistance metric (SVAR converted to water level percentile) estimates the percentage of time that still water (i.e., water level excluding wave effects) would remain below the mean elevation of the island. This metric can also be benchmarked against coastwide values and is easier to compare across islands and over time. For example, Whiskey Island had relatively low resilience compared to the ~50% of islands where lidar data was available in 2015 (Figure 9), with water levels below SVAR approximately 60% of the time. After restoration, SVAR at Whiskey Island approached the 90th percentile of water level, indicating that water levels are below the mean elevation of the island 90% of the time. This metric increase captures an increase in resistance to storms, in that most of the island will be inundated relatively less frequently than prior to restoration. However, the tradeoff between this version of the resistance metric and SVAR is that, with SVAR, a manager can make their own determination of what water level to use for comparison (e.g., a manager primarily interested in the coastal protection might only be interested whether SVAR exceeds the 90th–99th percentile of water level over time).

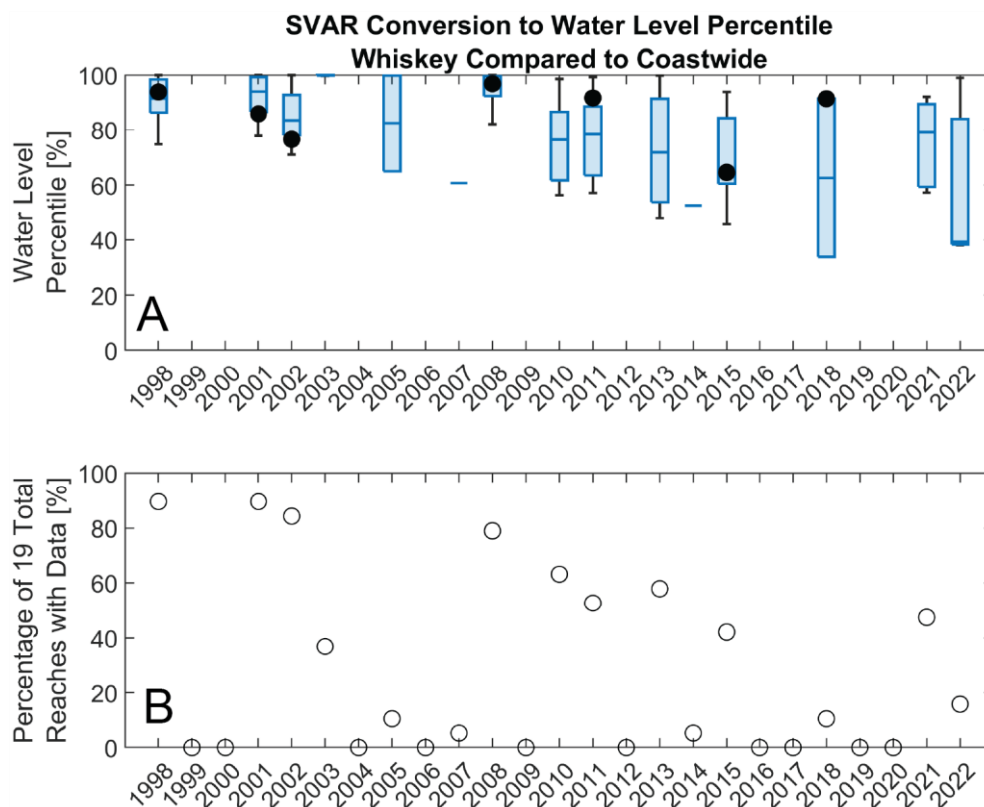


Figure 9. (A) SVAR converted to a water level percentile using tide gage data for Whiskey Island (black dots) compared to coastwide statistics of the same metric (blue line represents median value; blue box represents interquartile range; and black lines indicate the range of values). This metric represents the percentage of time still water (i.e., excluding wave effects) would be below the mean elevation of the island. (B) Percentage of the 19 coastal reaches for which lidar data, used to calculate SVAR, were available for each year.

Tier 2 Analysis Metrics

Tier 2 analysis metrics require more complex analysis and are targeted to address information needs for various coastal managers. The research team included high-resolution habitat mapping, high tide flooding analysis, and hypsometric curve analysis in this set of metrics.

High-resolution Habitat Mapping

While the Tier 1 metrics provide an efficient and effective tool for screening level analyses related to how subaerial land and vegetation area are changing over time, managers often need more detailed information on the composition of and change in specific habitat classes such as beach, dune, and wetland coverage. High-resolution habitat maps offer increased spatial and thematic detail that can be used to detect changes of vegetation type or setting (i.e., supratidal or intertidal) at fine scales. The change of habitat coverage over time was explored via simple stacked bar plots and assessing changes over time in maps (Figure 10).

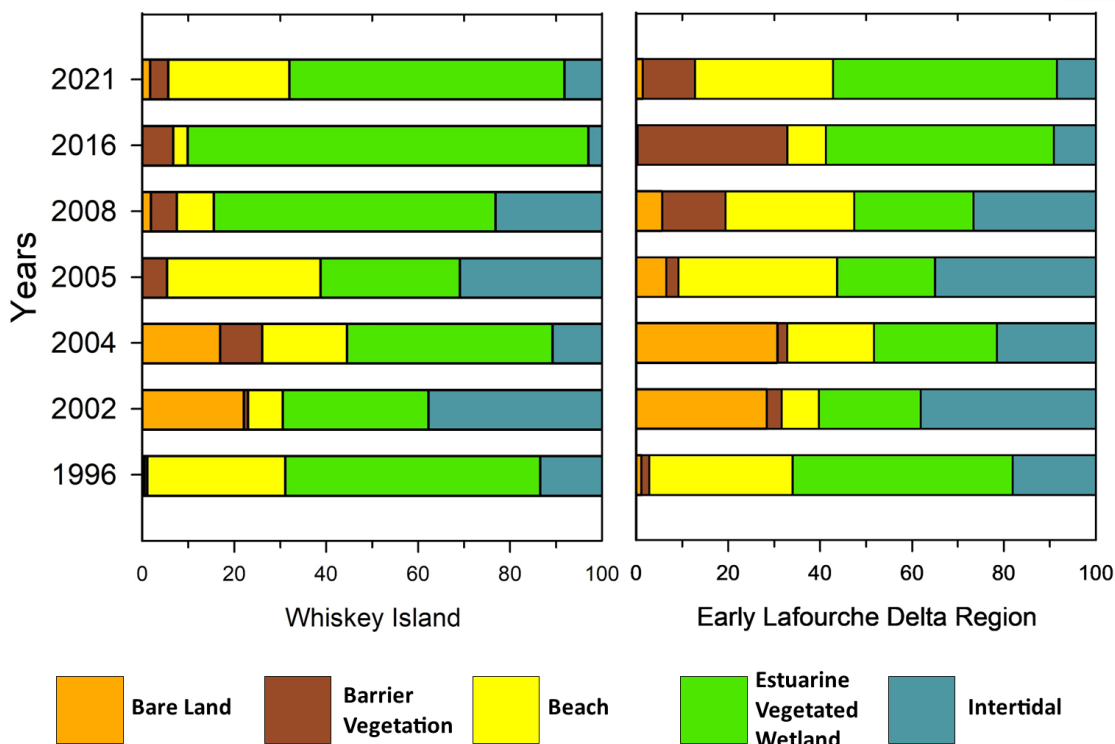


Figure 10. Example of stacked bar plot showing habitat coverage for Whiskey Island and the Early Lafourche Delta region (Raccoon Island to Wine Island) from 1996–2021 by reach (left) and region (right). The habitat classes shown here are a subset of the classes from the Louisiana Coastal Protection and Restoration Authority’s Barrier Island Comprehensive Monitoring Program’s general habitat classes (Fearnley et al., 2009).

High Tide Flooding Analysis

Building off the SVAR concept, understanding inundation patterns and frequency on barriers can advance understanding of coastal barrier resistance and resilience. For this metric, resistance is related to the relative proportion of area that is above each high tide flooding (HTF) water level. For example, a coastal barrier with a higher amount of area that is above the major HTF has greater resistance than a coastal barrier without any area above the major HTF. When assessed for multiple dates (i.e., lidar datasets), the metric can provide information on resilience by exploring how the areal coverage of HTF inundation levels are changing over time. This metric complements SVAR by providing more detailed information in the form of summary statistics for a coastal barrier (i.e., areal coverage below/above a specific threshold) and spatially explicit information in the form of a map showing areas that are above/below a specific threshold.

For this effort, the research team used NOAA’s HTF thresholds for the nearest tide gauge (Sweet et al., 2022). NOAA HTF thresholds (with example water thresholds from the Port Fourchon tide gauge) include: (1) minor HTF (e.g., 0.52 m above MHHW; includes water levels associated with the nuisance flooding or sunny day flooding); (2) moderate HTF (e.g., 0.81 m above MHHW; water levels associated with extreme storms); and (3) major HTF (i.e., 1.19 m above MHHW; water levels associated with

hurricanes). The research team used the HTF levels for Dauphin Island for the Chandeleurs region given that this region is closer to the Dauphin Island gauge than to Port Fourchon.

The research team developed maps of areas below each HTF and above the major HTF. Using an approach similar to Enwright et al. (2024), the research team incorporated elevation error and water level uncertainty estimates when mapping inundation zones. In order to estimate NOAA HTF thresholds in areas where only mean low lower water datum estimates are available, NOAA developed a model to predict HTF thresholds as a function of tidal range (Sweet et al., 2022). The research team used the standard deviation from this assessment as uncertainty estimates for the minor (0.18 m), moderate (0.25 m), and major (0.39 m) HTF threshold. The research team also incorporated error in VDatum transformation from NAVD88 to MHHW using a standard deviation of 0.8 m for the southeast Louisiana region. These uncertainty estimates were combined by calculating the root sum of squares. Land cover—especially vegetation cover—influences elevation error in DEMs (Su & Bork, 2006). Elevation error can be especially high in coastal wetlands due to tall dense vegetation and varying water levels (Buffington et al., 2016; Medeiros et al., 2015). A recent literature review of DEM error in coastal wetlands found the mean 95th percentile error was 0.46 m (Enwright, Cheney, et al., 2023). The research team assumed non-vegetated areas, which include barren land, unconsolidated shore, and all developed classes, to have a vertical accuracy with a root mean square error of 0.1 m based on USGS lidar base specification (USGS, n.d.-b). Similarly, the research team assumed vegetated, non-wetland areas had a vertical accuracy with a 95th percentile error of 0.3 m (USGS, n.d.-b), and that vegetated wetlands, which includes estuarine vegetated wetlands, had a vertical accuracy with a 95th percentile error of 0.46 m (Enwright et al. 2023). In order to be consistent with the root mean square error used for non-vegetated areas, the research team divided the 95th percentile error estimates for vegetated areas by 2 because the linear error at 95% confidence is 1.96 times the root mean square error.

The research team addressed water level uncertainty and elevation error by using Monte Carlo simulations with 1,000 iterations. For each iteration, a randomly selected number from a distribution with a mean of 0 and standard deviation of 1 was multiplied by the water level uncertainty (i.e., the root sum of square estimate). The elevation error was incorporated using a random field that had a normal distribution with a mean of 0 and a standard deviation of 1. The initial spatial resolution of the random field matched the distance for which elevation had a spatial autocorrelation value of 0 for each coastal barrier reach (Figure 1). To introduce some spatial variation and smoothing, the research team used inverse distance-weighted interpolation to create the final random field with a spatial resolution of 10 m from these initial, coarser, random field raster points. The land cover-based elevation error estimates were then multiplied by the 10-m random field. The elevation error was incorporated into the DEM by subtracting the random field from the DEM. The research team forced the random field to have a positive bias for vegetated areas, which would lead to an overall reduction of elevation estimates in vegetated areas. There was a positive bias for 950 of the 1000 iterations (i.e., the approach reduced elevation for vegetated areas for 95% of the iterations). The research team did not constrain the bias for the elevation correction of non-vegetated areas.

The research team developed individual maps that represented the frequency that each pixel was below each HTF, then combined these maps to a single map by setting the pixel as the class with the highest frequency (i.e., below minor HTF; below moderate HTF; below major HTF; and above major HTF (areas

that had a frequency of $\leq 0.33\%$ for being below the major HTF; Figure 11). Pixels that had an initial elevation of less than or equal to 0 NAVD88 were set to no data.

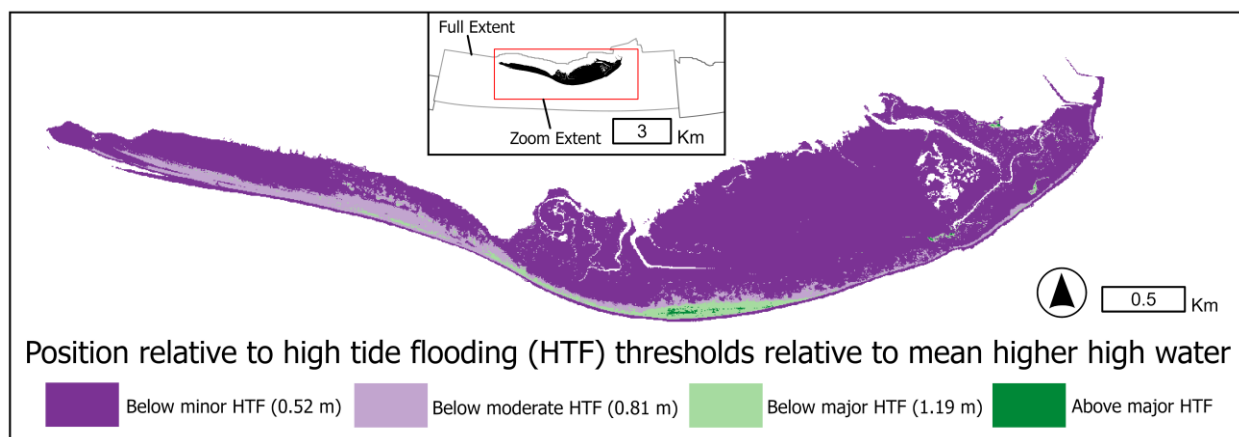


Figure 11. Example high tide flooding assessment for Whiskey Island using the digital elevation model from 2015. Areas that are below 0 m relative to the North American Vertical Datum of 1988 are omitted from the map.

Hypsometric Curve Analysis

Another Tier 2 analysis is founded in hypsometry, the measurement and study of the distribution of elevation on the Earth's surface. This approach is based on evaluating the normalized cumulative distribution of island elevation and comparing different island distributions and/or the trajectory of the distribution of a single island over time. This metric was restricted to only include elevations that were above 0 m MHHW, although it could be used for subaqueous data if it were consistently available across the coast. The hypsometric curve can be thought of as the extent of a barrier's area that is below a specific elevation, which complements the HTF analysis in providing additional information on the distribution of elevation across a barrier. For example, in Figure 12A, the curve indicates that none of the barrier has an elevation higher than approximately 1.8 m; approximately 0.25 km² has an elevation greater than 1 m; and the full area of island at elevation greater than 0 m is just over 3,000,000 km². This metric can also be normalized by dividing the area for each barrier (the x-axis values) by the total area of that barrier and then multiplying by 100 to convert to a percentage (Figure 12B). This value indicates the distribution of island elevation as a percentage of total area (e.g., approximately 5% of the island has an elevation greater than 1 m), which facilitates comparison across islands of different overall spatial extent.

The hypsometric curve analysis complements the HTF analysis by providing information in a different form, facilitating comparison across islands, and allowing users to consider their own elevation benchmarks in interpreting results, while conversely it does not include spatial maps that may be of interest to some managers. The HTF analysis uses established inundation levels from NOAA; for example, minor high tide flooding is considered nuisance flooding or extent of low-lying wetlands, whereas moderate or major high tide flooding is associated with extreme storms. Conversely, hypsometric curves provide an overall snapshot of the island where a manager can consider area for their own elevation threshold of interest. Comparing the hypsometric curves of different barriers can, for example, provide information in support of managing species with elevation-specific requirements for nesting that

may not align to the NOAA benchmarks. Evaluating hypsometric curves for the same barrier over time can also provide information on its trajectory and response to perturbations such as storms, which is more difficult to interpret in HTF maps. For example, shifts in elevation distribution from higher elevations to lower elevations are indicative of overwash and short-term erosional loss due to storms. The trajectory can be evaluated to determine if the barrier is recovering following storms. The normalized distributions can also be compared between islands, compared to regional or coastwide hypsometric curves, and/or compared to established barrier restoration templates to evaluate the evolution of a restored system over time and the relative magnitude of change due to restoration compared to change driven by storms, SLR, and other drivers.

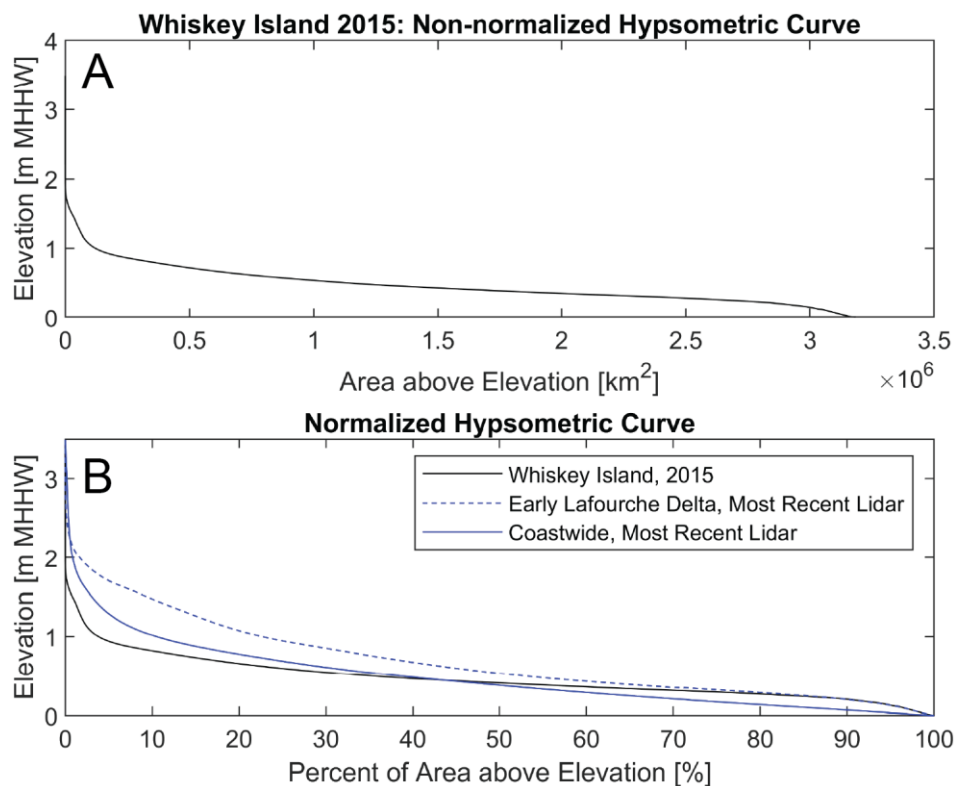


Figure 12. Example hypsometric curves representing cumulative distribution of barrier elevation in spatial units (A) and converted to a percentage by normalizing by the total area (black line) then benchmarked against the coastwide average curve (blue line) (B). Non-normalized curves provide estimates of area by elevation, e.g., estimates of the extent of different types of habitat and for comparisons to regional or coastwide curves, while normalized curves allow for comparison of the distribution of elevation across islands of different sizes.

RESULTS

The research team applied the analysis framework developed for assessing resilience and resistance to the coastal barriers of Louisiana, a synopsis of which is presented below. In addition, one of the objectives of this project was for the results to be accessible and actionable for coastal managers. The research team therefore developed island “Report Cards,” a format for synthesizing ecosystem information that has been shown to be effective in supporting management (e.g., Harwell et al., 2019). These report cards include an overview of restoration activities; a list of major hurricanes (category 3 or higher) passing within 200 km of the reach (note, a list of all tropical storms passing within 200 km is included in Appendix C, but was too long to include in the report cards); Tier 1 metrics for all available data for each island; and a selection of Tier 2 metrics for recent data as a snapshot of the current state of the island (Appendix D).

TIER 1 SCREENING METRICS

Comparison of non-normalized subaerial land and vegetated area for the barriers of Louisiana (Figure 13, Figure 14) allows for ready comparison of the overall size of the islands. Caminada Headland—the largest land mass considered in this analysis—dominates the other reaches in non-normalized subaerial area. Conversely, assessing island resilience through the same metrics normalized by the maximum for each island and headland over the period of analysis provides a robust metric for comparing the resilience between barriers (Figure 15). Although Caminada Headland is still relatively close to its historical maximum size, it is less resilient based on the normalized metric than, for example, Grand Isle.

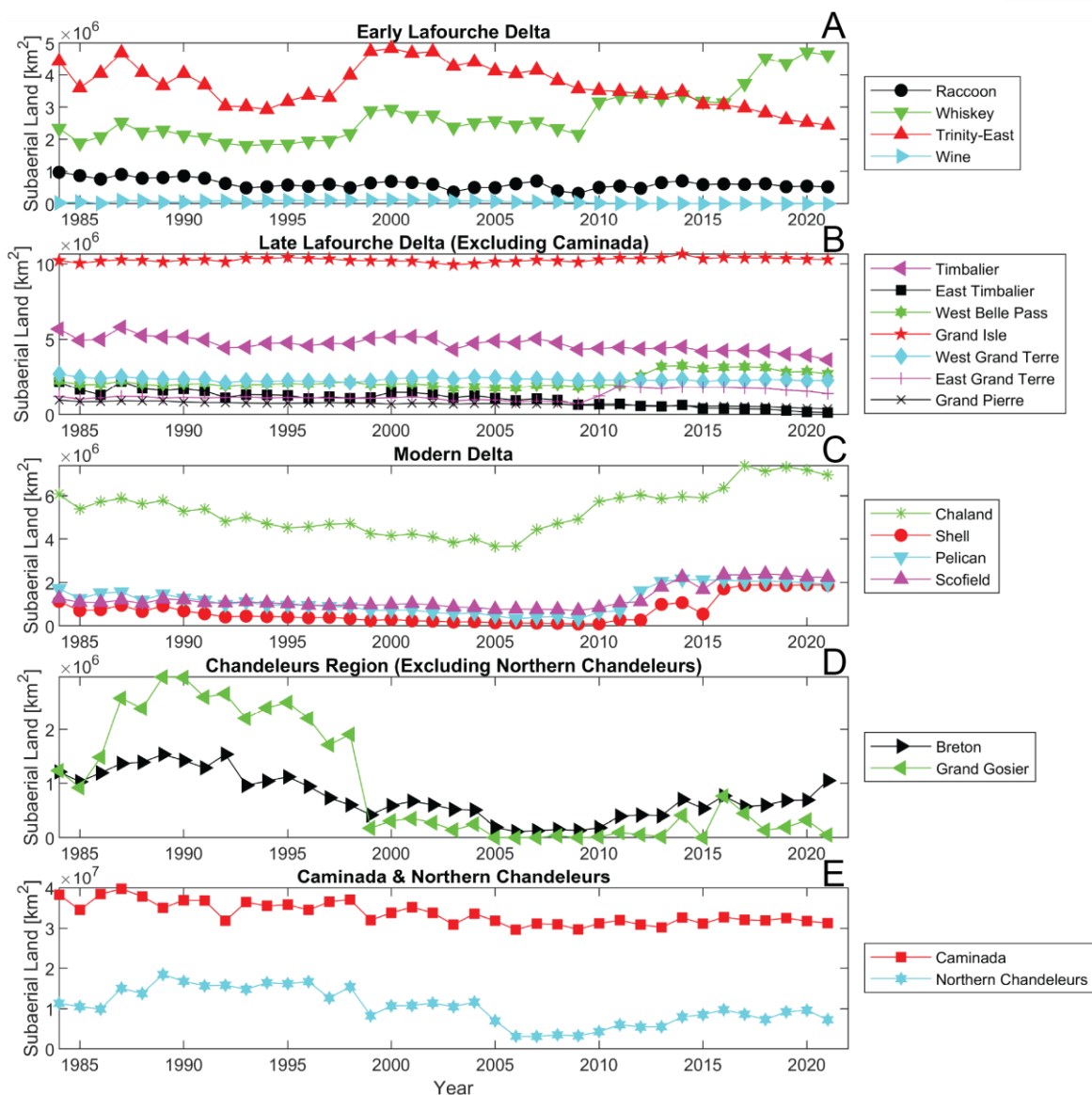


Figure 13. Total subaerial land area for barriers in the Early Lafourche Delta (A), Late Lafourche Delta (B), Modern Delta (C), and Chandeleurs (D) regions. Caminada Headland and the Northern Chandeleur Islands (E) are shown separately due to their large size relative to other barriers in their respective regions. Note, the y-axis scale varies between subplots to allow variability to be seen over time for each barrier. Refer to Figure 1 for the location of each barrier.

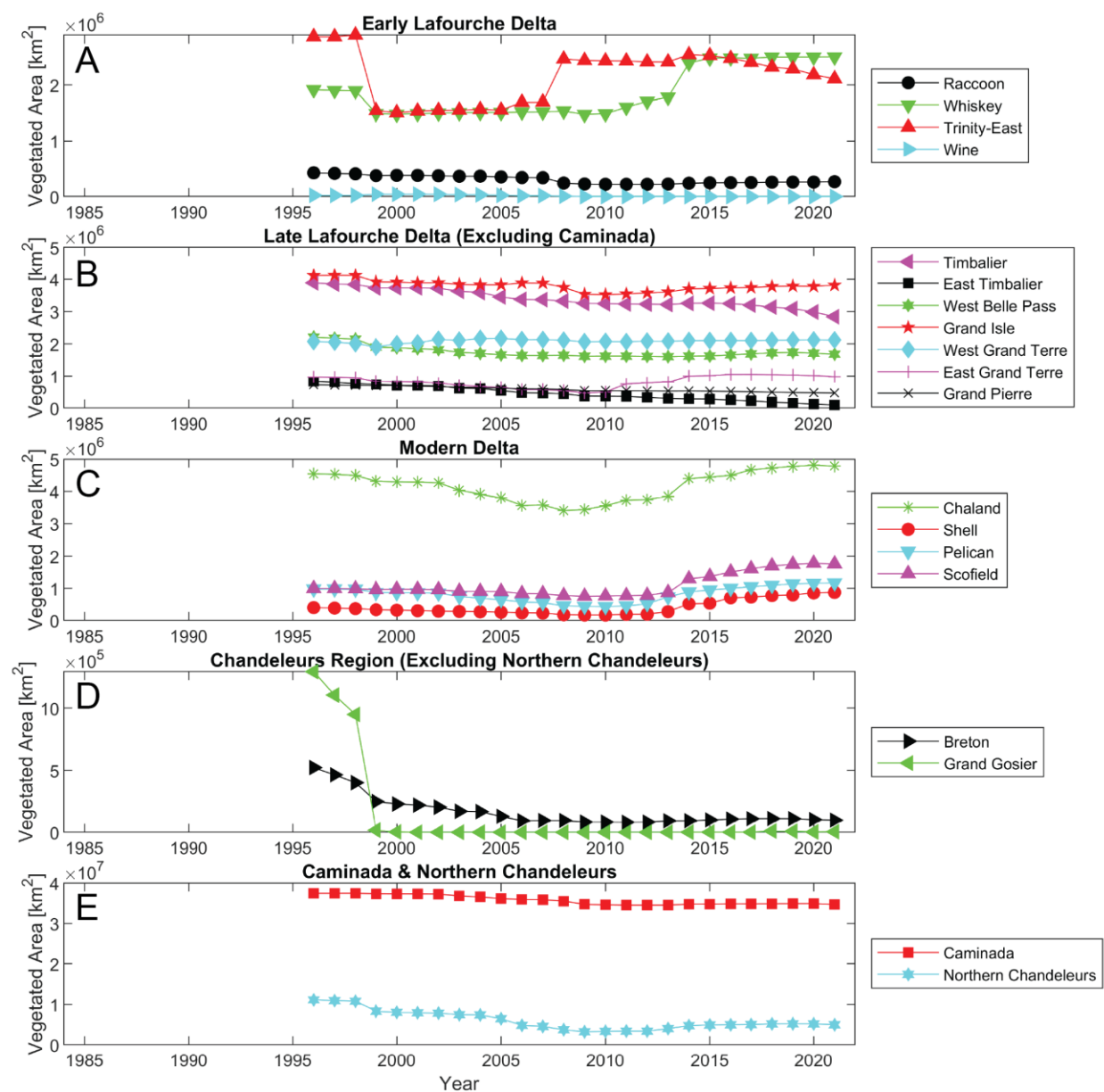


Figure 14. Total vegetated area for barriers in the Early Lafourche Delta (A), Late Lafourche Delta (B), Modern Delta (C), and Chandeleurs (D) regions. Caminada Headland and the Northern Chandeleur Islands (E) are shown separately due to their large size relative to other barriers in their respective regions. Note, the y-axis scale varies between subplots to allow variability to be seen over time for each barrier. Refer to Figure 1 for the location of each barrier.

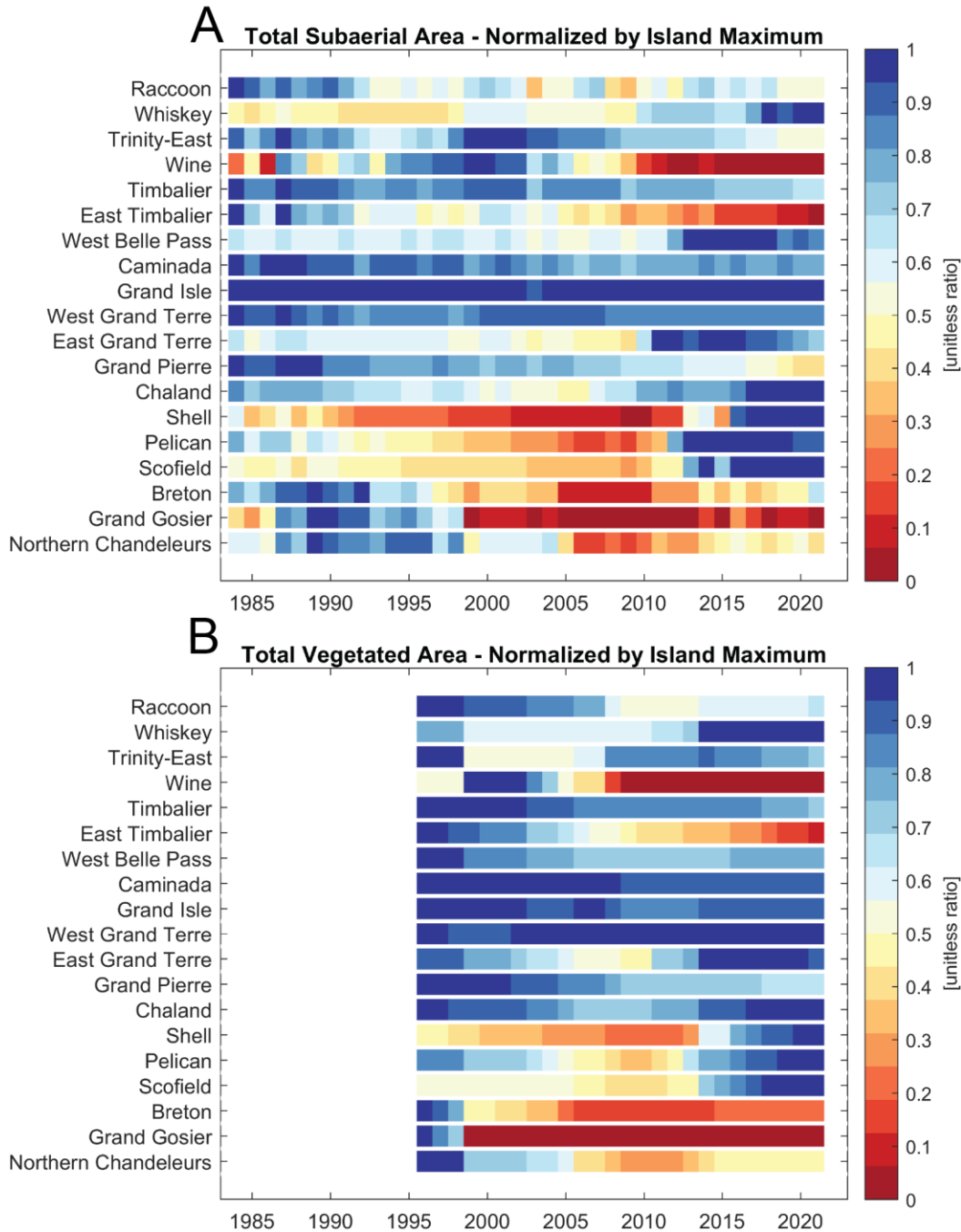


Figure 15. Subaerial land area (A) and vegetated area (B) for the coastal barriers of Louisiana, normalized by the maximum value for each island. Refer to Figure 1 for the location of each barrier.

The normalized resilience metrics also allow barriers to be clearly identified as relatively stable, declining, or increasing in resilience with restoration activities (Figure 16). For example, West Grand Terre was relatively stable in both subaerial and vegetated area over the analysis period, while Wine Island steadily declined until conversion to an intermittent shoal. Metrics also illustrate variability in vegetation response. For example, CPRA restored both Pelican Island and West Belle Pass in the early 2010s, increasing subaerial area to historical highs. At Pelican Island, vegetation gradually re-established

in response to this restoration, whereas vegetation has been relatively consistent over time at West Belle Pass with no significant increase after restoration.

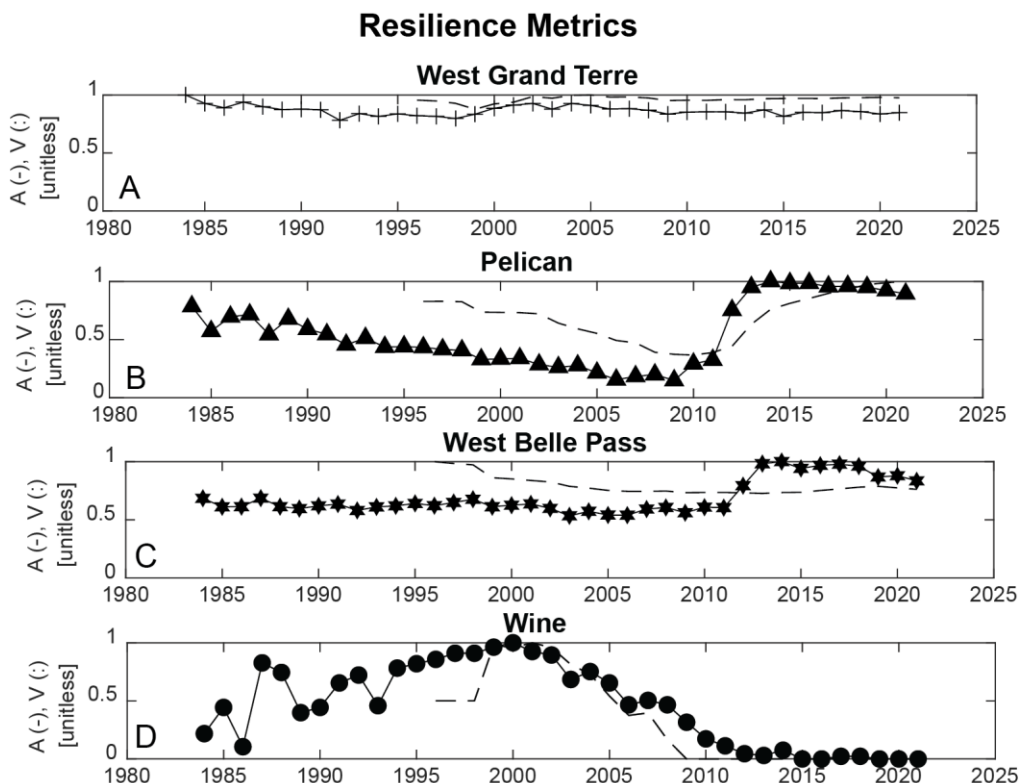


Figure 16. Resilience metrics of normalized subaerial area (“A(-)”, solid lines) and vegetated area (“V(:)”, dashed lines) for four Louisiana barrier islands: West Grand Terre (A, plus symbol), Pelican Island (B, triangles), West Belle Pass (C, stars), and Wine Island (D, circles). Refer to Figure 1 for the location of each barrier.

Comparison of the land area resilience metric to pre-restoration trends allow the impact of restoration in the context of the overall island trajectory to be evaluated (Figure 17). For example, restoration at East Timbalier Island and Trinity East Island added land area to those reaches but did not change the overall trajectory of land area loss. Each of the island resumed a negative trend of continued loss of resilience over time at approximately the same rate of change, with East Timbalier Island eventually approaching zero subaerial area. In contrast, a smaller restoration at Timbalier Island did not significantly increase the island’s resilience as measured by the subaerial land metric.

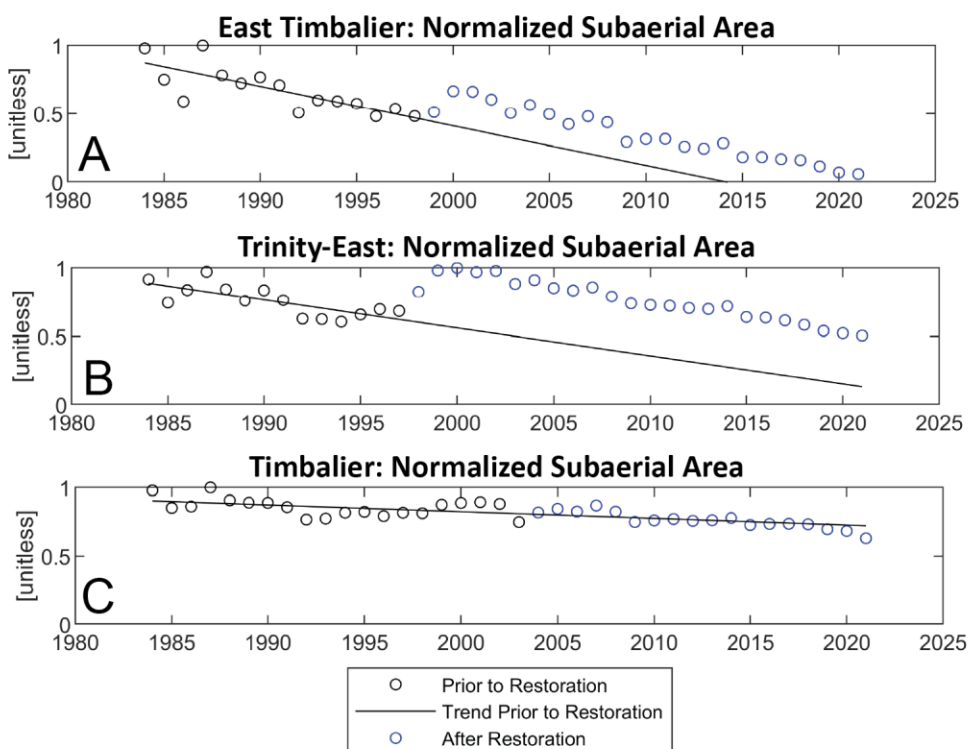


Figure 17. Normalized subaerial land resilience metric for East Timbalier Island (A), Trinity-East Island (B), and Timbalier Island (C). A linear trend is fitted to the metric for years prior to the first restoration (black circles) for comparison to metric post-restoration (blue circles). Refer to Figure 1 for the location of each barrier.

The developed resilience metrics enable coast-wide and regional assessments in addition to evaluating individual barriers. For this assessment, the research team used statistics calculated on the normalized metrics for each barrier and compared regionally (Figure 18). The barriers of Louisiana declined across both resilience metrics from the earliest year of record through the early 2000s. In addition, the range of variability across islands increased, reflecting that some islands declined more because of storms and other processes compared to others. Intense restoration of the Louisiana coast began after Hurricane Katrina in 2005 and the Deepwater Horizon Oil Spill in 2010, which can be seen as gradual recovery of both metrics since that time.

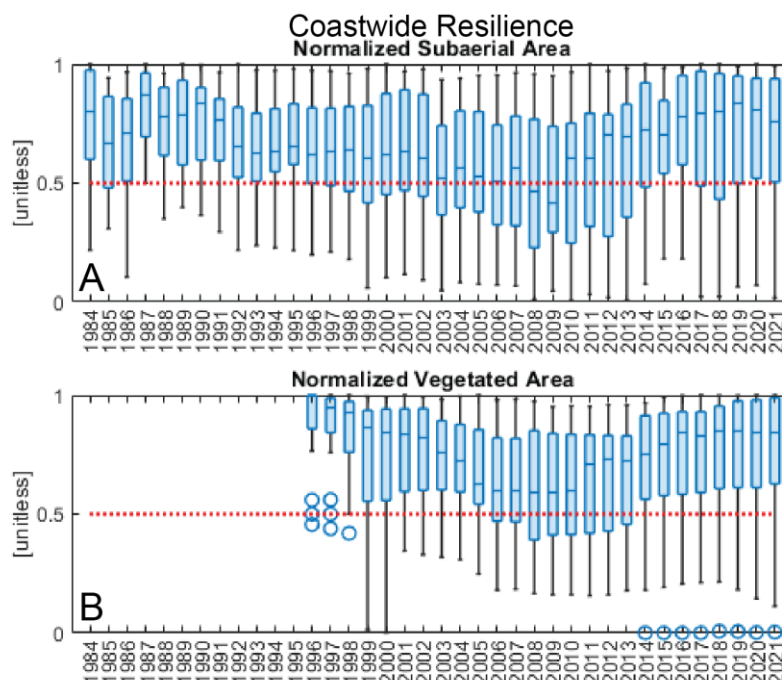


Figure 18. Coast-wide resilience characterized through normalized subaerial area (A) and normalized vegetated area (B). The box plots show the median (blue horizontal line), interquartile range (blue box), overall range (black lines), and outliers (blue circles) calculated over all barriers for each year. A unitless value of 0.5, corresponding to half of historical high values for these normalized metrics, is shown for reference (red dashed line). Outliers are defined as being more than 1.5 times the interquartile range (i.e., the height of the blue box) below the 25th percentile (i.e., the lower bound of the blue box). The outliers in vegetated area are Wine Island, Shell Island, and Scofield Island (1996); Shell (1997); and Wine Island and Grand Gosier/Curlew Islands (2014–2021).

A similar assessment can be done to evaluate and compare different regions of the Louisiana coast (Figure 19). Most of the restoration efforts in Louisiana have focused on the Central Coast barrier chain, comprised of the Early Lafourche Delta, Late Lafourche Delta, and Modern Delta regions delineated by the BICM program (Figure 1; Byrnes et al., 2018). Analysis shows that these restoration efforts have mitigated historical trends of island decline, increasing and stabilizing subaerial and vegetated area along the coast. In contrast, limited restoration occurred in the Chandeleurs region during the analysis period, and the resilience metrics remain at historical lows.

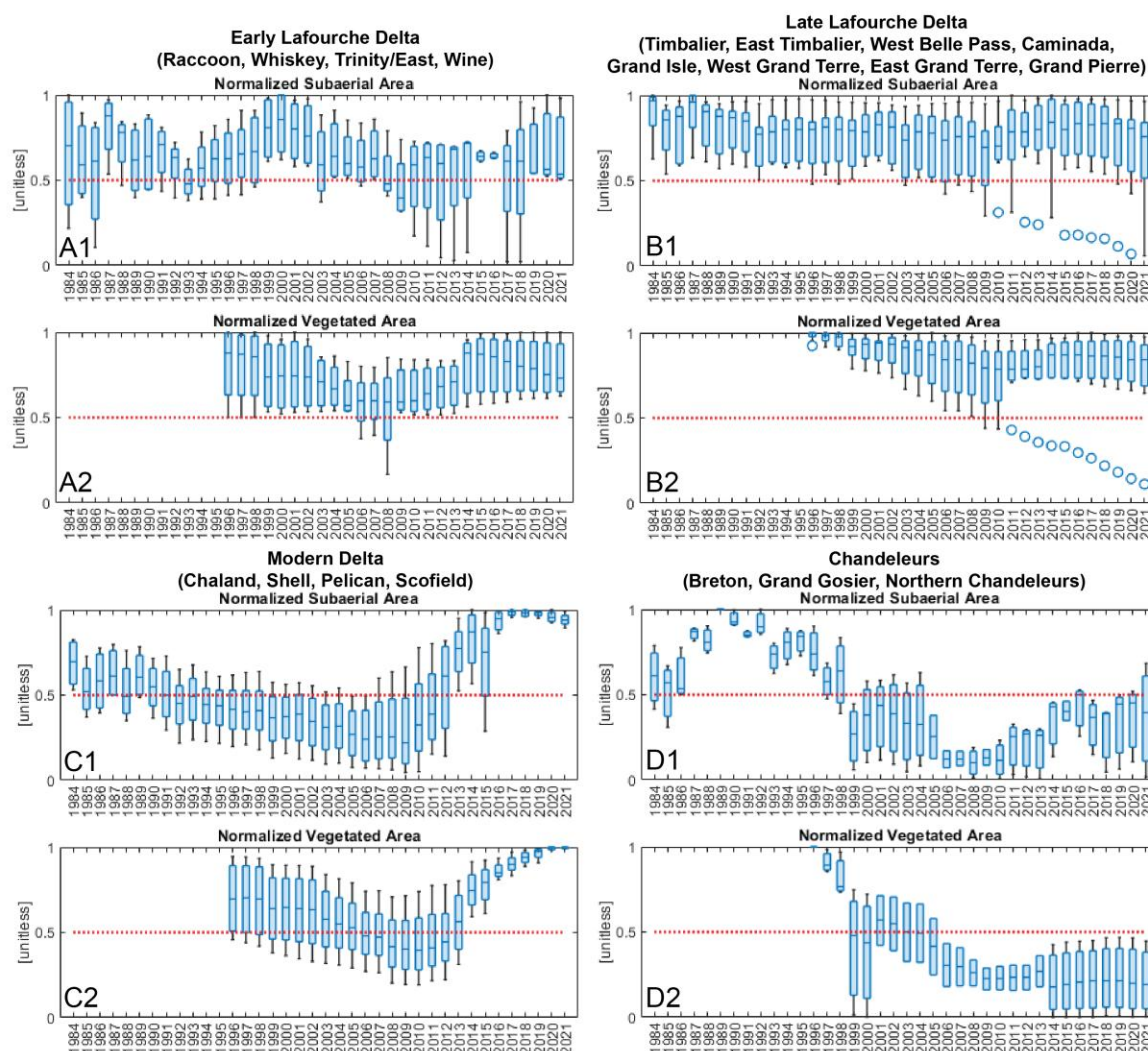


Figure 19. Resilience for four regions of the Louisiana coast (Early Lafourche Delta, (A); Late Lafourche Delta, (B); Modern Delta, (C); and Chandeleurs (D)), characterized through normalized subaerial area (1) and normalized vegetated area (2). Regions used correspond to reaches delineated in the Barrier Island Comprehensive Monitoring program (Byrnes et al., 2018). The box plots show the median (blue horizontal line), interquartile range (blue box), overall range (black lines), and outliers (blue circles) calculated over all of the islands for each year. A unitless value of 0.5, corresponding to half of historical high values for these normalized metrics, is shown for reference (red dashed line). Outliers are defined as being more than 1.5 times the interquartile range (i.e., the height of the blue box) below the 25th percentile (i.e., the lower bound of the blue box). East Timbalier Island is the outlier in the Late Lafourche Delta in both land area and vegetation from 2011–2021; East Grand Terre is the outlier in vegetated area the Late Lafourche Delta in 1996 (note, however, this is due to the tight clustering of values for the other islands in that region during that year). Refer to Figure 1 for the location of each barrier.

The research team also calculated the Tier 1 resistance metrics (SVAR and SVAR converted to water level percentile) for each barrier for all available lidar surveys over the period of analysis (Figure 20, Figure 21). SVAR is more limited in spatial and temporal coverage due to the irregular nature of lidar collection. In addition, lidar quality improved over time, particularly in the early 2010s. Several trends can be observed despite these data limitations, however. Virtually all barriers declined in resistance over

time from the earliest surveys through approximately 2010, particularly when SVAR is converted to a water level percentage (i.e., water levels would more frequently exceed the mean island elevation, reflecting increased vulnerability to short-term change). Restoration events increase SVAR at least in the short-term; for example, the noticeable increase in SVAR for Pelican Island in 2014. Conversely, increasing water levels can decrease barrier resistance over time without restoration or mitigating factors. SVAR doesn't degrade significantly between 2008–2021 at East Grand Terre, for example (Figure 20), but when SLR is factored in the island has become less resistant over time (Figure 21). In other words, the island has become less resistant over time because of the change in water level rather than because of a change in the physical state of the island. This outcome is consistent with the goal of the Tier 1 resistance metrics to capture the likelihood of significant short-term change to the barriers in response to storms or other drivers; in this case, the island is becoming less resistant over time to storms with otherwise identical characteristics due to SLR.

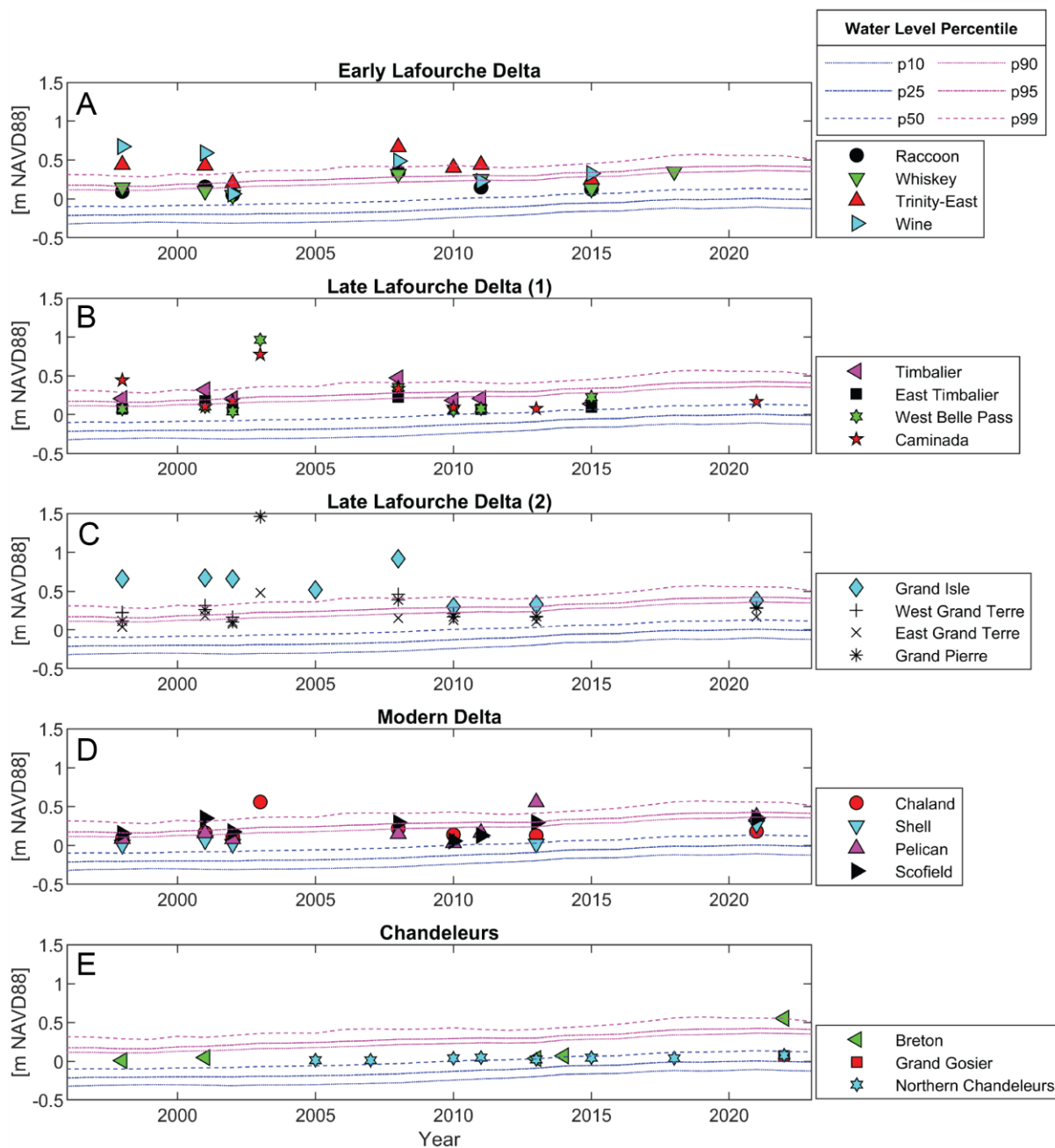


Figure 20. Standardized Volume to Area Ratio (SVAR) for the Louisiana Coast. SVAR is calculated from lidar data, the quality of which improved considerably from the early 2000s to early 2010s. Subplots show regions (Early Lafourche Delta, (A); Late Lafourche Delta: (B and C); Modern Delta, (D); and Chandealeurs (E)), corresponding to reaches delineated in the BICM program (Byrnes et al., 2018). Refer to Figure 1 for the location of each barrier.

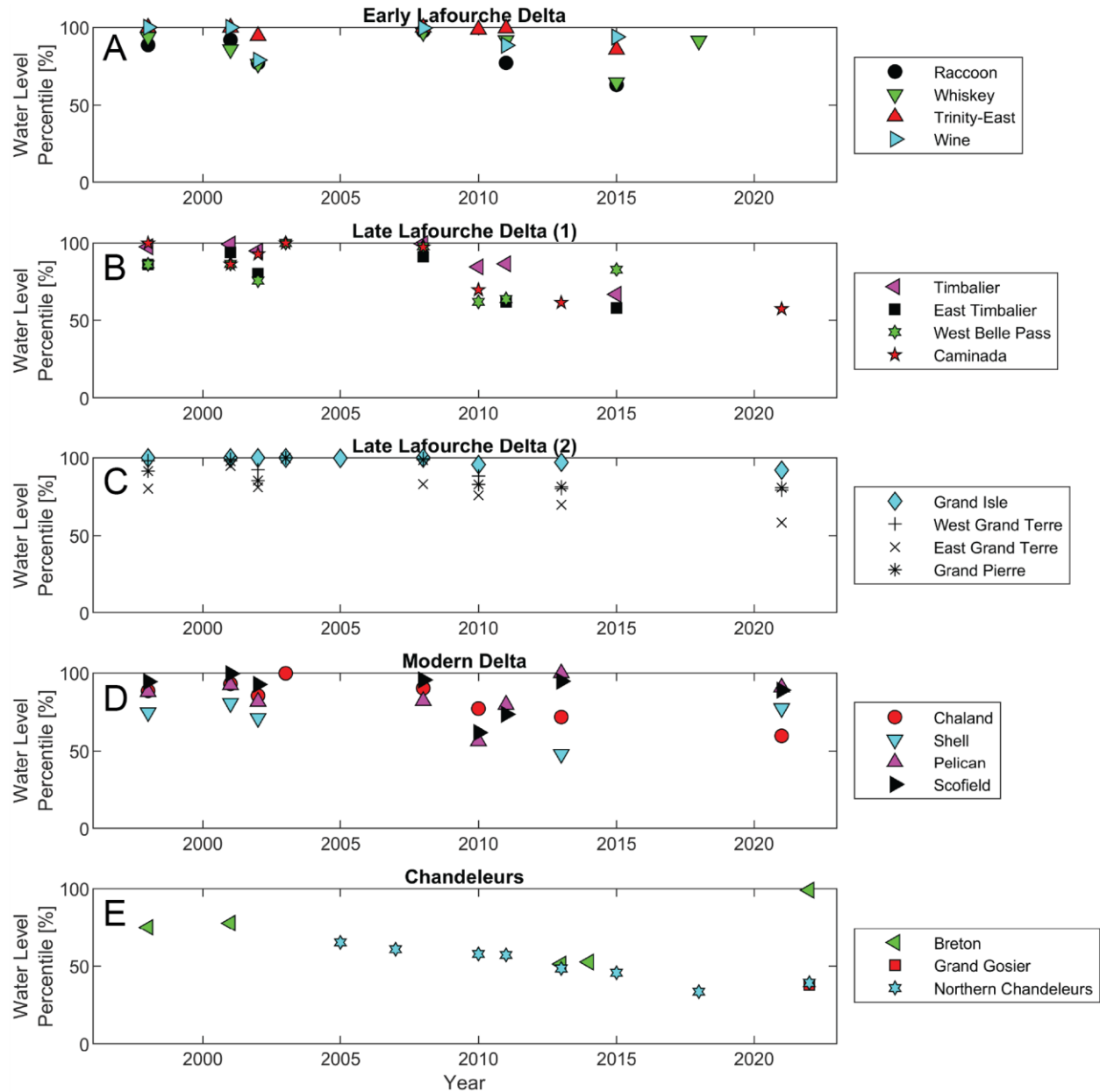


Figure 21. Standardized Volume to Area Ratio (SVAR) converted to Water Level Percentile. SVAR is calculated from lidar data, the quality of which improved considerably from the early 2000s to early 2010s. Subplots show regions (Early Lafourche Delta, (A); Late Lafourche Delta: (B and C); Modern Delta, (D); and Chandeleurs (E)), corresponding to reaches delineated in the BICM program (Byrnes et al., 2018). Numbers in italics indicate the number of available lidar surveys for that year. Refer to Figure 1 for the location of each barrier.

Resistance can also be evaluated regionally and coastwide using these metrics (Figure 22), although care should be taken in interpreting the results due to the limited spatial and temporal coverage of available lidar data and the changing quality over time (particularly the higher error and uncertainty associated with lidar data before the earlier 2010s). Coastwide, resistance became more varied across islands with time. This outcome is likely the result of the entire coast becoming less resilient over time due to environmental

processes (erosion, water levels increase with SLR), while at the same time restoration events in different years brought individual islands up to target elevations (compared to sea level at time of restoration) and thus increased their resistance.

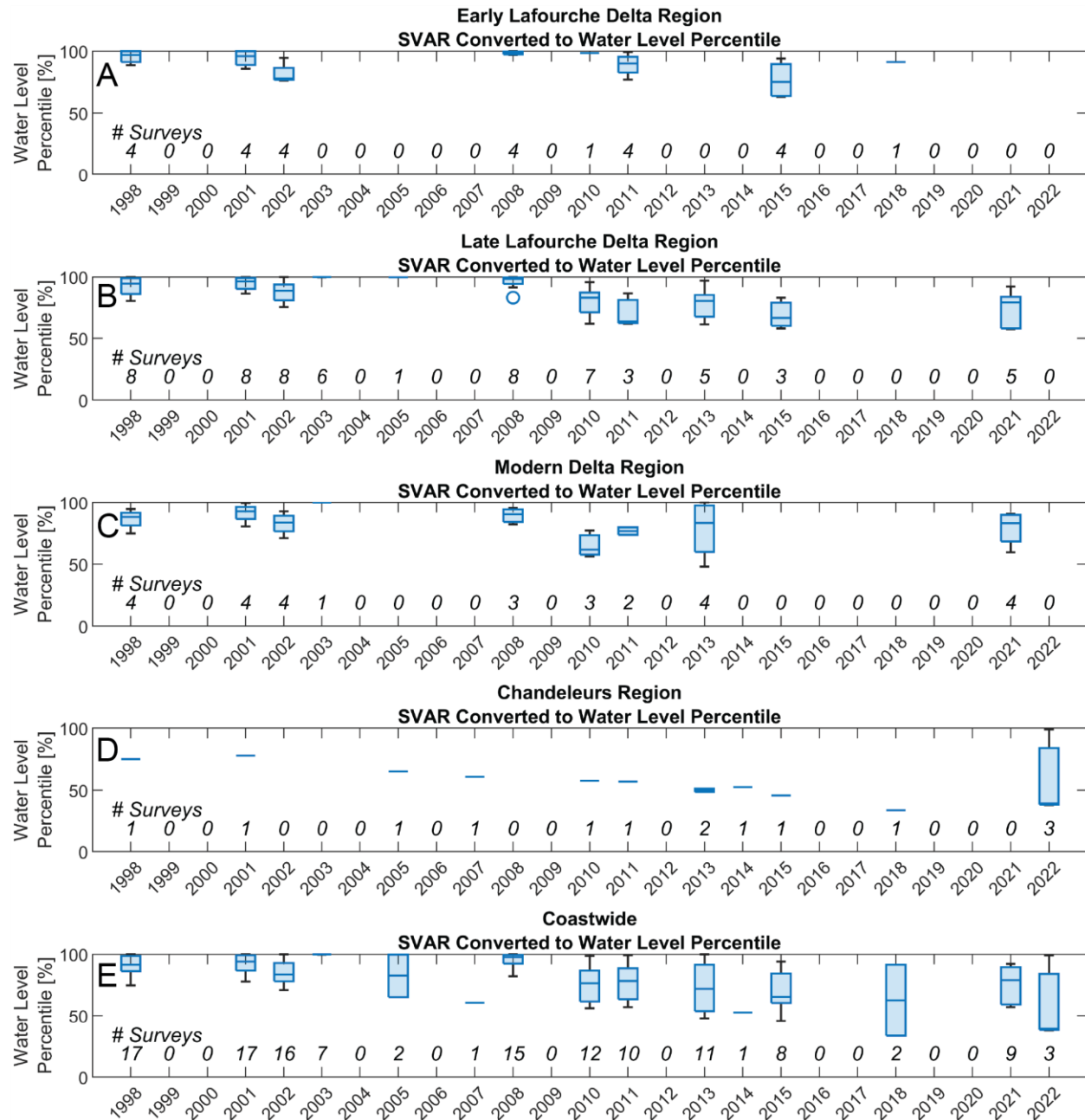


Figure 22. Standardized Volume to Area Ratio (SVAR) converted to Water Level Percentile for four regions of the Louisiana coast (Early Lafourche Delta, (A); Late Lafourche Delta, (B); Modern Delta, (C); and Chandeleurs (D)) as well as coastwide (E). Regions used correspond to reaches delineated in the BICM program (Byrnes et al., 2018). The box plots show the median (blue horizontal line), interquartile range (blue box), overall range (black lines), and outliers (blue circles) calculated over all of the islands for each year. Numbers in italics indicate the number of lidar surveys for each year and region. SVAR is calculated from lidar data, the quality of which improved considerably from the early 2000s to early 2010s. Refer to Figure 1 for the location of each region.

The resilience and resistance metrics provide a more holistic assessment when used together. Whiskey Island, for example, increased in subaerial area in the late 1990s because of sediment placement in 1998–1999 (Figure 23). That restoration did not impact vegetated cover, and after restoration the island declined in resilience through 2009 with a loss of both subaerial area and vegetated area. The barrier’s resistance also declined over the same time period, with SVAR starting at the 90th–95th percentile of water level immediately post-restoration and declining to approximately the 75th percentile of water level by the early 2000s. Together, these trends indicate the island was losing volume relative to its area in addition to becoming smaller, suggesting that inundation events that degraded the berm were occurring but that those events were not resulting in sufficient increases in land area (e.g., through overwash and deposition of material in the back barrier) to keep pace with shoreline erosion. A marsh restoration project in 2009 increased resilience and resistance, with an immediate increase in subaerial area and SVAR and a lagged increase in subaerial vegetation. After 2009, vegetation increased somewhat while subaerial land decreased slightly, indicating the island was generally maintaining resilience. However, SVAR declined over the same time period, reflecting a decrease in resistance to storms. A large-scale beach, dune, and back-barrier restoration in 2018 significantly increased subaerial land and SVAR, but did not result in substantial increases in vegetated cover. The 2018 restoration increased both the subaerial footprint of the island and SVAR to the maximum over the periods of analysis. However, SVAR did not reach its historical high relative to water level due to SLR.

At the Northern Chandeleur Islands (Figure 23), there was a consistent decline in subaerial area and vegetation from the mid-1980s through the mid-2000s, with significant loss occurring in 2004–2005 due to hurricanes Ivan, Katrina, and Dennis. An emergency berm constructed in 2010 increased subaerial area, and further natural recovery occurred from that point through approximately 2015 when island area stabilized. Lidar data are unavailable for this area prior to 2005, but SVAR has remained relatively stable since that time. With SLR, however, SVAR has dropped relative to water level, falling from approximately the 70th percentile in 2005 to approximately the 40th percentile in the late 2010s and early 2020s. This loss suggests that although the island has remained relatively stable in terms of resilience (i.e., capacity to maintain itself subaerially), it has increasingly lost resistance (i.e., capacity to maintain its form in the short term in response to storms) as SLR has increased the overall water level elevation that an otherwise identical storm would reach.

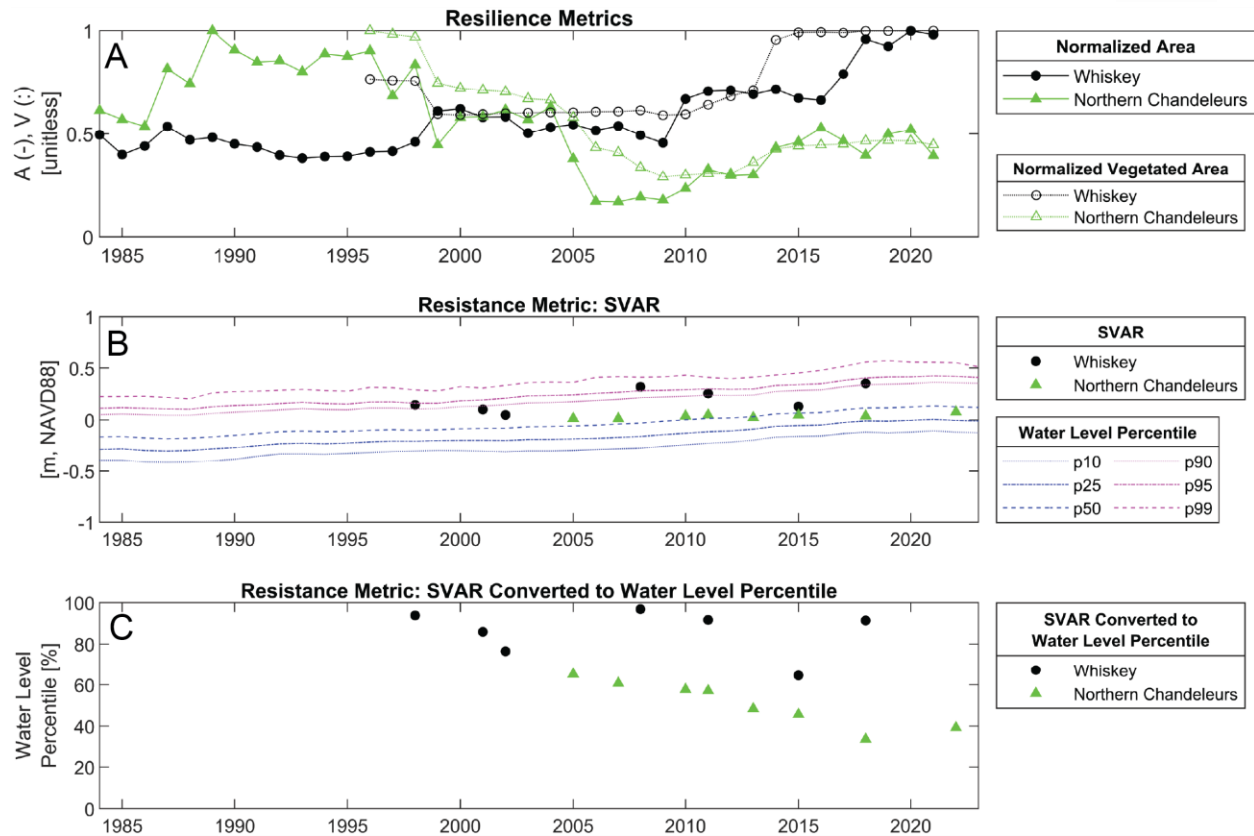


Figure 23. Resilience and resistance metrics for Whiskey Island and the Northern Chandeleur Islands. The top panel shows total subaerial land area and total vegetated area (A); the bottom panel shows normalized subaerial land area and vegetated area (B). Standardized Volume to Area Ratio (SVAR; black circles) resistance metric calculated for the Northern Chandeleur Islands. Water level percentiles over time are calculated by year using data from the Grand Isle tide gage (<https://tidesandcurrents.noaa.gov/stationhome.html?id=8761724>), which is shown as a rolling year average. Water level benchmarks include those associated with relatively quiescent conditions (percentiles shown in blue: 10th, p10; 25th, p25; and 50th, p50) as well as more stormy conditions (percentiles shown in pink: 90th, p90; 95th, p95; and 99th, p99). Water levels increase over time due to sea-level rise. Refer to Figure 1 for the location of each barrier.

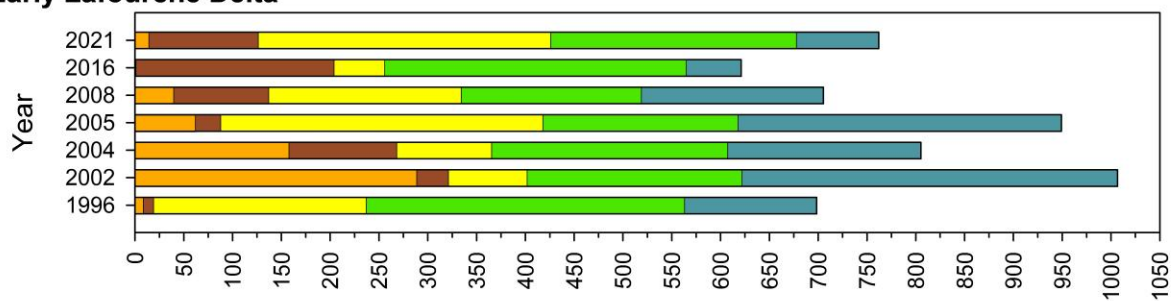
TIER 2 ANALYSIS/METRICS

High-resolution Habitat Mapping

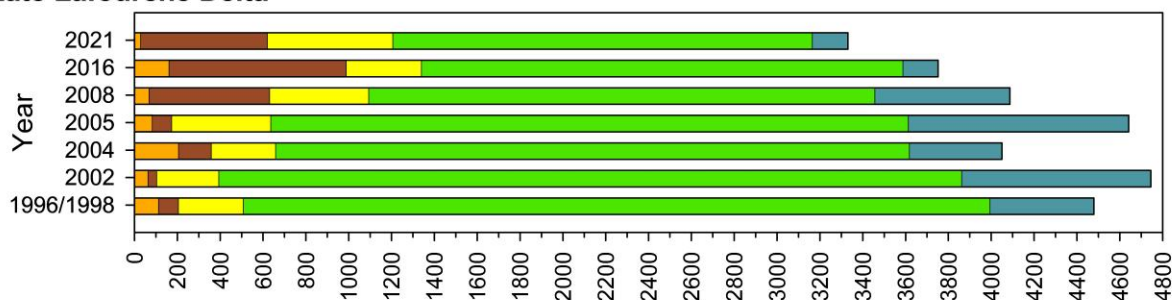
The absolute cover of bare land, beach, barrier vegetation, estuarine vegetated wetland, and intertidal is summarized in Figure 24 by region for all currently available BICM habitat maps. These high-resolution habitat maps allow for detailed delineation of supratidal areas (beach, barrier vegetation, bare land) and intertidal unvegetated areas and vegetated wetlands (estuarine vegetated wetland class). Although the research team included the intertidal class in these plots, it is important to note that this class can vary substantially depending on the water level at the time of imagery acquisition. The other four classes provide a more reasonable representation of subaerial land. At the regional level, results tracked the screening-level analyses that pointed to restoration in the Central Coast barrier chain regions (Early Lafourche Delta to Modern Delta regions) along with the storm-related impacts and recovery in the Chandeleurs region (Figure 24). Of all regions, the Modern Delta region had the most notable increase in supratidal areas and estuarine vegetated wetlands with an increase from around 517 ha in 2008 to 1,253

ha 2016 (~142% increase) with the restoration actions resulting in relatively similar amounts of barrier vegetation, beach, and estuarine vegetated wetlands in 2016. The Chandeleurs region—the region with the least restoration activity during the analyzed time period—had the most notable decrease in supratidal areas and estuarine vegetated wetlands, falling from around 1,769 ha in 1998 to 814 ha in 2016 (~54% decrease), with a large amount of this loss being in the estuarine vegetated wetland class (~761 ha).

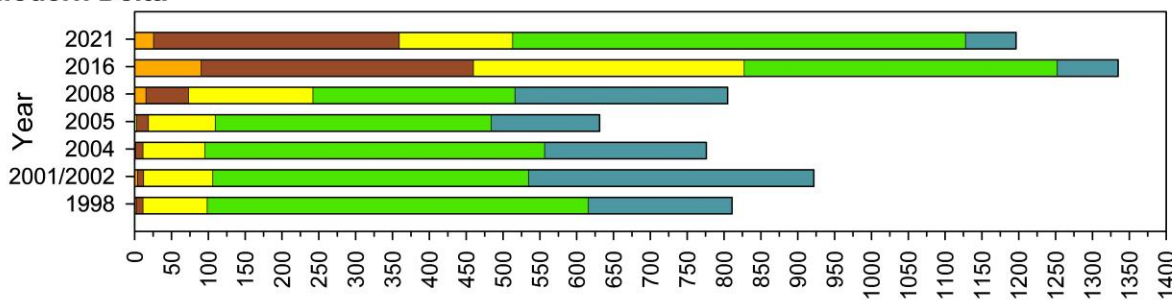
A Early Lafourche Delta



B Late Lafourche Delta



C Modern Delta



D Chandeleurs

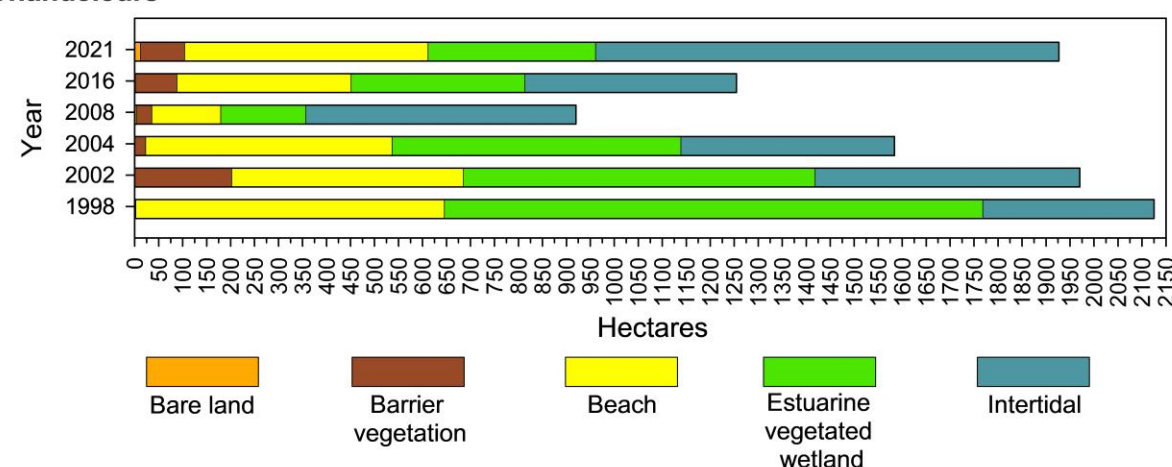


Figure 24 Habitat coverage along the Louisiana coast. The habitats classes shown are the Louisiana Coastal Protection and Restoration Authority's Barrier Island Comprehensive Monitoring Program's general habitat classes (Fearnley et al., 2009) by region: Early Lafourche Delta (A); Late Lafourche Delta (B); Modern Delta (C); and Chandeleurs (D). Please note, the x-axis scaling is different for each plot. Refer to Figure 1 for the location of each region.

The BICM general habitat maps for Whiskey Island from 1996–2021 are shown in Figure 25. Generally, these changes in subaerial land and vegetation track the changes detected in the Tier 1 screening-level analyses (Figure 13, Figure 14, Figure 15) while providing additional, more detailed information. The high-resolution habitat maps show the successful two beach, dune, and marsh restorations in 1998 and 2009 as well as the large-scale beach, dune, and back-barrier restoration in 2018. A benefit of the high-resolution habitat maps is the ability to understand habitat heterogeneity, including detecting changes in small patches of vegetation. For example, Figure 25D shows small vegetation patches on the Gulf-side of the dune that would likely be too small to be detected in a moderate spatial resolution (i.e., 10–30 m²) pixel from satellite imagery.

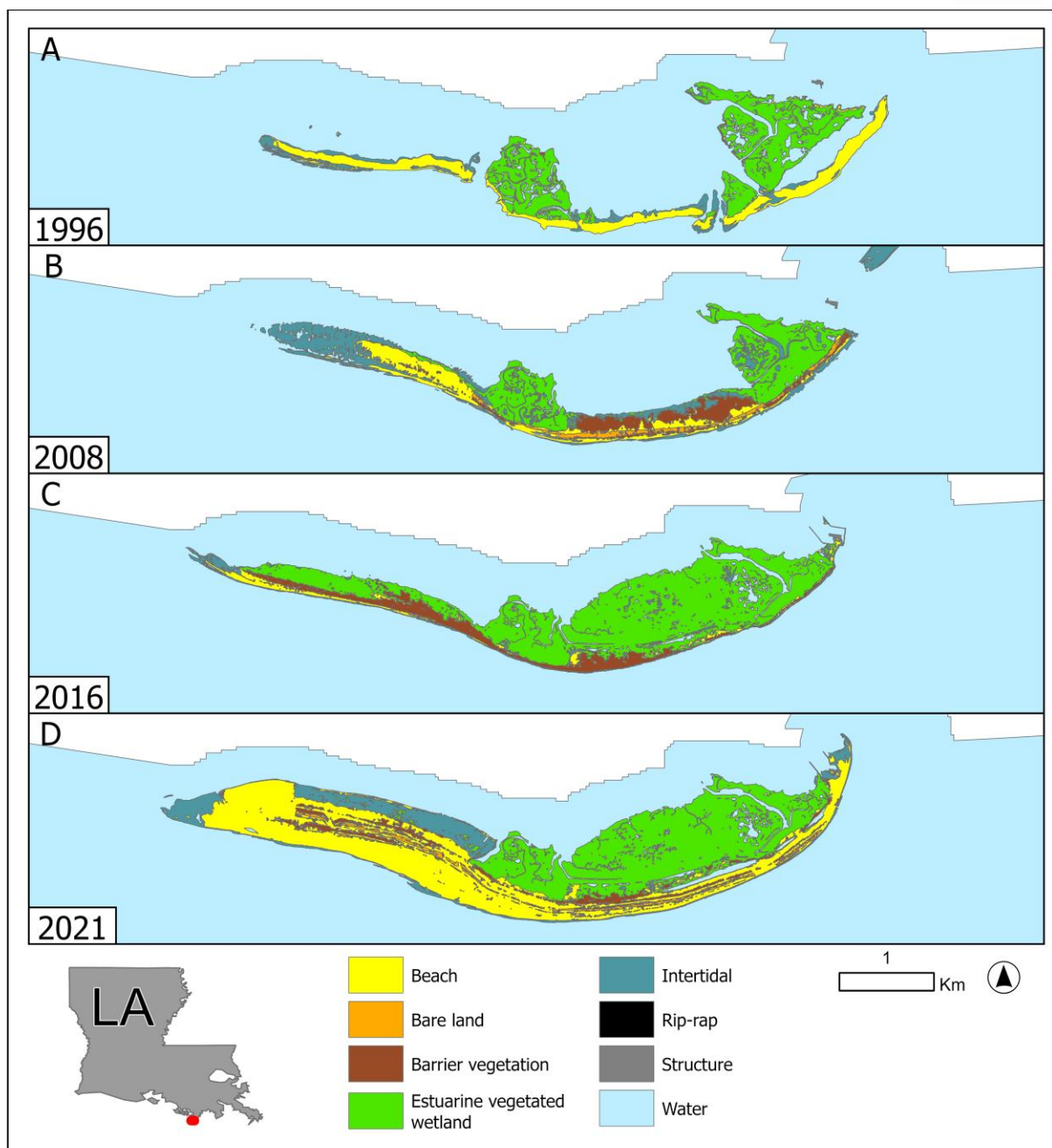


Figure 25. Whiskey Island habitat maps for 1996 (A), 2008 (B), 2016 (C), and 2021 (D). The habitat classes shown are from the Louisiana Coastal Protection and Restoration Authority's Barrier Island Comprehensive Monitoring Program's general habitat classes. The source for maps for A and B is Fearnley et al. (2024), the source for map C is Enwright et al. (2018), and the source for map D is Thompson et al. (2025).

The BICM general habitat maps for the Northern Chandeleur Islands from 1998 to 2021 are shown in Figure 26. Similar to Whiskey Island, the Northern Chandeleur Islands track the results from the Tier 1 screening-level analyses with a decrease in subaerial land and vegetation through most of the early time series and an increase in both metrics between 2005 and 2015. The loss of estuarine vegetated wetland to

intertidal is noticeable when comparing the 1998 and 2016 map for the central portion of the Northern Chandeleur Islands.

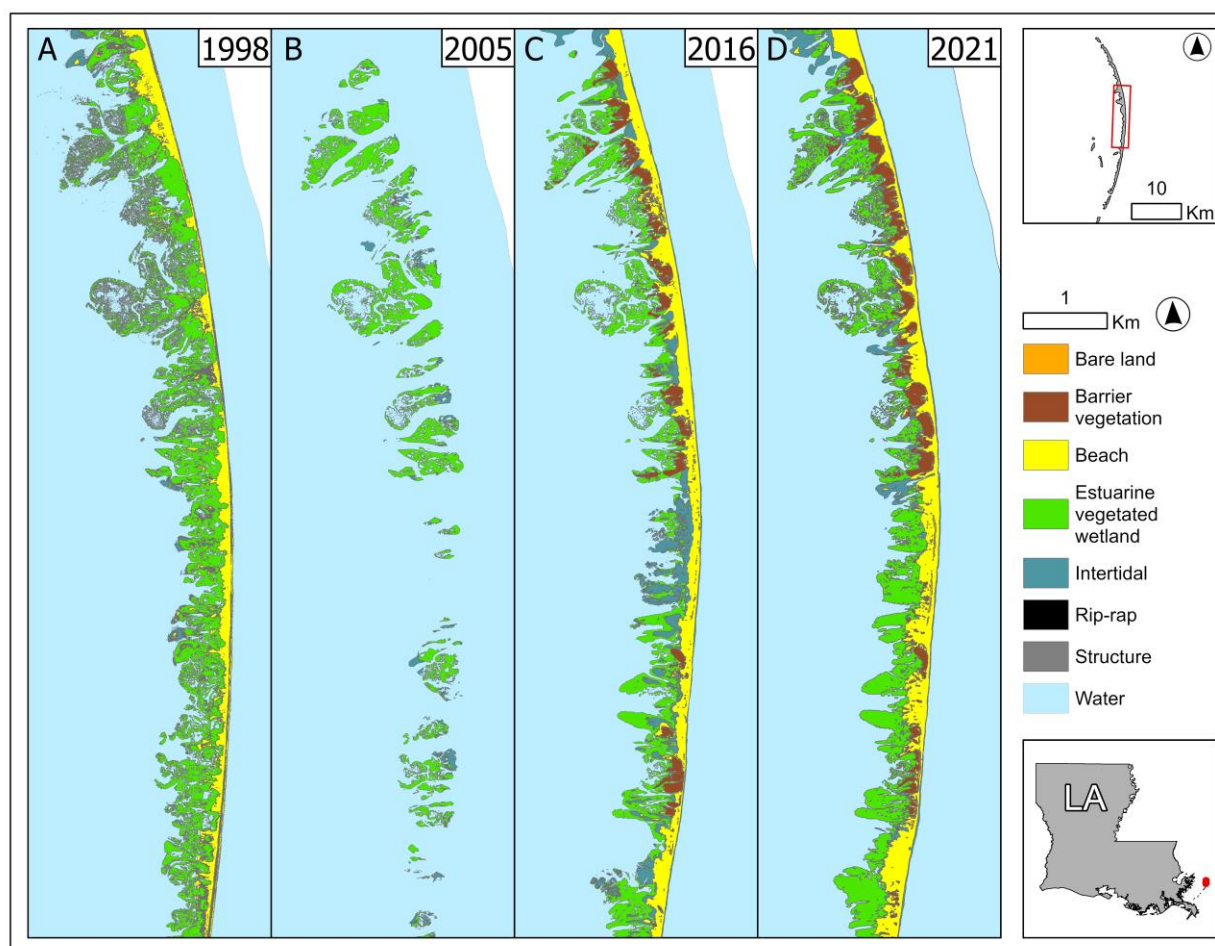


Figure 26. Northern Chandeleur Islands habitat maps for 1998 (A), 2005 (B), 2016 (C), and 2021 (D). The habitat classes shown are from the Louisiana Coastal Protection and Restoration Authority's Barrier Island Comprehensive Monitoring Program's general habitat classes. The source for maps for A–B is Fearnley et al. (2024), the source for map C is Enwright et al. (2020), and the source for map D is Landry et al. (2026b).

High Tide Flooding Analysis

The relative coverage of areas below/above the NOAA's HTF thresholds are shown by reach in Figure 27. These inundation estimates provide a snapshot of resistance in greater detail than the Tier 1 SVAR metrics because they differential regions of elevation in greater detail (i.e., higher areas are less frequently exposed to extreme water levels). Prior to the restoration in 2018, for example, Whiskey Island had limited resistance with a concentration of higher areas (above moderate HTF) limited to the central portion of the island (Figure 28). Four reaches—Trinity-East Island, Grand Isle, Shell Island, and Breton Island—have high coverage of area that is above the moderate HTF (either of the green shades in Figure 27). The restoration of Trinity-East Island and Breton Island led to over 40% of these islands being above the moderate HTF. Trinity-East Island, Grand Isle, and Breton Island have about 10% of their area above

the major HTF. Moving forward, researchers can use this methodology to develop inundation maps (similar to the one shown for Whiskey Island in Figure 28) over time to provide useful insights into the resilience and evolution of a coastal barrier.

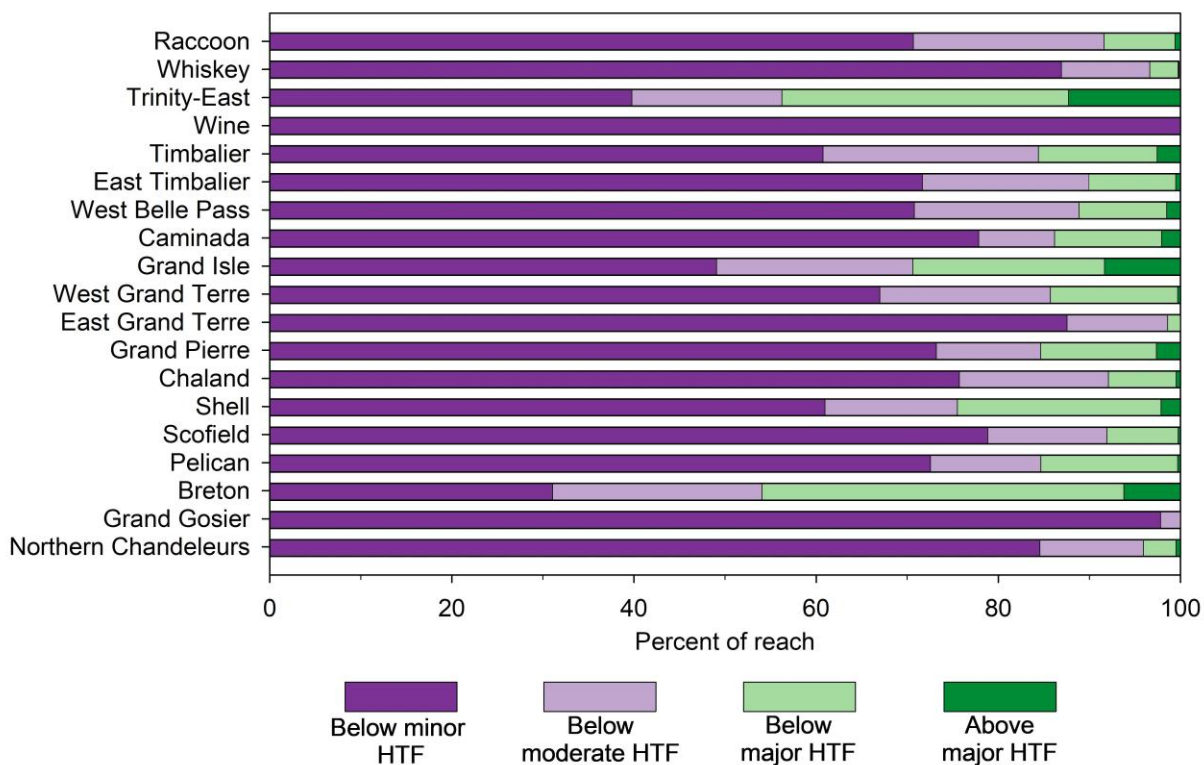


Figure 27. Relative coverage of high tide flooding (HTF) thresholds by reach. Analysis was conducted using lidar data for 2015 for Raccoon Island to West Belle Pass, 2021 for Caminada Headland to Pelican Island, and 2022 for Breton Island to Northern Chandeleur Islands. Refer to Figure 1 for the location of each barrier.

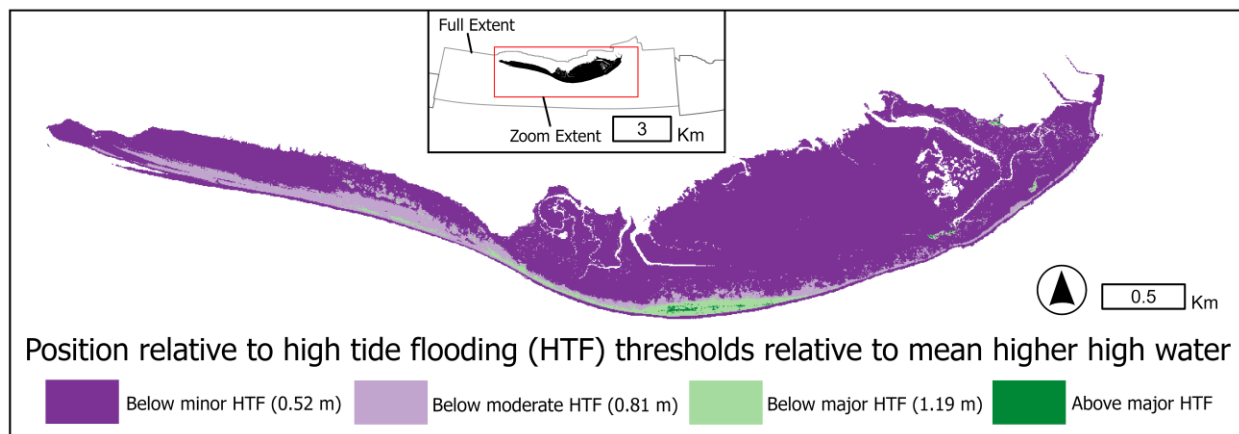


Figure 28. Whiskey Island high tide flooding map using lidar collected in 2015. Areas that are below 0 m relative to the North American Vertical Datum of 1988 are omitted from the map.

Hypsometric Curve Analysis

Hypsometric curve analysis can also provide more detailed information about the distribution of elevation (and by extension resistance, as well information about habitat) for each barrier, in this case allowing the user to consider elevation thresholds of interest to them. Whiskey Island is relatively small in total area compared to the Chandeleurs region (Figure 29A), and as a result the distribution of total area across different elevation ranges is also smaller. Normalizing these curves by the total island area shows that the elevation profile at Whiskey Island is higher, with a large portion of the island falling at slightly higher elevations (~0.25–0.75 m) compared to the Chandeleurs region where a large area of the island is just above MHHW (Figure 29B). Combined with the Tier 1 screening metrics and other Tier 2 analyses, a more complete picture of the islands emerges. Although the Northern Chandeleur Islands recovered somewhat post-Katrina, they have never fully recovered their subaerial area and vegetation, and the remaining area is relatively low-lying and vulnerable to inundation. Conversely, restoration at Whiskey Island has increased area as well as elevation, increasing both overall resilience and resistance to overwash and inundation during storm events.

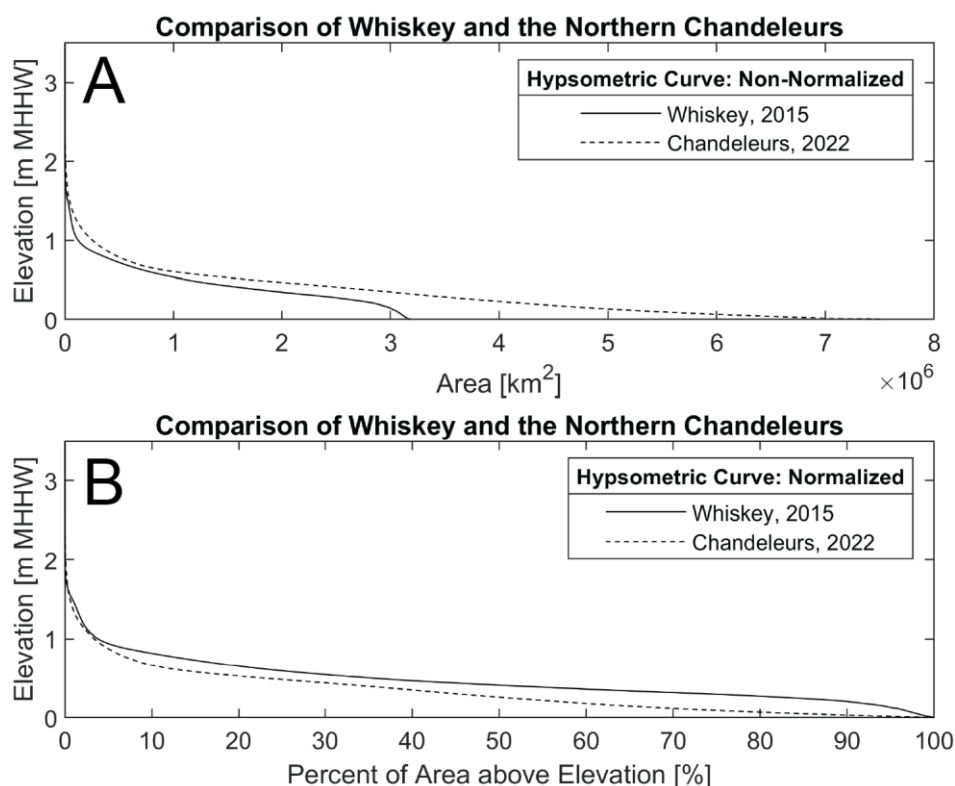


Figure 29. Hypsometric curve for Whiskey Island (solid line) and the Northern Chandeleur Islands (dashed line) showing elevation relative to mean higher high water (MHHW) for elevation data from 2015 and 2022, respectively (A). Also shown is the hypsometric curve for each island normalized by the total area (B). Refer to Figure 1 for the location of each barrier.

Hypsometric curve analysis can also be used to assess and compare barriers across the Louisiana coast (Figure 30). The barriers comprising the Early Lafourche Delta region are all small in area, with the smallest being Wine Island that was a low-lying, intermittently submerged shoal as of 2015. These islands varied in their elevation distribution in 2015: for example, Trinity-East Island had a relatively large area within the 0.5–2 m relative to MHHW elevation range compared to Whiskey Island, although the islands

had similar areas of lower lying elevation. Raccoon Island exhibits a very steep transition from higher elevations to below MHHW, with the island shape likely influenced by the presence of breakwaters.

Within the Late Lafourche Delta region, Grand Isle stands out as having the largest amount of area at higher elevations, reflecting an artificial dune that is maintained there, while Caminada Headland stands out for the large area of lower-lying elevation associated with its extensive back barrier marsh. Except for Chaland Headland, the barriers that comprise the Modern Delta region have very similar hypsometric curves, with Chaland Headland having a greater area of lower-lying elevation also associated with its back barrier wetland areas. This underscores how Louisiana's barriers are different from barrier islands along the U.S. Atlantic coast that have more variable and distinct topography (Monge & Stallins, 2016b). The three islands in the Chandeleurs region vary considerably from each other. Grand Gosier/Curlew Islands was an intermittent shoal as of 2022, while the Northern Chandeleur Islands have greater area ranging from marsh up to small berm features. Breton Island—which was restored just prior to the lidar survey that the hypsometric curve is based on—has a distinct hypsometric curve shape characterized by a relatively steep drop off in area with decreasing elevation (i.e., limited extent of very low-lying areas). This shape may result from the placed sediment not yet having time to distribute from the placed restoration template.

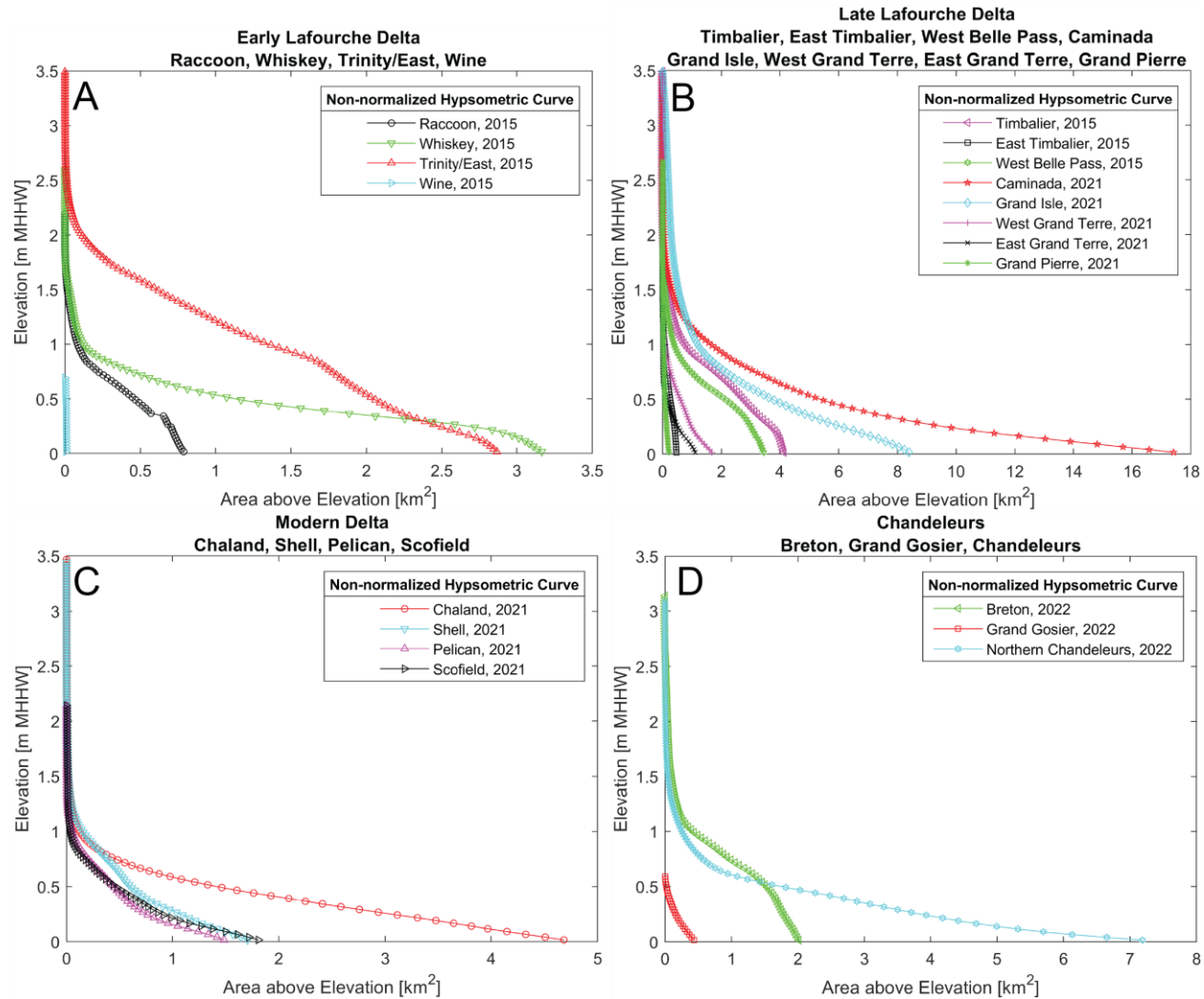


Figure 30. Hypsometric curves showing the distribution of elevation in mean higher high water (MHHW) for Louisiana coastal barriers in the Early Lafourche Delta (A), Late Lafourche Delta (B), Modern Delta (C), and Chandealeurs (D) regions of the Louisiana coast. Refer to Figure 1 for the location of each barrier.

Normalizing the hypsometric curve for each island by its total area allows the elevation distribution to be more readily compared across islands of disparate size (Figure 31). The barriers of the Modern Delta region exhibit a very similar distribution to one another, characterized by relatively little area at elevations greater than 1 m with a steady and smooth increase in area as elevations drop below that threshold; the exception is Shell Island, with a slightly higher percentage of elevations in this range. A similar pattern is also observed at the Northern Chandeleur Islands, West Grand Terre, and Caminada Headland, although threshold elevations where the increase is seen and the relative distribution across elevation varies. Conversely, the barriers that were recently restored prior to their lidar surveys (e.g., Breton Island, Whiskey Island, West Grand Terre) tend to have both greater area at somewhat higher elevations (greater resilience) and a sharper transition to areas with lower elevations. The barriers with relatively greater area at the lowest lying elevation (e.g. East Grand Terre, Northern Chandeleur Islands) may provide habitat

for, for instance, some beach-nesting bird species, but they also have the greatest area exposed to overwash, inundation, and associated erosion.

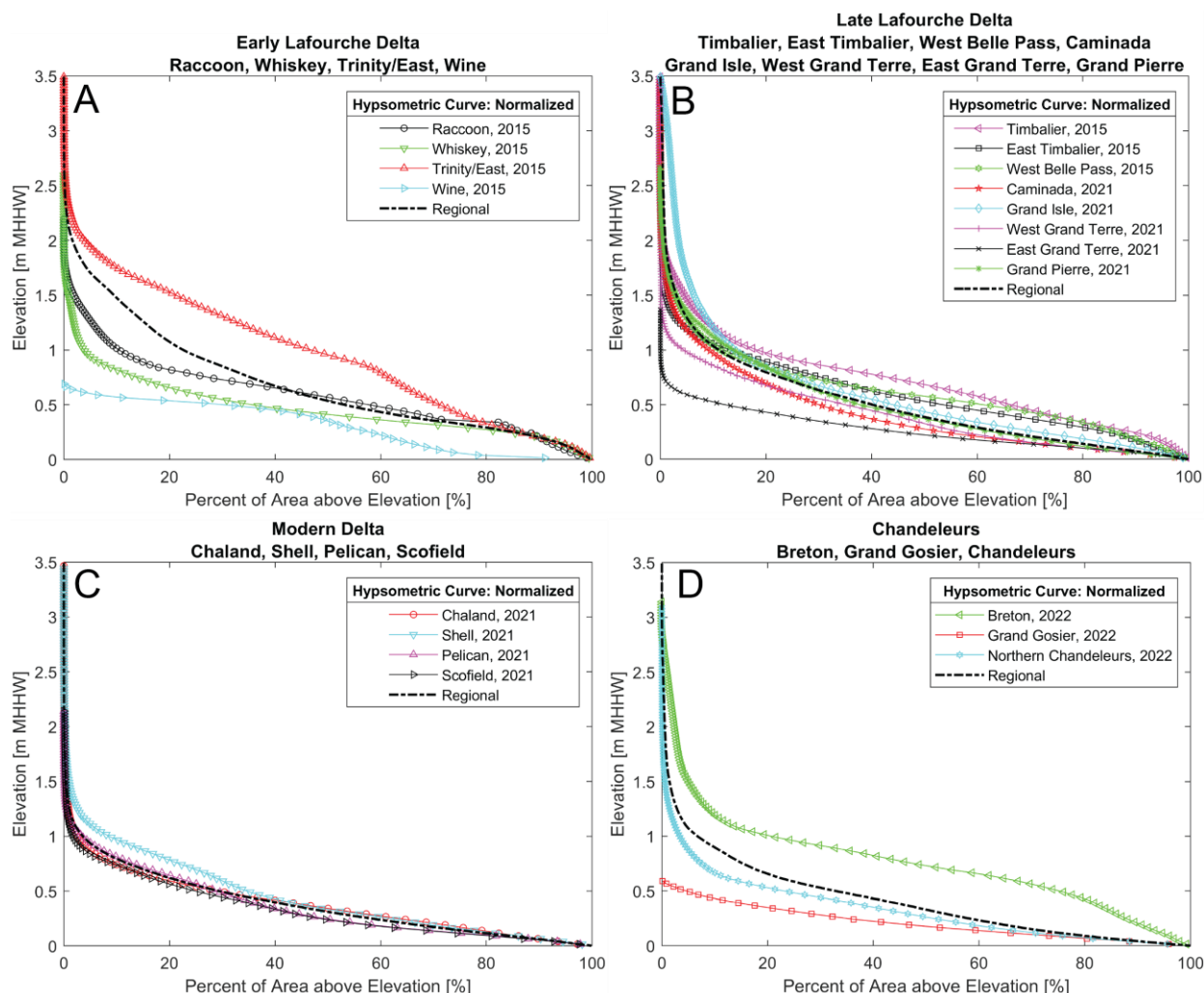


Figure 31. Hypsometric curves normalized by the total area for each coastal Louisiana barrier showing the distribution of elevation in mean higher high water (MHHW) for the Early Lafourche Delta (A), Late Lafourche Delta (B), Modern Delta (C), and Chandeleurs (D) regions of the Louisiana coast. Regional curves are shown as a benchmark and then compared to each other and a coastwide value in Figure 32. Refer to Figure 1 for the location of each barrier.

Lastly, the normalized regional hypsometric curves can also be compared to hypsometric curves calculated on a regional and coastwide basis (Figure 32). The Early Lafourche Delta region has the greatest percentage of area at the highest elevation, driven in large part by the relatively high elevations found at Trinity-East Island. The Late Lafourche Delta region has the next greatest percentage of area at relatively high elevation owing to this region including barriers that were recently restored prior to their elevation survey (Whiskey Island, West Grand Terre) as well as Grand Isle where an artificial dune is maintained. This region also has the distribution most closely approximately coastwide. Similarly, Breton Island—also restored just prior to its lidar survey—results in a relatively greater percentage of higher elevations for the Chandeleurs region than for the Modern Delta region. Although beyond the scope of

this study, hypsometric curves could be benchmarked to a lower threshold (e.g., below MHHW) to evaluate elevation distributions across intertidal and nearshore areas, assuming very low elevation and subaqueous data were available for analysis.

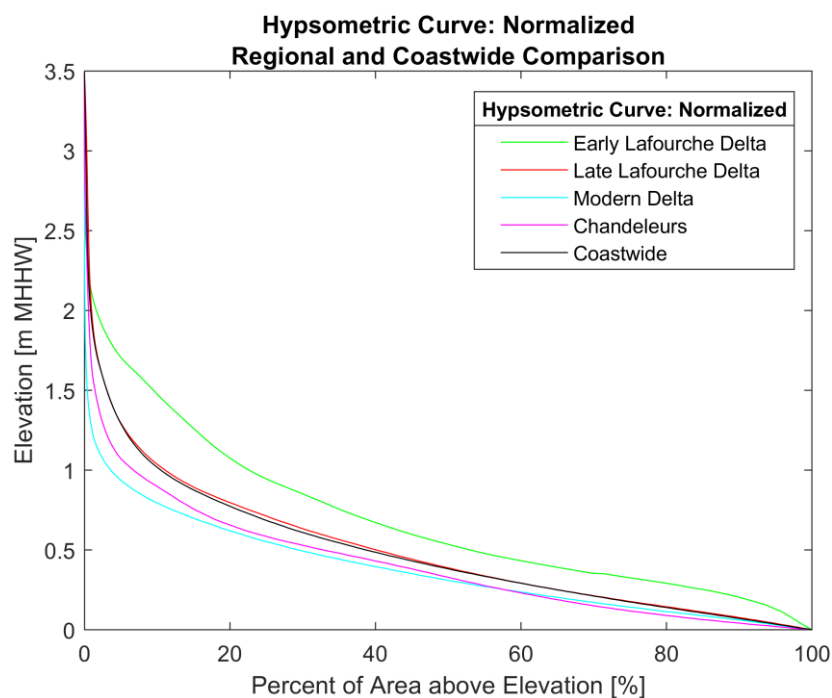


Figure 32. Hypsometric curves showing the distribution of elevation in mean higher high water (MHHW), calculated regionally and coastwide and then normalized by dividing by the total area. Shown for the Early Lafourche Delta (green), Late Lafourche Delta (red), Modern Delta (blue), and Chandeleurs (magenta) regions, along with coastwide (black). Refer to Figure 1 for the location of each region.

DISCUSSION

The metrics and analyses presented here provide a framework to support screening-level assessment of coastal barriers (Tier 1) as well as more in-depth information suited for specific management questions (Tier 2). This section includes a description of potential management use within Louisiana—including how these metrics can support developing and assessing Specific, Measurable, Achievable, Relevant, appropriate Timeline (SMART) objectives for barrier island and headland restoration—as well as opportunities for broader application.

MANAGEMENT INTERPRETATION OF FINDINGS: LOUISIANA

Evaluating restoration success is a primary goal of adaptively managing coastal barriers. This effort advances that objective and can specifically support the LA TIG MAM Strategy (LA TIG, 2021); its goal of reducing coastal land and habitat loss; and the documented need for an approach to assess and characterize restored barrier response to natural processes. The Tier 1 metrics provide a robust and intuitive framework for analyzing barriers, including how resilience and resistance evolve with storms and SLR. The magnitude and trajectory of these metrics after restoration can then be compared to pre-restoration trends to evaluate restoration impact. For example, restoration at Whiskey Island (Figure 23) temporarily reverses long-term trends of the island losing sediment and subaerial area, but the restoration is unlikely to be a permanent solution due to continued SLR and sediment loss.

Monitoring of the Tier 1 metrics can be used to benchmark the rate of change in the island post-restoration to assess when restoration may be needed in the future. The Tier 2 metrics, on the other hand, can be linked to more specific management goals as a way of assessing and tracking restoration success that may vary by project. For example, if a restoration project is specifically designed to increase nesting bird habitat associated with supratidal areas, HTF analysis and hypsometric curve assessment can be used to assess the trajectory (gain or loss) of land at elevations necessary to support this habitat.

This flexibility allows managers to assess barrier resilience and resistance based on their own definition, which may vary from those used as the basis for the Tier 1 screening metrics developed here (i.e., that resilience is a barrier's capacity to remain subaerial in the long-term and resistance is the capacity to resist change during storms). For example, a manager may prefer to define resistance and resilience based on the short- and long-term persistence of different habitat types or associated elevations, which can be assessed with the Tier 2 metrics. Higher-resolution habitat mapping can be used periodically in conjunction with those tools to determine whether other factors that define habitat (such as presence or absence of vegetation) are also in the desired ranges. Lastly, Tier 1 and Tier 2 metrics can be used together to maximize the efficiency and effectiveness of monitoring programs. Thresholds can be set for Tier 1 metrics that trigger additional, more focused (and potentially expensive) data collection and analysis required for Tier 2 metrics. For example, a loss or rate of loss in subaerial land and vegetation assessed via readily available satellite imagery could trigger a lidar survey for calculation of SVAR and/or Tier 2 analyses.

The analysis developed here can also be used in conjunction with other CPRA and Federal agency programs. The underlying datasets used for the analysis, including lidar and satellite imagery, are available and, in some cases, collected and used by the BICM program and other restoration monitoring

and adaptive management programs (e.g., Louisiana Outer Coast Restoration Project; NRDA Project ID: 35).⁵ The metrics developed here could be used to augment existing analyses of coastal barriers and/or, as noted above, support the BICM program in evaluating when and where to focus *in situ* data collected based on trends observed in Tier 1 analysis of readily available satellite imagery.

The metrics and analysis can also support the BISM program, developed within CPRA to determine where and when to restore barrier islands and headlands (Dalyander et al., 2021). The BISM program develops restoration schedules using the Barrier Island Restoration Tradeoff Analysis (BIRTA) toolkit, which uses reduced complexity models to project the evolution of the barriers with and without restoration. These schedules estimate optimized timelines of when, where, and how much sediment to place at different barriers. The inputs to the toolkit include barrier elevation, sediment fluxes, rates of SLR and subsidence, and other environmental parameters, all of which are uncertain and require user selection and/or calibration.

The assessments developed here can be used in support of high-level quality assessment and quality control (QAQC) by providing a benchmark of the historical evolution of the islands compared to a future without action simulation (i.e., are islands losing area within BIRTA at similar rates to those observed in Tier 1 screening metrics, and if not, are there reasons such as recent restoration that may explain the differences). In addition, the metrics can be used to evaluate if the coast has changed significantly enough to warrant BISM reassessing planned restoration schedules. For example, storms may impact the Louisiana coast after BIRTA simulations were used to select restoration schedules, leading to uncertainty as to whether resources need to be focused toward the impacted region of the coast. Tier 1 screening metrics can be used to evaluate if significant change occurred to islands during the storm necessitating additional BIRTA simulations, or to trigger the need for Tier 2 analysis to make that decision. Tier 1 satellite-based evaluation of island areas can also be used to manually adjust inputs to BIRTA ahead of new lidar surveys or other elevation data being collected.

Lastly, comparison of resilience and resistance metrics over time—both historical changes and updating in the future as restoration, storms and relative SLR change the coast—provide a mechanism for evaluating the impact and success of restoration efforts. These impacts can be summarized on a regional and coastwide basis to assess and adaptively manage the BISM program. For example, the Tier 1 subaerial land area resilience metric can be compared over time — as restoration projects are put on the landscape — to the metric value prior to restoration of a Louisiana barrier or other historical benchmarks. Similar evaluation can be done with each of the Tier 1 and Tier 2 metrics. This analysis provides a direct mechanism to quantify the value of restoration efforts, including those conducted under the BISM program. In addition, comparison of post-restoration metrics over time—which can be compared for different restoration activities of varying scale or other parameters, such as mean grain size used—can be used to inform successful restoration in the future by allowing determination of what factors in restoration

⁵ <https://www.gulfspillrestoration.noaa.gov/project?id=35>

planning or implementation provide the strongest likelihood of increasing barrier resilience long-term and/or short-term resistance to storms.

BROADER APPLICATIONS

Although the research team developed the Tier 1 and Tier 2 metrics for Louisiana coastal barriers—with specific consideration of management concerns specific to this region, such as barriers becoming subaqueous with SLR and storms—the framework is readily transferable to other locations and management applications. Tier 1 resiliency metrics rely exclusively on publicly available satellite imagery and can therefore be readily applied to any barrier island worldwide. The normalized resiliency metrics allow disparate islands to be compared to each other. For example, entities researching the Gulf or managing regionally focused restoration programs can assess the characteristics and trends of different barriers to determine similarities and differences in responses to natural processes and/or to decide critical areas most in need of focused restoration. Similarly, Tier 1 resistance metrics and Tier 2 analyses rely on data such as lidar that have been collected for decades at locations around the United States’ coastline. Regional and national comparison of the metrics developed here can be used to, for example, understand the relative resilience of Gulf versus Atlantic barriers, or to provide a more comprehensive assessment of habitat availability for coastal species across their ranges.

LESSONS LEARNED

The Tier 1 and Tier 2 metrics developed by the research team provide efficient and effective ways to use remotely sensed data to understand and track how coastal barrier resilience and resistance has changed over time. Despite successfully addressing the overall project objectives, there were lessons learned by the research team that can inform further development of these or other metrics used to inform coastal barrier resilience and resistance. Besides the need for periodic updates to these metrics and integration of these metrics into existing programs and projects, potential future enhancements to the framework presented here include: (1) refining and expanding the methodology to accommodate the increased availability of higher resolution satellite imagery; (2) integrating elevation metrics and vegetation metrics; (3) increasing analyses and predictions of geomorphic state and exposure to abiotic stressors with vegetation condition tracking; (4) expanding evaluation of linkages between drivers of coastal barrier change and the ecogeomorphic response; (5) testing, analyzing, and integrating assessment of additional data characterizing sediment flux trends and/or the condition of the subaqueous portion of the barriers (e.g., exploring SVAR or hypsometric curves for thresholds below 0 m MHHW, when data allows); (6) exploring ways to utilize restoration-project specific data (i.e., lidar, topographic surveys, habitat maps, vegetation surveys) that may only be available for certain reaches at the reach-scale or transect-level; (7) modification of existing reaches, as needed (e.g., subdividing a specific reach); and (8) exploring metrics that capture different aspects or perspectives on resilience or resistance, such as integration of rate-of-change information with coastal state.

The research team utilized publicly available existing data for Tier 1 metrics (i.e., subaerial land and vegetation coverage), with the benefit being that managers or researchers could update the Louisiana analysis and/or apply this approach to other regions with limited cost and time considerations. However, a downside of this approach is that it may lead to delays in metric updates due to product availability and latency (e.g., lidar taken at infrequent and inconsistent intervals) and/or consistency issues if an input data source is discontinued or the product methodology is changed (e.g., changes in LCMAP processing).

Quality control presents another issue with utilizing existing products (i.e., C-CAP maps); in this case, the research team corrected commission error for cropland and developed areas in LCMAP products.

Consequently, the research team did not produce vegetation coverage estimates prior to 1996.

Consistency across products was another issue noted by the research team, specifically that subaerial land area occasionally may be lower than the vegetated area for some barriers and years (this occurred for ~8% of the observations from 1996–2021). This issue is reasonable, particularly for barriers where vegetated area comprises a large percent of total area and is likely a result of the different methodologies and time periods included in the underlying input product sources (i.e., the product for subaerial land uses all available imagery, whereas the methodology product used for vegetated area methodology aims to predict vegetation cover for July 1 of a given year).

These inconsistencies do not hinder the overall interpretation of results given the focus on overall trends and because metrics are interpreted individually rather than combined; however, this issue could be overcome by developing an integrated approach that utilizes a consistent methodology for extracting subaerial land and vegetation cover. Future efforts could explore the use of the satellite-based maps of vegetation and subaerial land from a NRDA project titled “Quantifying Changes in Wetland Area and

Habitat Types,” (NRDA Project ID: 307)⁶ that was ongoing at the time of this project. Additionally, the methodology used for that effort could be explored for developing products with new data.

Another common challenge when assessing changes in coastal environments is the tradeoffs between spatial resolution/coverage and temporal resolution/coverage, including for remote sensing data (Enwright et al., 2025). The research team utilized Landsat satellite imagery, which has a 30-m spatial resolution, because data availability enabled assessing trends going as far back as the mid-1980s (i.e., subaerial land metric was developed back to 1984). Currently, abundant coverage of satellite data with a 10-m spatial resolution and near weekly temporal resolution is available via the European Space Agency’s Sentinel-2 satellites (*ESA - Sentinel-2*, n.d.) and the availability of these data are expected to increase in the future with the expected launch of Landsat Next (NASA & USGS, 2024). To expand utility of the analysis in future efforts and maximize benefits across spatial and temporal resolution and coverage, a custom approach could be developed for utilizing all available moderate spatial resolution satellite imagery (i.e., 30-m and 10-m imagery). That development could be further enhanced by developing benchmarks for moderate spatial resolution screening metrics (e.g., abrupt change in the metric) that trigger the metric calculation and assessment with high spatial resolution commercial satellite imagery, similar to how current Tier 1 metrics can trigger Tier 2 assessment. The incorporation of metrics at variable resolutions also supports exploring and enhancing the utility of data at varying spatial resolutions by evaluating and comparing metrics from concurrent or near concurrent imagery with different spatial resolutions, as well as with in situ data collection.

The Tier 2 inundation and hypsometry metrics developed by the research team highlight elevation variability within a single reach and across reaches. These metrics can, however, also provide robust information on resilience and resistance changes when assessed with elevation data captured over time. At present, lidar acquisition occurs at irregular intervals through programs like the U.S. Army Corps of Engineers National Coastal Mapping Program. In addition, lidar data collection occasionally excludes some portions of islands, such as the back barrier. The utility of these data for barrier state evaluation would be enhanced if future data collection efforts span the entire barrier and capture the entire coast at the same snapshot in time, which the TAG has mentioned is something that BICM is working toward implementing. New lidar data collected using these criteria could be combined with similarly robust lidar acquired after the mid-2000s (to avoid issues elevation bias due to vegetation in early lidar datasets) as part of assessing time-varying inundation.

Where feasible, targeted lidar acquisition via uncrewed aerial surveys may help fill information gaps by reducing the time between lidar acquisitions (Pricope et al., 2022). The metrics produced by the research team in this effort, which only include elevation, could similarly be expanded to include vegetation coverage if more frequent and widespread input data were available. Specifically, inundation maps and hypsometric curves could be developed that differentiate non-vegetated and vegetated areas, allowing increased interpretation of results. An island that has a high proportion of low-lying area (i.e., area below

⁶ <https://www.gulfspillrestoration.noaa.gov/project?id=307>

the minor HTF) that is vegetated (e.g., Caminada Headland), for example, is typically more resilient than an island with abundant low-lying land that lacks vegetation (e.g., Grand Gossier) (Zinnert et al., 2017). Coastal barrier vegetation condition can also be investigated more extensively through approaches that assess phenology (Vrieling et al., 2018) and detect breaks in predicted patterns (Kennedy et al., 2010), providing automated and threshold-based approaches for assessing conditions that can provide decision makers with an early warning sign to possible changes in resilience and resistance.

Another assessment applied by USGS at multiple locations around the Atlantic and Gulf coast is the extraction of benchmarks of beach and dune morphology (e.g., dune toe, dune crest, etc.) from elevation data (Doran et al., 2026). These data are combined with still water and wave observations to predict total water level and assess Sallenger storm impact regimes (i.e., swash, collision, overwash, inundation) (Sallenger Jr., 2000) using machine learning approaches (Buckley et al., 2024) or the relationship between total water level and beach/dune morphology (Enwright, Dalyander, et al., 2023). Doran et al. (2024) have produced beach/dune morphology data for the Louisiana barriers for some of the available lidar acquisitions. In the future, these data and assessments could be incorporated with the framework developed here in several ways. For example, comparisons of historical Tier 1 metrics with beach/dune morphology assessments at the same time periods could be used to assess correlations and relationships across the two approaches. In addition, triggers could be developed that use the Tier 1 screening assessment to inform when beach/dune morphology metrics and corresponding assessments of overwash risk become inaccurate due to changes in the landscape, such as with the passage of an extreme storm.

Lastly, the metrics developed here focus on the subaerial portions of the barriers. The overall condition of the barriers is also driven by the amount of sediment stored within the subaqueous platform, and the long-term resilience of each barrier will be a function of the net sediment flux (i.e., is the barrier gaining or losing sediment, and at what rate). Additional information about barrier condition, particularly long-term resilience, could be provided through characterizing the net sediment flux of each barrier and integrating that information with the metrics developed here. For example, the relative flux to volume ratio of a barrier could be calculated and benchmarked against the resilience metrics developed here. In Louisiana, this flux information can be provided by the Operational Sediment Budget, which characterizes sediment flux along the coastal system (Applied Coastal Engineering, Inc., 2020).

In summary, the refinement and enhancement of the current Tier 1 and Tier 2 metrics — along with inclusion of beach/dune morphology, total water level data, and vegetation condition — could provide decision makers with a more nuanced understanding of the relationship between drivers of coastal barrier change and ecologic and geomorphic response. Collectively, these enhancements would further advance the LA TIG MAM Strategy related to coastal barriers and inform when, where, and what management decisions are most effective in enhancing the barrier resistance and resilience.

CONCLUSIONS

This project focused on the initial development of metrics and analyses that can be used to characterize the resilience, resistance, and condition of coastal Louisiana barriers using readily available data sources. The analysis is comprised of a two-tiered framework including Tier 1 Screening Metrics, designed to provide a high-level snapshot of coastal condition, and Tier 2 Analysis Metrics, designed to support more specific management applications (e.g., advancing restoration targets for different habitat types). The Tier 1 metrics include resilience metrics characterizing the subaerial land and vegetated area of coastal barriers calculated from existing products created from moderate-resolution satellite imagery. Tier 1 metrics also include the SVAR, calculated from lidar data, which can be benchmarked against water level recurrence intervals as a metric of resistance. An additional Tier 1 metric converts SVAR to the water level percentile corresponding to that elevation, providing a single resistance metric that explicitly incorporates water level information. Tier 2 analyses include high-resolution habitat mapping, which provides a more comprehensive assessment of the diversity of habitats on a barrier, as well as HTF inundation and hypsometric curve analysis for a more focused analysis of elevation and inundation potential of barriers.

Collectively, this analysis framework can be used to both evaluate the state and trajectory of natural coastal barriers as well as to benchmark restoration impact. Lastly, the restoration team identified lessons learned and key areas of potential future work that would allow for more extensive exploration of barrier state and resilience/resistance metrics, including alternate definitions than those used here depending on management need and interest; methods for integrating and comparing across the Tier 1 and Tier 2 metrics developed here or others derived the same or other data sources; and application of these analyses to more comprehensively assess barrier response to drivers, such as storms, SLR, and restoration.

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APPENDICES

APPENDIX A. OTHER RELATED METHODS

As part of the background literature review, the research team evaluated existing methods for assessing the resilience and resistance of coastal barriers. These approaches may be useful to coastal managers with different needs, although they were not incorporated into the framework for the reasons described below.

A.1 USACE COASTAL ENGINEERING RESILIENCE INDEX

The first methodology the research team considered was the Coastal Engineering Resilience Index (CERI), which was developed by the U.S. Army Corps of Engineers Joint Airborne LiDAR Bathymetry Technical Center for Expertise (USACE JALBTCX) (Coleman, 2023; Dong et al., 2018; Spurgeon, 2023). CERI uses parameters of a coastline, extracted from transects, to quantitatively define engineering resilience. An Esri based toolbox is provided for feature extraction and metric calculation. The beach profile features needed to calculate CERI are protective elevation (PE), protective width (PW), dune elevation (DE), and beach slope (β). The definitions of each are shown in Figure A-1. The index also uses the frontal dune (FD) width, defined as the distance from the dune toe to the back trough. Additional parameters related to storm surge (maximum storm induced shoreline recession, maximum storm surge, tidal level) and wave run-up (wave run-up height, dune crest freeboard above storm water level) are also part of the index (Ostojic et al., 2023). The Dune Feature Extraction Toolbox handles the CERI workflow from creating transects to extracting profiles and features to calculating the index. The toolbox and CERI have been successfully used at Gulf Coast beaches in Mississippi and was still in active development as of 2024.

For this study, the research team tested using the CERI tool through application to Timbalier Island using transects from the Barrier Island Comprehensive Monitoring (BICM) program. The results for feature extraction were mixed. For profiles that are closer to the shape of an engineered profile, built with a protective dune, the features extract by the tool are reasonable (Figure A-2). On profiles without a distinctive dune, the tool struggled to extract meaningful features (Figure A-3). Because the profile shape of an island that is allowed to evolve naturally is much more variable than one that is engineered to provide infrastructure protection, the CERI index is less successful (i.e., key features are not correctly identified) and the results are less meaningful.

Several other aspects of the Dune Feature Extraction Toolbox and CERI made it challenging to apply to Louisiana barriers for this study. The tool expects a landward limit of the transects, such as at a road backing an engineered beach profile. The coastal barriers in this study largely do not have infrastructure such as roads to provide a consistent, meaningful landward limit. Using the tool with digital elevation model (DEM) resolutions coarser than 1 m can also be challenging for feature extraction because of the smoothing required; coarser DEMs that are smoothed over a minimum of 3 points may result in poorly resolved profile features. Historical elevation data is, in some cases, at coarser resolution than 1 m. Finally, as noted above, this tool was developed for engineered profiles that are designed and maintained with a protective dune and distinctive dune crests.

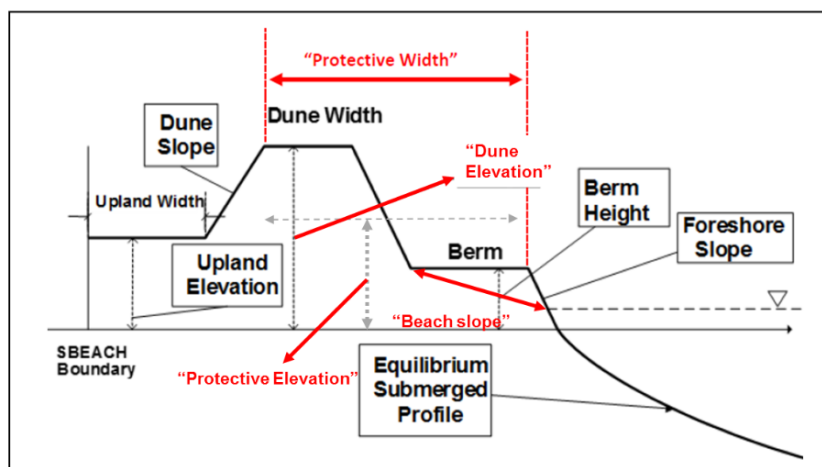


Figure A-1. Coastal Engineering Resilience Index (CERI) feature definitions as shown in (Dong et al., 2018).

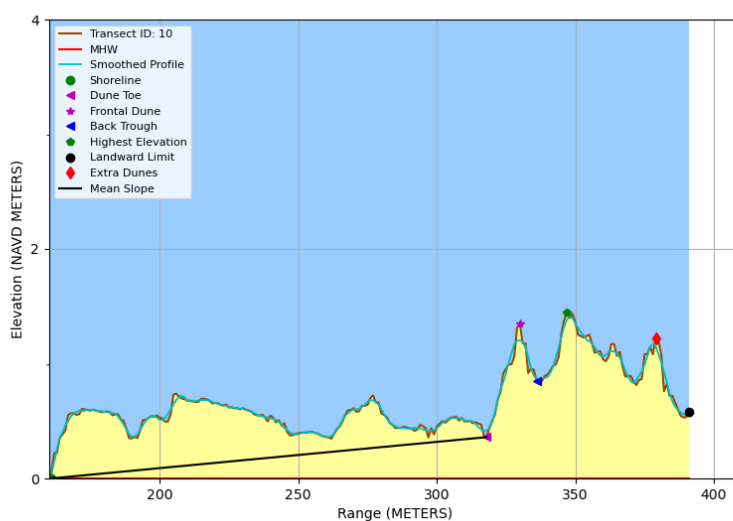


Figure A-2. Example of the profile feature extraction for Timbalier Island where the Dune Feature Extraction Toolset was able to identify key features.

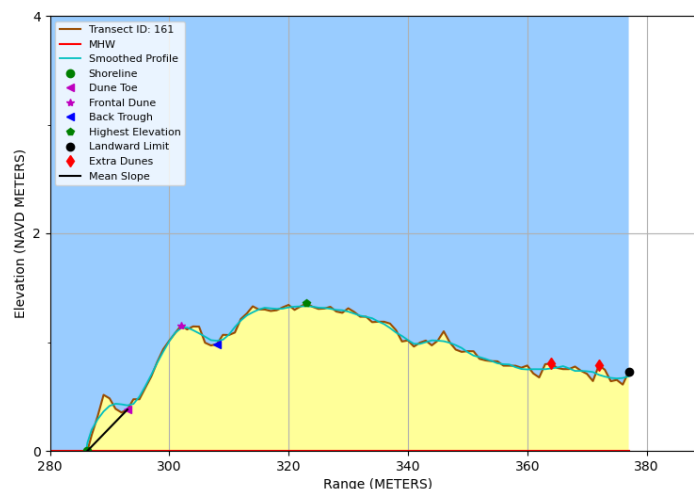


Figure A-3. Example of the profile feature extraction for Timbalier Island where the Dune Feature Extraction Toolset worked poorly in identifying key features.

A.2 USGS COASTAL HAZARD INDICATORS AND TOOLS

The U.S. Geological Survey (USGS) has developed several tools for assessing the vulnerability of U.S. coastlines, both as indicators and for real time forecasting, which can be found on an online portal (<https://marine.usgs.gov/coastalchangehazardsportal/>). The tools most relevant to this study and their relationship to the coastal barrier resilience and resistance framework developed here include:

- **Storm Scenarios:** Evaluation of the likelihood of erosion, overwash, and inundation during pre-developed storm scenarios. This assessment can be useful to coastal managers evaluating potential impacts of specific storms, as opposed to the overall resistance metric developed for this study.
- **Shoreline Change Rates:** Short- and long-term erosion or accretion of shorelines. This evaluation can provide information on land loss, particularly for coastal barriers with fixed infrastructure. However, it does not provide an assessment of the overall barrier condition (the focus of the current study), which is particularly relevant for undeveloped barriers that may transgress while retaining their overall form.
- **Coastal Response Likelihoods:** This assessment evaluates whether coasts are likely to respond in a dynamic or static fashion to sea-level rise and relies on probabilistic modeling of the landscape. This assessment could be useful to coastal managers interested in long-term change, but is not yet available for the Louisiana coast, and does not provide a snapshot of resilience and resistance.
- **Coastal Vulnerability Index (CVI):** The CVI provides an assessment of the relative susceptibility of the coast to sea-level rise based on geomorphology, coastal slope, tide range, wave height, relative sea-level rise, and shoreline change. The tool is designed and applied nation-wide; it therefore highlights that coastal Louisiana is highly vulnerable, but does not inform relative resilience of coastal barriers within the state (Figure A-4).

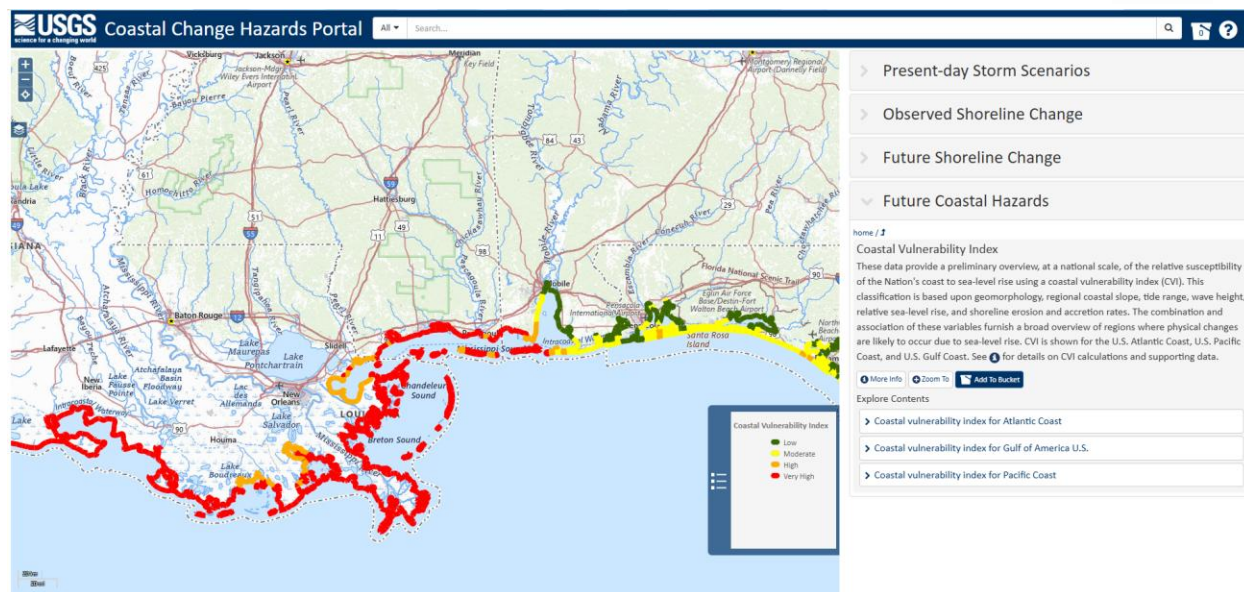


Figure A-4. Screen shot of the Coastal Vulnerability Index for Louisiana.

As noted in Lessons Learned, there are opportunities for incorporation and leveraging of these tools in future work to advance and utilize the barrier resilience and resistance framework developed in this study.

APPENDIX B. TECHNICAL ADVISORY GROUP

A key component of this project was coordination with a Technical Advisory Group (TAG) comprised of subject matter experts and stakeholders engaged in management of Louisiana's barriers and associated resources. The TAG was assembled to provide input on the project and to ensure the outcomes help advance the Monitoring and Adaptive Management goals of the Louisiana Trustee Implementation Group (LA TIG) that supported the project. Participants invited to the TAG include representatives of the agencies that make up LA TIG, including the Louisiana Coastal Protection and Restoration Authority (CPRA), U.S. Fish and Wildlife Service (USFWS); U.S. Geological Survey (USGS); National Oceanic and Atmospheric Administration (NOAA); U.S. Environmental Protection Agency (EPA); and U.S. Department of Agriculture (USDA) (Table B-1).

Table B-1. Composition of the Technical Advisory Group (TAG). Several TAG members left their agencies or otherwise became unavailable during the course of the study, and in some cases were replaced with other representatives.

Agency	Representative(s)
Coastal Protection and Restoration Authority	Glen Curole Michelle Felterman Syed Khalil Darin Lee Matthew Vincent
Department of the Interior – U.S. Fish and Wildlife Service	Dianne Ingram Patty Kelly
Department of the Interior – U.S. Geological Service	Sarai Piazza Dave Hewitt Richard Rebich Greg Steyer
National Oceanic and Atmospheric Administration	David Reeves Courtney Schupp
Environmental Protection Agency	Philip Lee
U.S. Department of Agriculture	Benjamin Battle

The following meetings were held with the TAG:

1. May 23, 2023. This kickoff meeting introduced the TAG members to the goals and objectives of the project, as well as the project team. The team also presented, and elicited feedback on, a conceptual model of coastal barrier resilience and resistance; data sources that could support the analysis; synergistic projects and activities; and criteria for selecting pilot sites, including data availability and sites that represent and capture the variability of the Louisiana coast. The TAG were also asked to provide information on data and synergistic activities via email after the meeting. Criteria identified for pilot site selection included:
 - a. Availability of relevant data on temporal and spatial scales that can be used to assess the resilience and resistance;

- b. Sites that vary from each other in terms of the intensity of restoration activities (i.e., one site with a longer history of sediment placement and restoration vs. another that is in a relative unaltered state);
 - c. Sites that together as a set are as representative of coastal Louisiana as possible; and
 - d. Avoiding sites where location-specific factors outside the scope of this study are likely to dominant coastal barrier condition and state (e.g., gray infrastructure such as jetties, breakwaters, etc.).
2. July 27, 2023. This meeting was a working session to discuss a preliminary conceptual framework for assessing coastal barrier resilience and resistance (Figure B-1), data sources, and potential pilot site locations. Based in part on feedback received, the team subsequently shifted toward a more continuum-based approach to characterizing Louisiana barrier condition. The TAG also suggested potential locations for the pilot, including:
- a. Whiskey Island: This island has a long history of restoration of varying intensity and is a wide island relative to others in Louisiana, which is expected to influence its resilience to drivers such as storms.
 - b. Timbalier Island: This site is an area of sediment deposition in contrast to other areas of Louisiana that are sediment starved, a factor that is expected to alter its long-term resilience.
 - c. Caminada Headland: This area of the coast is undergoing shoreline straightening, erosion, and coastal change, contrasting it with areas such as Timbalier Island that are depositional.
 - d. Chaland Headland and/or Shell Island, Pelican Island, or Scofield Island: These sites have undergone significantly less restoration over time than other regions of the Louisiana coast, therefore their characteristics and change over time is likely more indicative of natural processes.
 - e. Northern Chandeleur Islands and Breton Island: Restoration at these sites has been very limited and is confined to emergency sand berms (Northern Chandeleur Islands) and a recent ecosystem restoration (sediment placement and dune creation) at Breton Island. These islands have also been relatively narrow and frequently overwashed in recent years, providing an opportunity to look at island characteristics in response to storms.

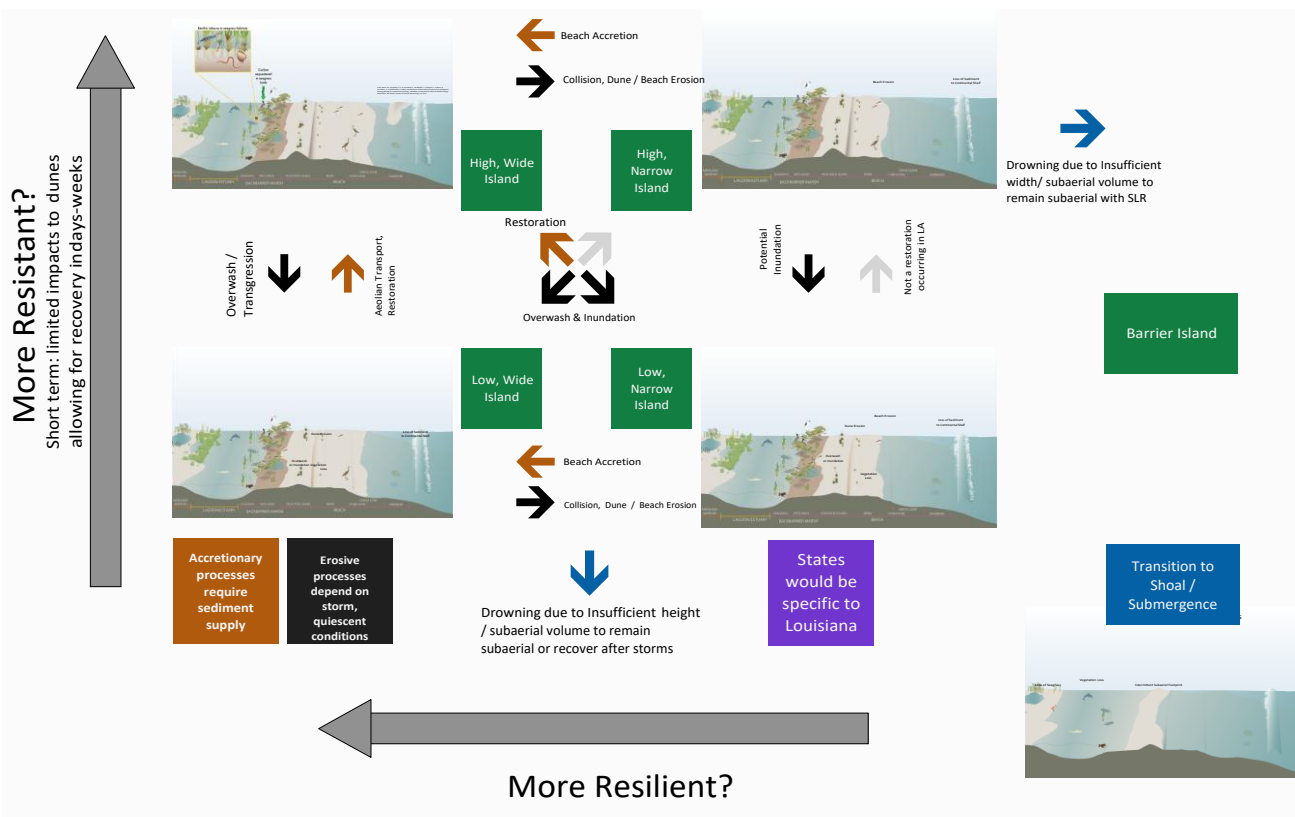


Figure B-1. Preliminary draft conceptual diagram of resilience and resistance. Based on data evaluation and feedback from the Technical Advisory Group (TAG), this model was revised to the continuum-based approach presented in the main body of this report.

3. April 29, 2024. This meeting presented preliminary results from the pilot studies and introduced the concept of a tiered approach to analysis, where Tier 1 metrics provide a snapshot of barrier island and headland condition and Tier 2 metrics provide a more in-depth, application specific analysis of barrier condition. The research team elicited input from the TAG, who were generally supportive of the framework but suggested simplification, streamlining, and a focus on metrics that can help compare the condition across barriers as well as the change in condition of a single barrier over time.
4. November 15, 2024. The research team presented the results of the updated resilience and resistance methodology, which is presented in the main body of this report. The TAG was supportive of the new framework and had minor suggestions for refinement and display of the results, which were made to the framework following the meeting.
5. September 2, 2025. The research team presented the resilience and resistance methodology and our findings. The research team also provided an overview of the report and highlighted the timeline for the project report review.

APPENDIX C. TROPICAL STORMS

Table C-1. List of tropical events passing within 200 km of a Louisiana barrier during the period of 1985-2021. Data were extracted from the HURDAT-2 database (Landsea & Franklin, 2013). H1, category 1 hurricane; H2, category 2 hurricane; H3, category 3 hurricane; H4, category 4 hurricane; TS, tropical storm.

Name	Category	Date	Reaches within 200km
Danny	H1	1985-08-15	Raccoon Island, Whiskey Island, Trinity-East Island
Elena	H3	1985-09-02	Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Juan	TS	1985-10-31	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Beryl	TS	1988-08-09	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Florence	H1	1988-09-10	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Andrew	H4	1992-08-26	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands
Erin	H1	1995-08-03	Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Opal	H3	1995-10-04	Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Danny	H1	1997-07-18	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Earl	H2	1998-09-02	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands

Name	Category	Date	Reaches within 200km
Georges	H2	1998-09-28	Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Hermine	TS	1998-09-20	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Helene	TS	2000-09-22	Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Allison	TS	2001-06-11	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Bertha	TS	2002-08-05	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Hanna	TS	2002-09-14	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Isidore	TS	2002-09-26	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Lili	H3	2002-10-03	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre
Bill	TS	2003-06-30	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Ivan	H3	2004-09-16	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands

Name	Category	Date	Reaches within 200km
Matthew	TS	2004-10-10	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands
Arlene	TS	2005-06-11	Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Cindy	H1	2005-07-06	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Katrina	H3	2005-08-29	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Rita	H3	2005-09-23	Raccoon Island, Whiskey Island
Edouard	TS	2008-08-04	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands
Gustav	H2	2008-09-01	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Ida	TS	2009-11-10	Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Lee	TS	2011-09-03	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Isaac	H1	2012-08-29	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands

Name	Category	Date	Reaches within 200km
Nate	H1	2017-10-08	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Gordon	TS	2018-09-05	Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Barry	TS	2019-07-13	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island
Olga	TS	2019-10-26	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island
Cristobal	TS	2020-06-07	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Marco	TS	2020-08-25	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Sally	H1	2020-09-16	Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Zeta	H3	2020-10-28	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Claudette	TS	2021-06-19	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands
Ida	H4	2021-08-29	Raccoon Island, Whiskey Island, Trinity-East Island, Timbalier Island, East Timbalier Island, West Belle Pass, Caminada Headland, Grand Isle, West Grand Terre, East Grand Terre, Grand Pierre Island, Chaland Headland, Shell Island, Pelican Island, Scofield Island, Breton Island, Grand Gosier/Curlew Islands, Northern Chandeleur Islands

APPENDIX D. REPORT CARDS

Breton Island Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (pages 2–3). This information tells us how the reach compares to other reaches in the region.

Tier 2 analysis metrics for the reach (page 4) that provide detail and supporting information on the state of the reach with comparisons to the region and rest of the coast.

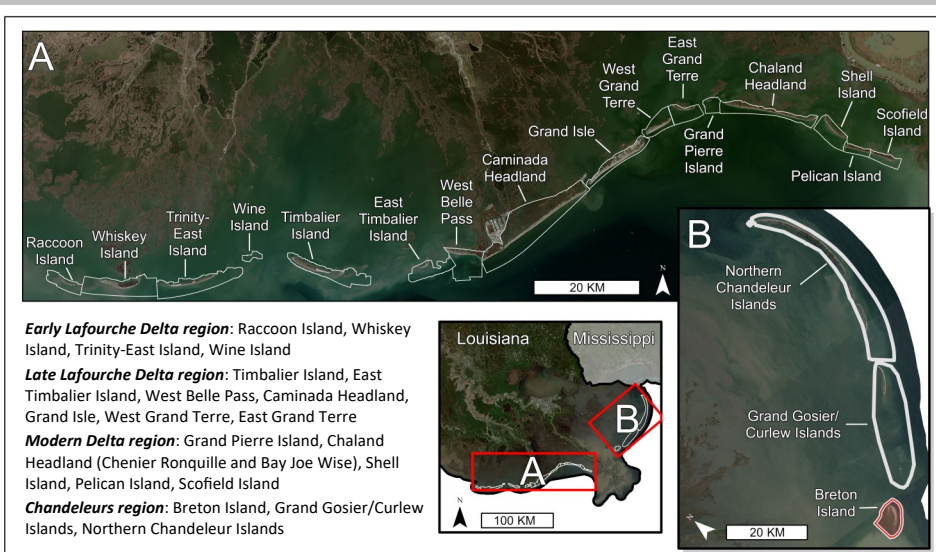
Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsplillrestoration.noaa.gov/project?id=306>.



April, 2026

Location



Oblique imagery



Oblique image from 2023 showing Breton Island.

Restoration history

- Sediment placement (5.9 million cubic yards [MCY]) by the U.S. Fish and Wildlife Service at the beach, marsh, and dune areas to create 400 acres of restored barrier island habitat between 2020 and 2021.

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Ivan (H3)	2004	115 km
Katrina (H3)	2005	41 km
Zeta (H3)	2020	106 km
Ida (H4)	2021	108 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

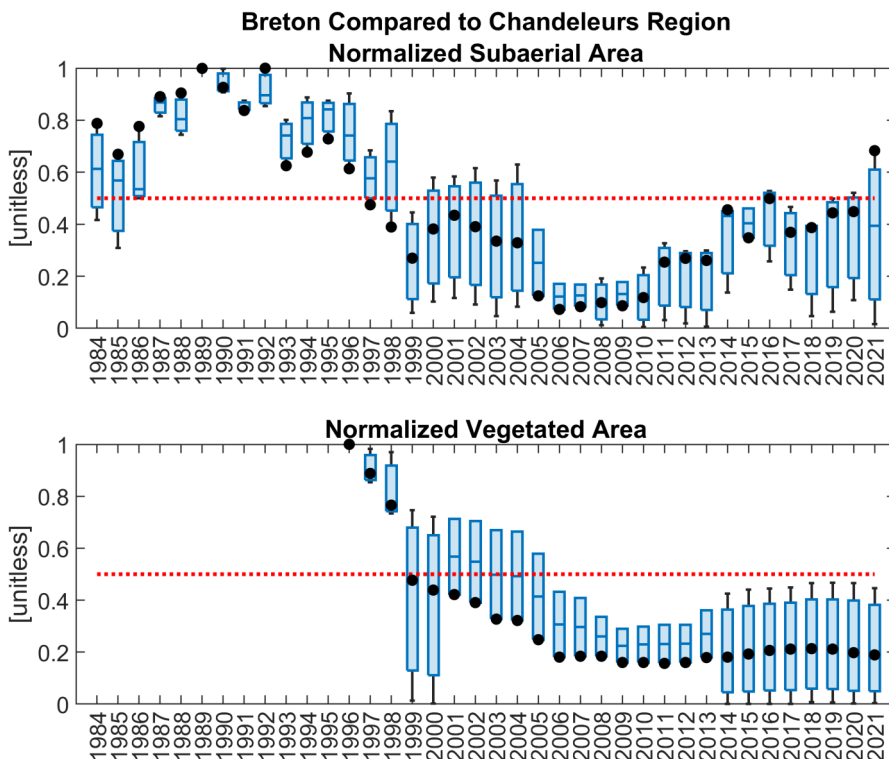
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



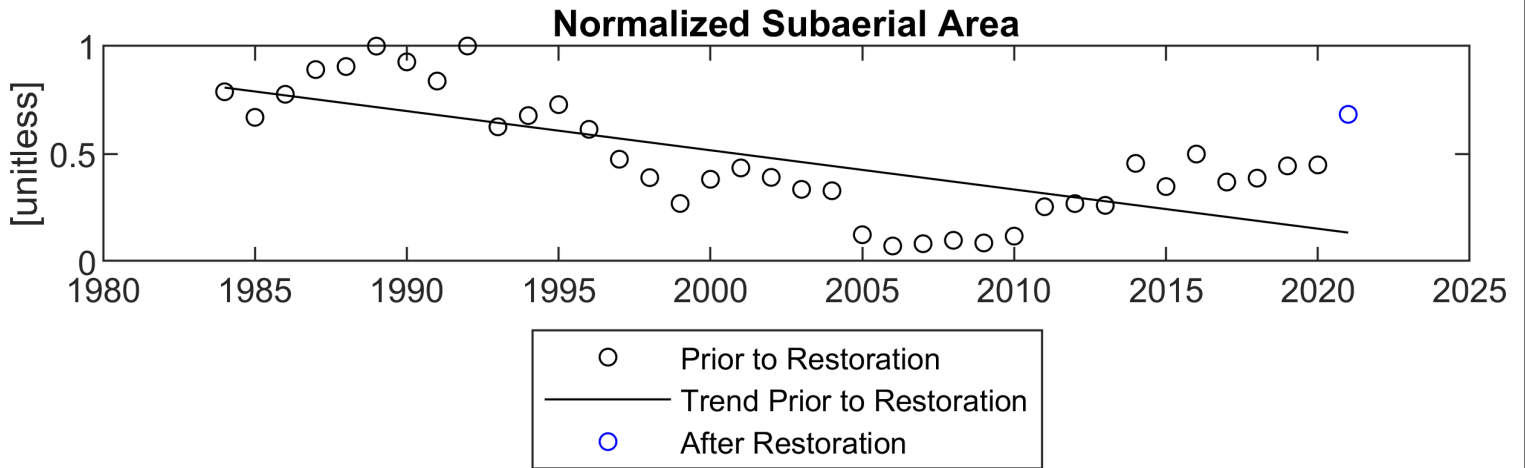
Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Subaerial area and vegetated area were highest at Breton Island in the late 1980s, decreasing steadily in the 1990s before reaching a low after Katrina in 2005. Restoration in 2020–2021 increased subaerial land, although the vegetated area had not yet increased in response as of 2022.

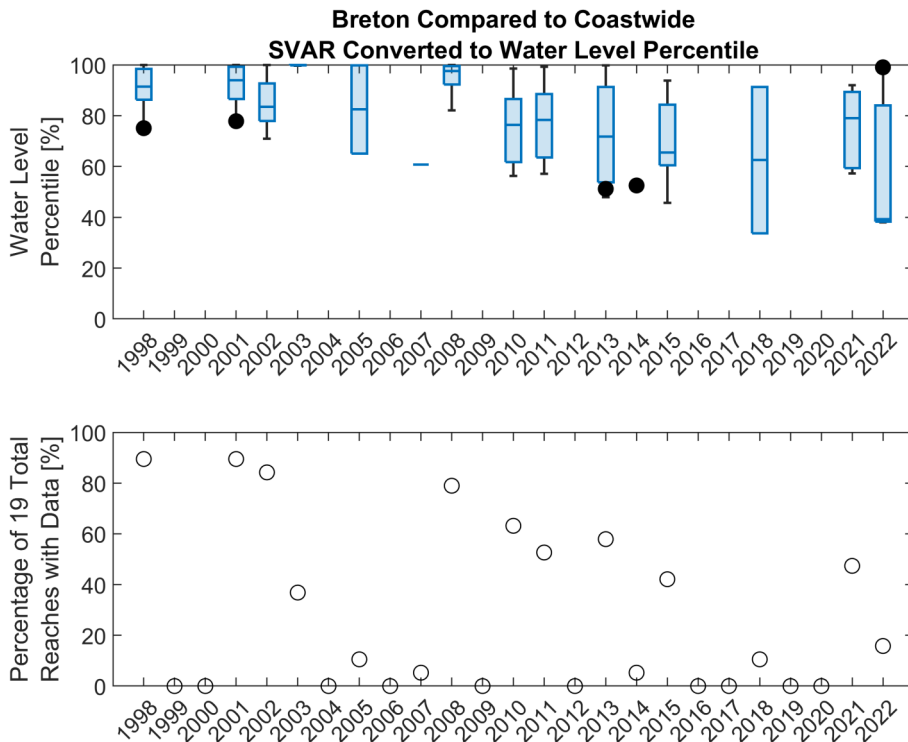
Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?



Results: Subaerial area declined from the 1980s–2010s, with occasional short-term increases lost as part of overall decline. Restoration increased area, but it is too soon to assess impacts to island trajectory.

What do data tell us about resistance to storms?



Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

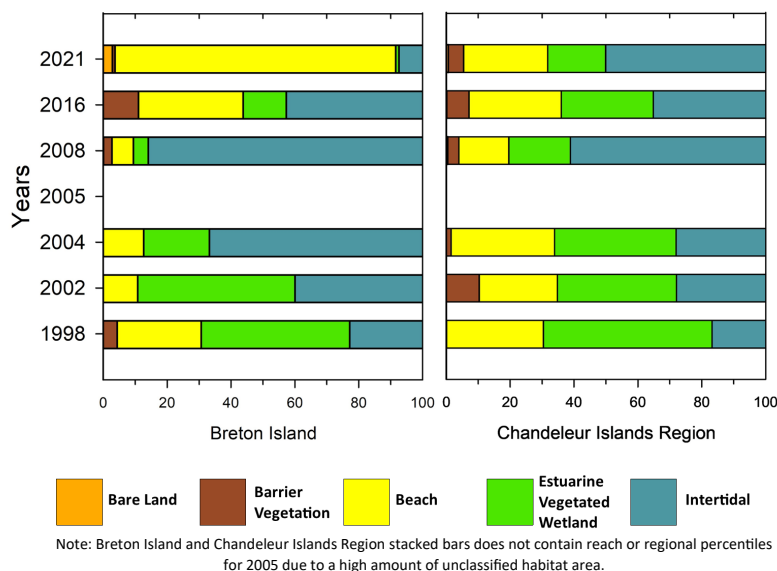
Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level (black dots) data compare to the region (box plots)?

Results: SVAR for Breton Island was at or slightly above the 50th percentile of water level for the 20 years prior to 2020. Restoration in 2020–2021 increased the islands resilience, with SVAR, as of 2022, at approximately the 99th percentile of water level.

Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

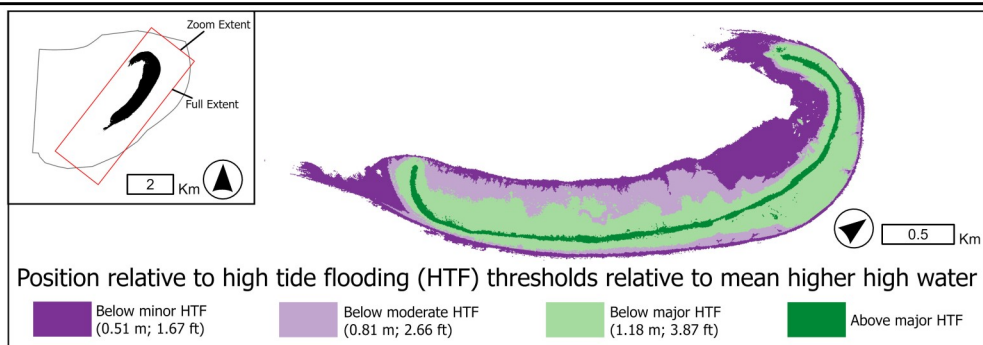


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	-	+
Vegetated & Low (Estuarine Vegetated Wetland)	-	-
Nonvegetated & High (Bare Land/Beach)	+	≈
Nonvegetated & Low (Intertidal)	-	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUZI>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P19VXXH>

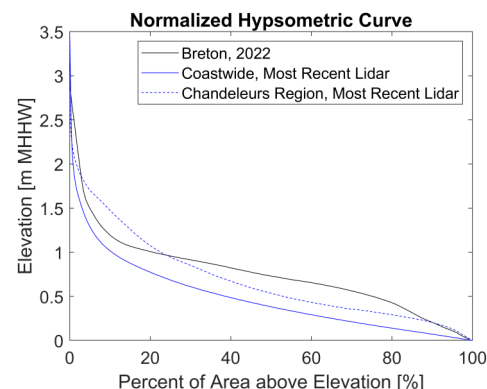
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	30.26	78.30	79.20
Below moderate	21.80	12.20	11.06
Below major	41.60	8.24	7.85
Above major	6.40	1.20	1.89



Hypsometric curve

Distribution of elevation relative to island area:

	Elevation (m relative to mean higher high water [MHHW])		
Percentile	Reach	Region	Coastwide
95	0.111	0.021	0.036
75	0.501	0.141	0.176
50	0.731	0.331	0.381
25	0.956	0.556	0.686
5	1.501	1.071	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NG0>.

Caminada Headland Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

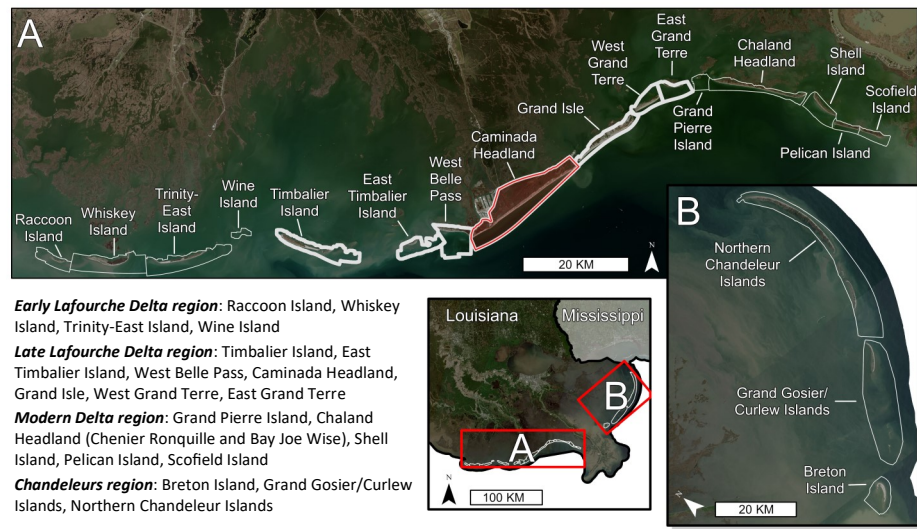
Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsplillrestoration.noaa.gov/project?id=306>.



April, 2026

Location



Oblique imagery



Oblique image from 2023 showing Caminada Headland.

Restoration history

- Sediment placement (3.6 million cubic yards [MCY]) to increase island height and width by 353 acres of restored habitats in 2013–2015 (BA-45)
- Sediment placement (5.2 MCY) in 2015–2016 (BA-143) to increase island height and width to restore 686 acres habitat and native dune vegetation planting in 2017
- Created/nourished 900 acres of marsh with vegetative planting in 2022, working synergistically with BA-45 and BA-143 (BA-171)

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Lili (H3)	2002	168 km
Katrina (H3)	2005	56 km
Zeta (H3)	2020	45 km
Ida (H4)	2021	7 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

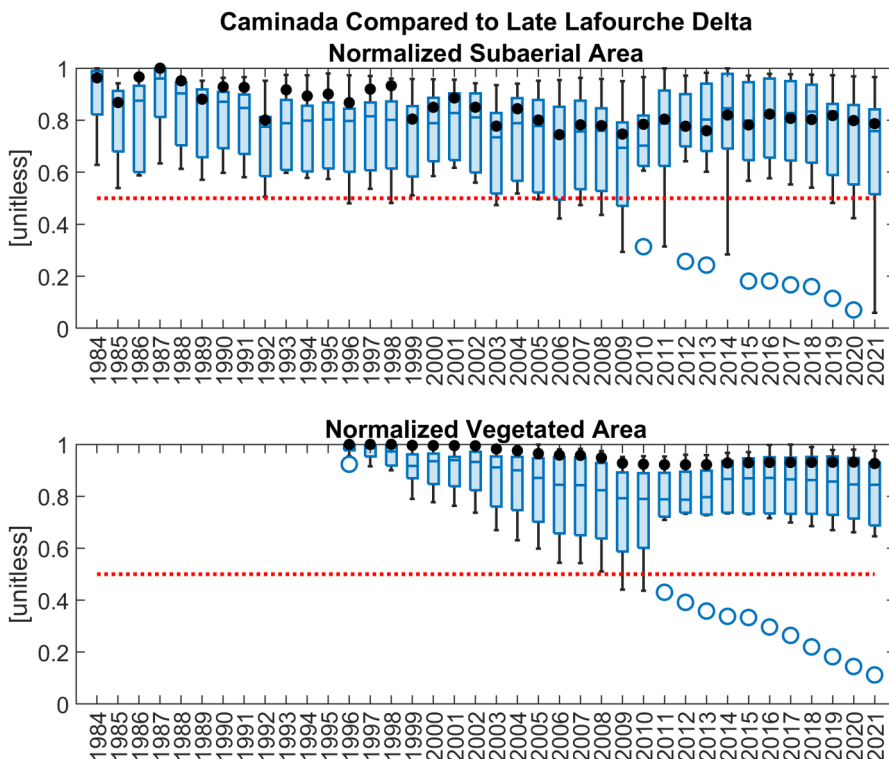
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetated cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



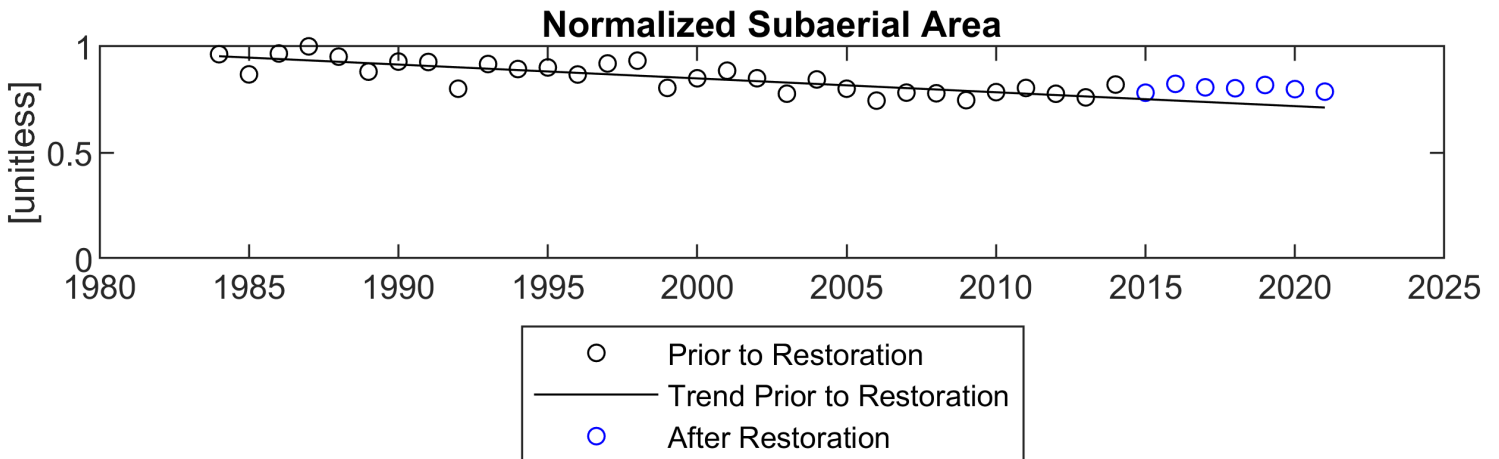
Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: The total and vegetated area of Caminada Headland was highest in the 1980s and 1990s, with a decline occurring during the hurricanes of the early 2000s. Resilience metrics have been relatively stable since, with restoration in 2013–2017 leading to a slight increase (relative to the headland’s size).

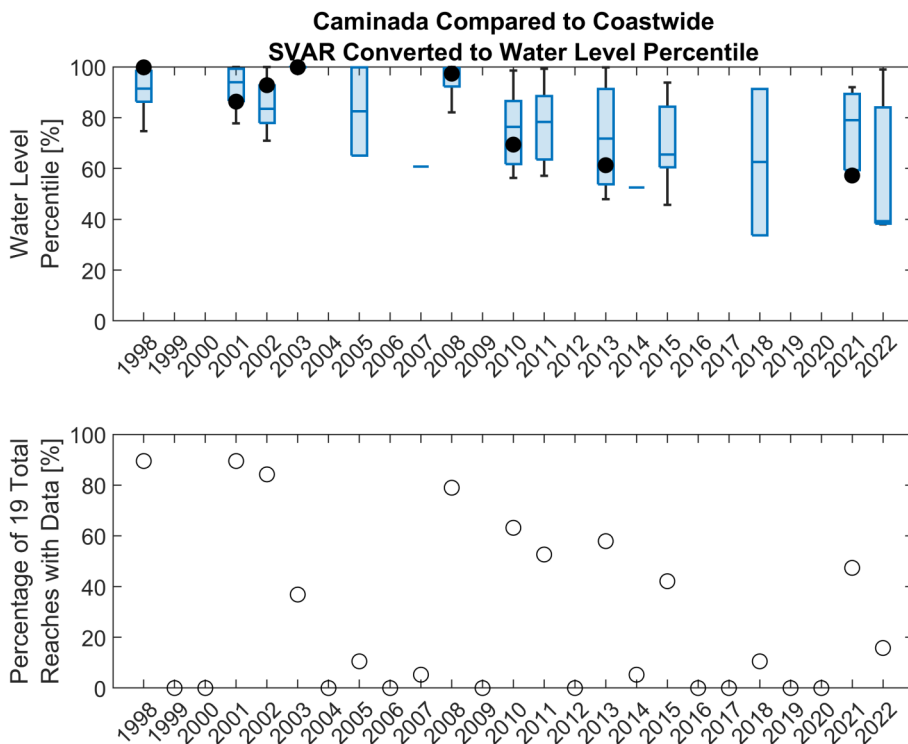
Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?



Results: Subaerial area declined slightly from 1985 through the restorations in the mid-2010s. Subaerial area since then has been relatively stable.

What do data tell us about resistance to storms?



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

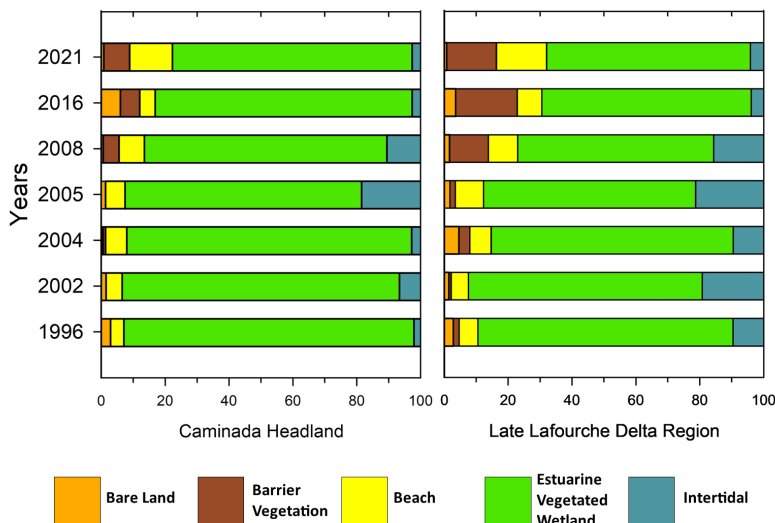
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: The hurricanes in the 2000s impacted resistance more than the resilience metrics, lowering SVAR from above the 90th percentile to just above the 50th percentile. Sediment placement has allowed SVAR to keep pace with sea-level rise and remain at this percentile.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

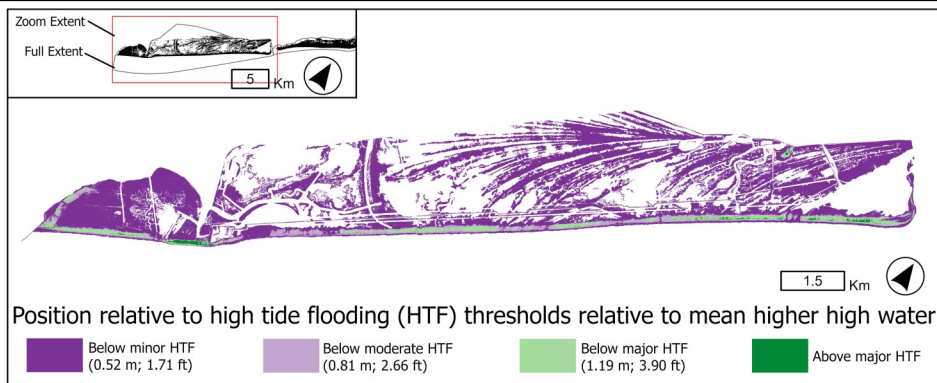


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	≈	≈
Vegetated & Low (Estuarine Vegetated Wetland)	-	≈
Nonvegetated & High (Bare Land/Beach)	≈	+
Nonvegetated & Low (Intertidal)	≈	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUZJ>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P18X4JJ8>

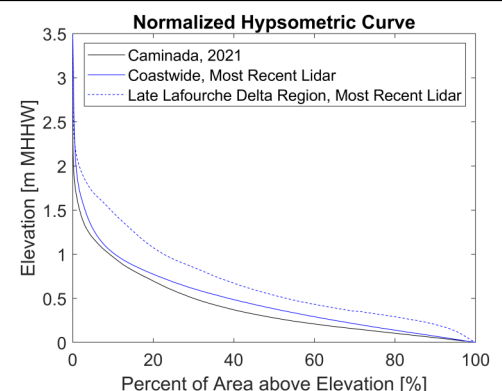
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	86.20	78.60	79.20
Below moderate	6.94	11.40	11.06
Below major	6.13	7.88	7.85
Above major	0.78	2.10	1.89



Hypsometric curve

Distribution of elevation relative to island area:

Elevation (m relative to mean)			
Percentile	Reach	Region	Coastwide
95	0.026	0.041	0.036
75	0.131	0.176	0.176
50	0.276	0.391	0.381
25	0.591	0.711	0.686
5	1.186	1.296	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NGO>.

Chaland Headland Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

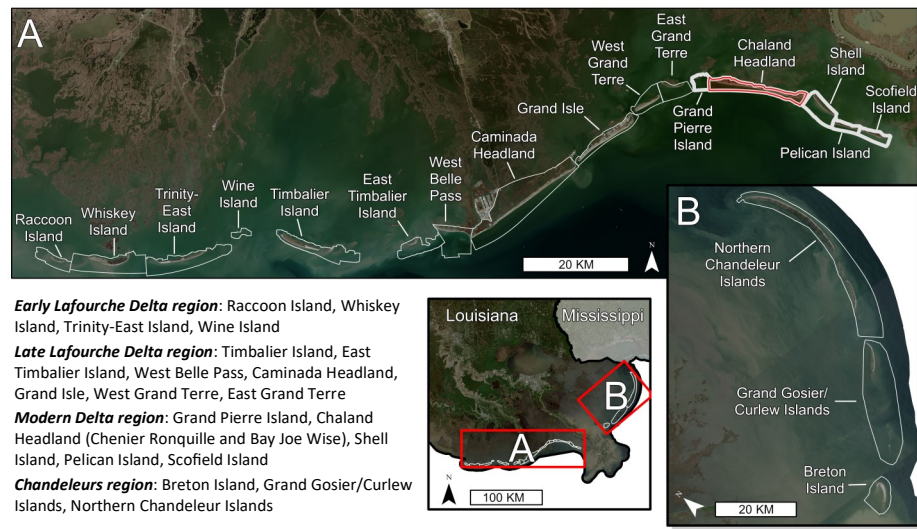
Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsillrestoration.noaa.gov/project?id=306>.



April, 2026

Location



Oblique imagery



Oblique image from 2023 showing Chaland Headland.

Restoration history

- Sediment placement (3.4 million cubic yards [MCY]) to increase island height and width by creating 484 acres of filled area in 2007 (BA-38-1)
- Sediment placement (3.0 MCY) for breach mitigation and 350 acres of total fill area for habitats in 2008–2009 (BA-35)
- Sediment placement to increase island height and width and vegetation plantings to contribute to 518 acres of beach/dune/marsh restoration in 2017 (BA-76)
- Sediment placement (5.9 MCY) to increase island height and width by creating 604 acres of filled area in 2017–2018, along with the addition of sand fencing (BA-111)

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Ivan (H3)	2004	157 km
Katrina (H3)	2005	14 km
Zeta (H3)	2020	84 km
Ida (H4)	2021	50 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

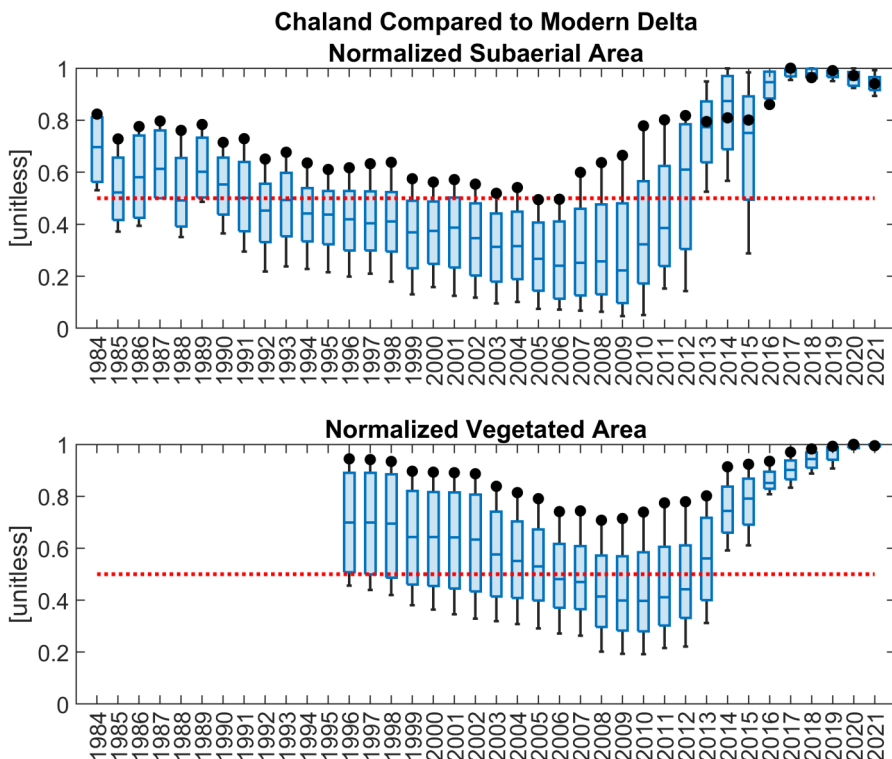
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



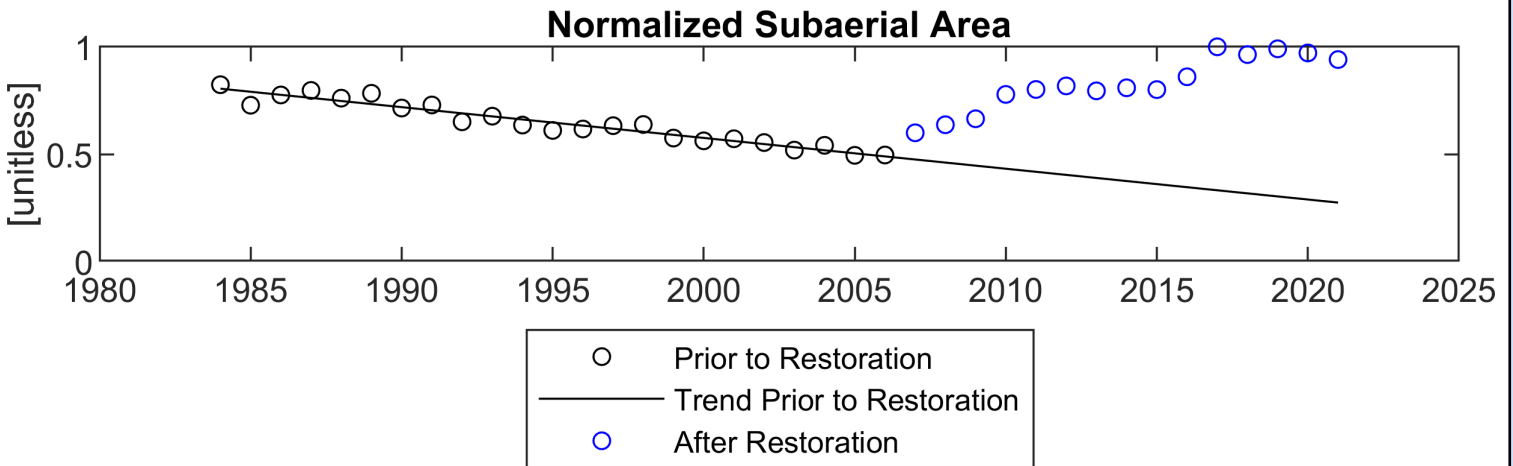
Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Resilience at Chaland Headland steadily decreased through the 1980s, 1990s, and early 2000s, reaching a low in 2006 after Hurricanes Katrina and Ivan. Multiple restoration events in the 12 years after those storms increased both total subaerial land area and vegetated areas, which reached a peak in 2017.

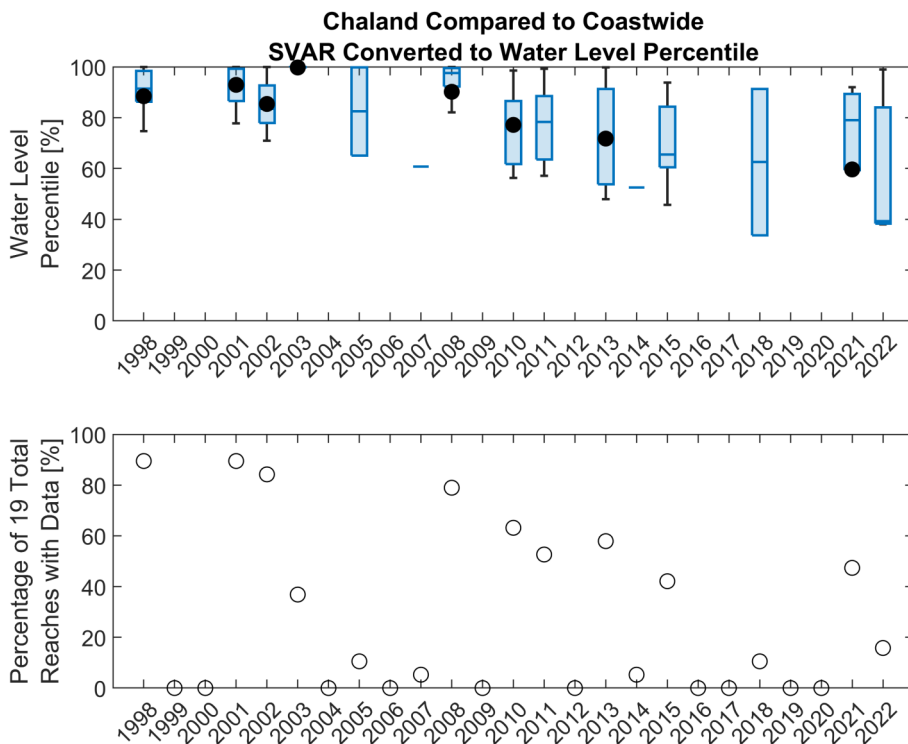
Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?



Results: Subaerial area steadily declined prior to restoration, but a series of sediment placements led to increases from 2015–2020.

What do data tell us about resistance to storms?



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

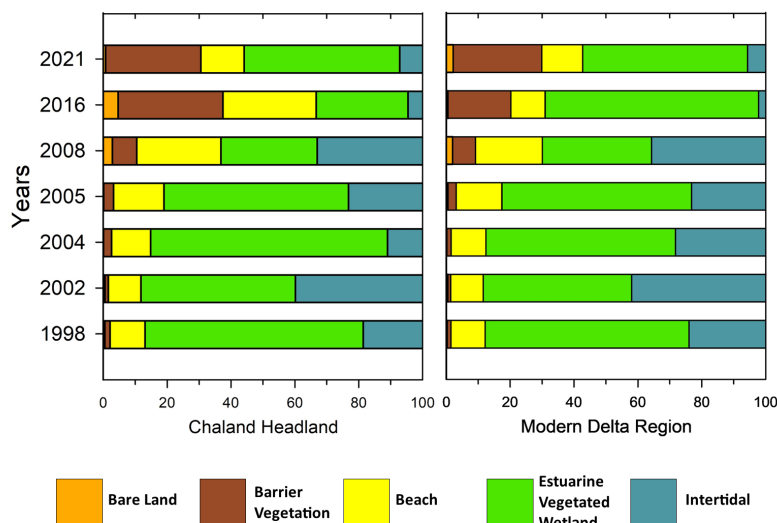
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: SVAR at Chaland Headland has generally ranged between the 50th and 90th water level percentile. The SVAR value has been fairly consistent since 2008 at ~10–20 cm, therefore with sea-level rise SVAR has fallen closer to the 50th percentile of water level over time.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

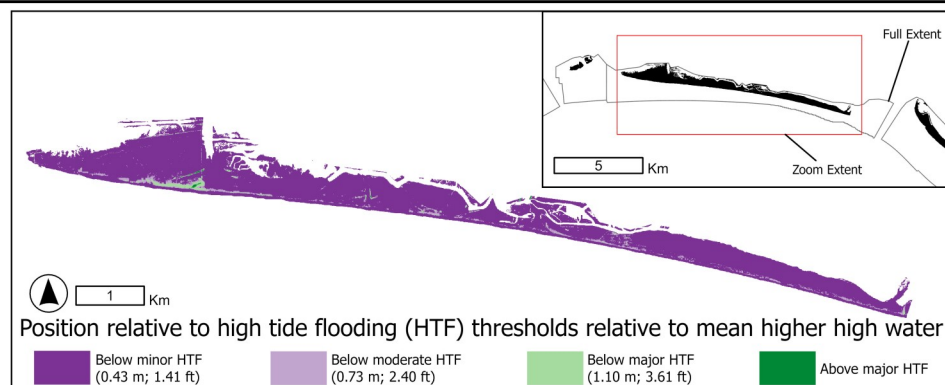


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	≈	+
Vegetated & Low (Estuarine Vegetated Wetland)	+	-
Nonvegetated & High (Bare Land/Beach)	-	≈
Nonvegetated & Low (Intertidal)	≈	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUJZ>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P1ZQP7SN>

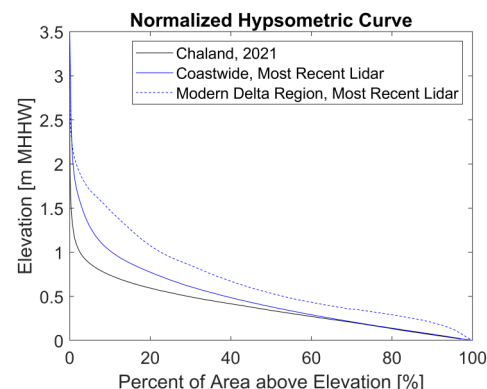
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	94.10	90.60	79.20
Below moderate	4.35	6.46	11.06
Below major	1.41	2.79	7.85
Above major	0.14	0.20	1.89



Hypsometric curve

Distribution of elevation relative to island area:

	Elevation (m relative to mean higher high water [MHHW])		
Percentile	Reach	Region	Coastwide
95	0.031	0.031	0.036
75	0.171	0.141	0.176
50	0.341	0.311	0.381
25	0.541	0.556	0.686
5	0.876	0.946	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NGO>.

East Timbalier Island Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

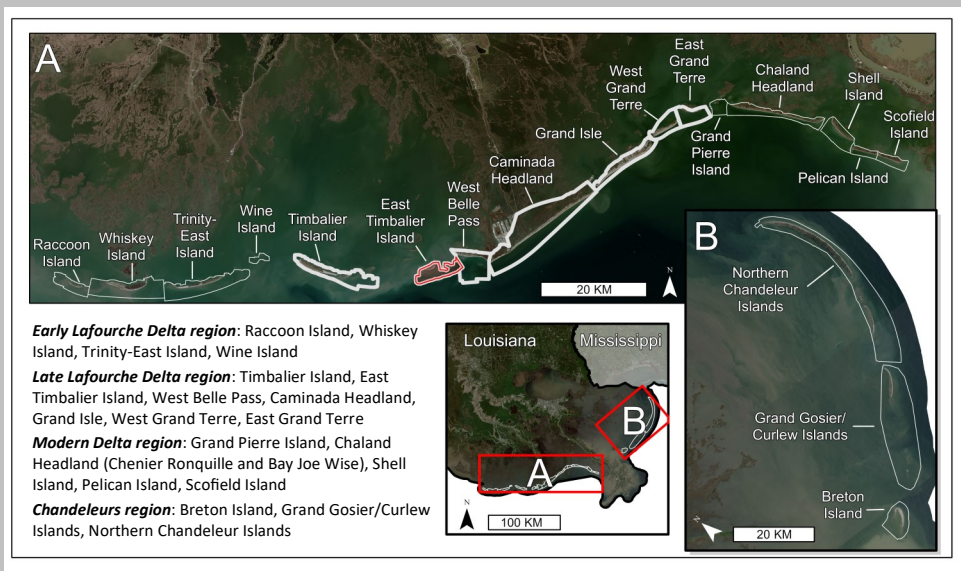
- Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (pages 2–3). This information tells us how the reach compares to other reaches.
- Tier 2 analysis metrics for the reach (page 4) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfspillrestoration.noaa.gov/project?id=306>.



Location



Oblique imagery



Oblique image from 2023 showing East Timbalier Island.

Restoration history

- Sediment placement (3 million cubic yards [MCY]) in 2000 to create 217 acres of tidal habitats on the island (TE-25 & TE-30)

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Lili (H3)	2002	150 km
Katrina (H3)	2005	75 km
Zeta (H3)	2020	31 km
Ida (H4)	2021	13 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

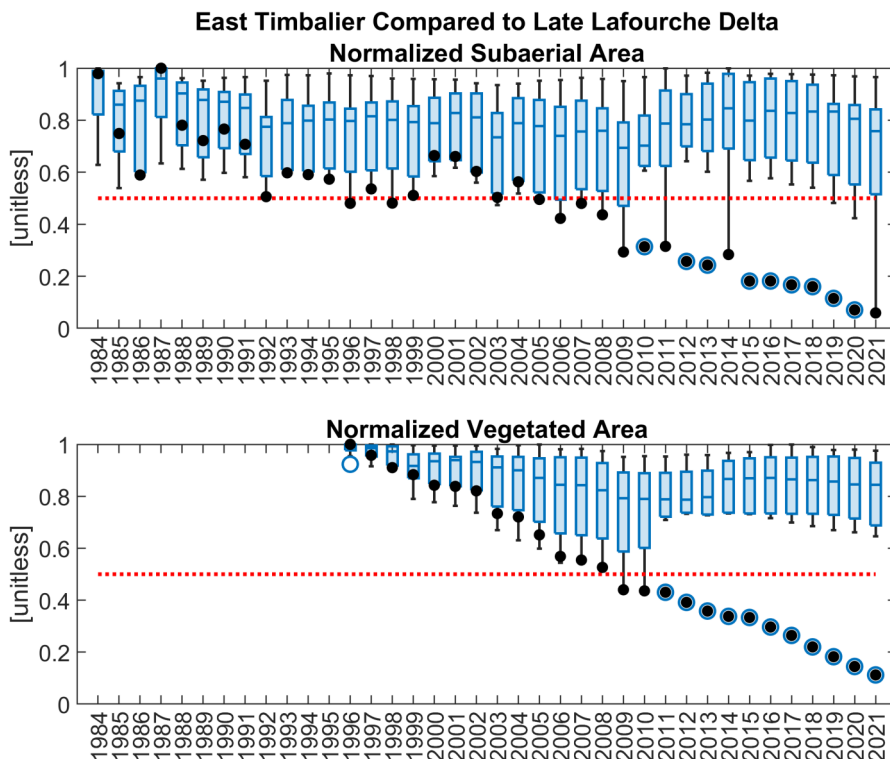
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



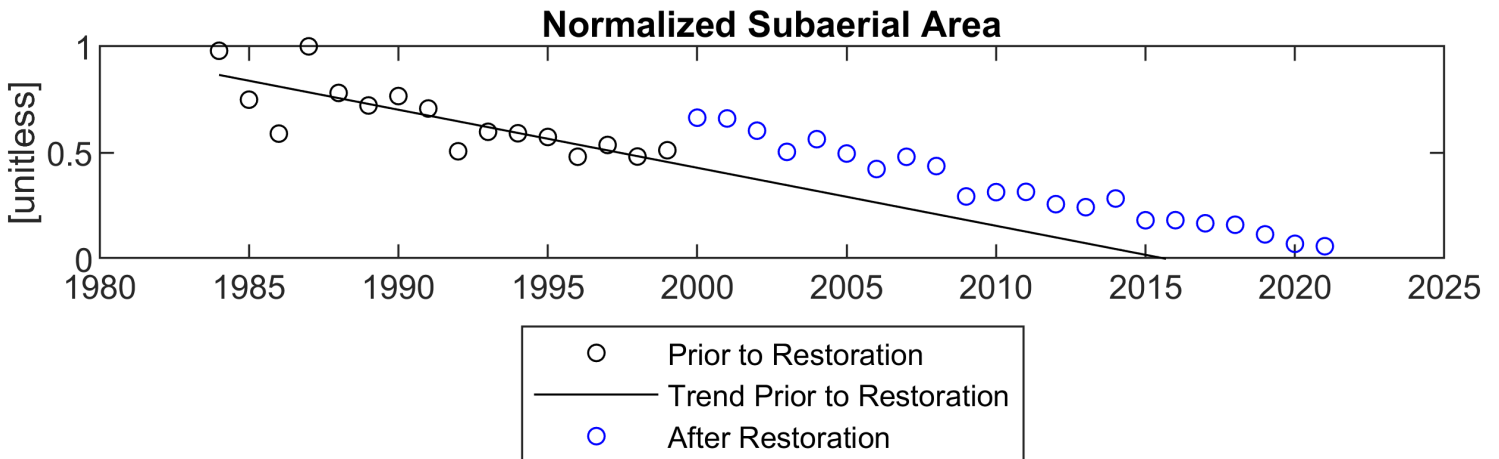
Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Subaerial area at East Timbalier has steadily declined since 1984, virtually disappearing by 2021. Similarly, the vegetated area declined from 1996–2021. Both subaerial and vegetated area had a small, temporary increase in response to restoration in 2000.

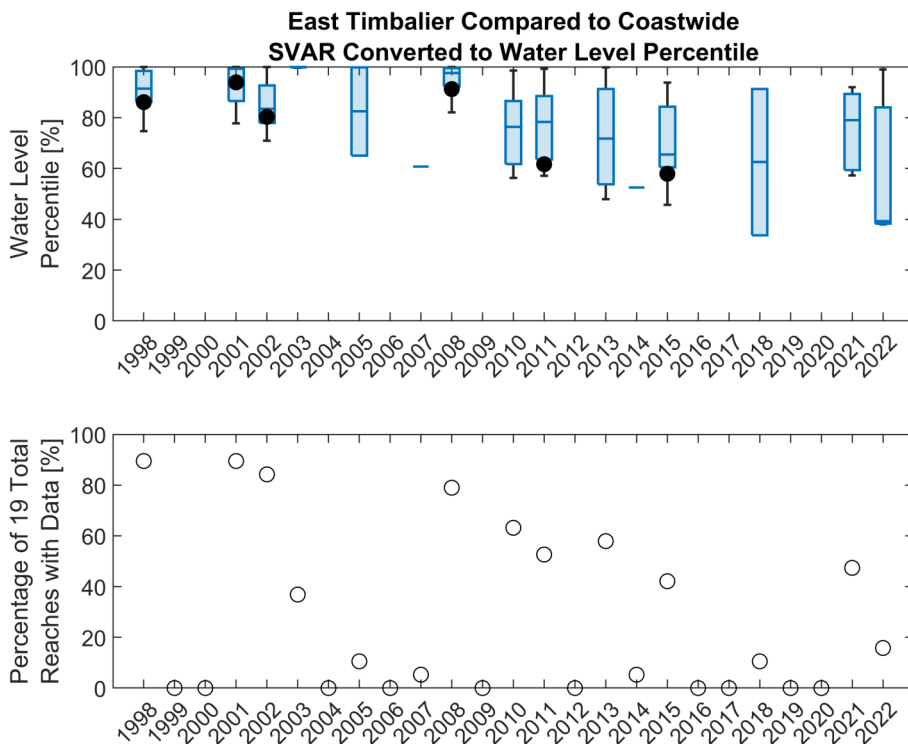
Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?



Results: Subaerial area decreased steadily from 1987 through 2000. Although the restoration increased subaerial area, the overall trend remained the same, and the island was virtually gone by 2020.

What do data tell us about resistance to storms?



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

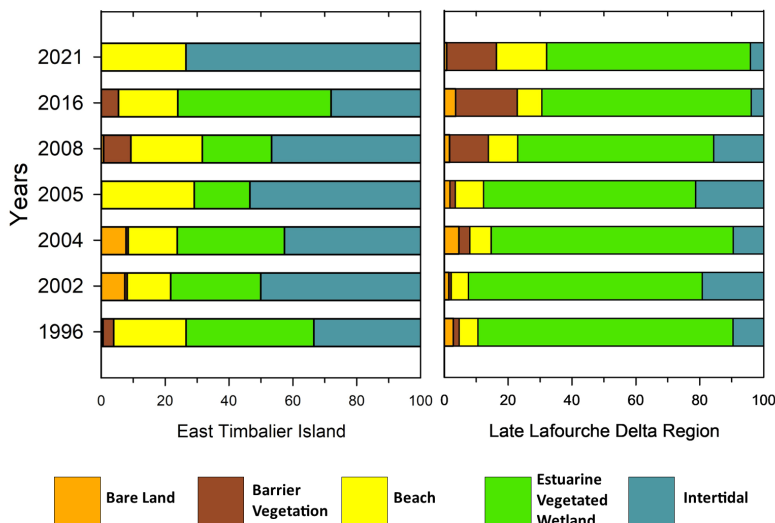
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: SVAR ranged between the 50th and 90th percentile of water level between the late 1990s and early 2000s. This value dropped to the 50th percentile in 2011 and continued to lose ground to sea-level rise in 2015.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

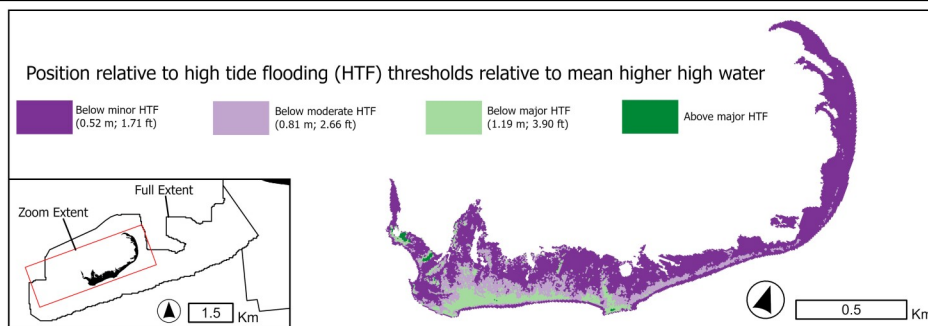


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	-	≈
Vegetated & Low (Estuarine Vegetated Wetland)	-	≈
Nonvegetated & High (Bare Land/Beach)	+	+
Nonvegetated & Low (Intertidal)	+	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUJ1>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P18X4JJ8>

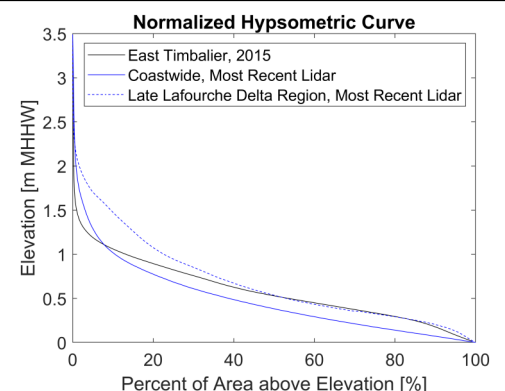
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	71.70	78.60	79.20
Below moderate	18.30	11.40	11.06
Below major	9.53	7.88	7.85
Above major	0.50	2.10	1.89



Hypsometric curve

Distribution of elevation relative to island area:

	Elevation (m relative to mean higher high water [MHHW])		
Percentile	Reach	Region	Coastwide
95	0.081	0.041	0.036
75	0.336	0.176	0.176
50	0.531	0.391	0.381
25	0.821	0.711	0.686
5	1.191	1.296	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the

Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NGQ>.

East Grand Terre Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

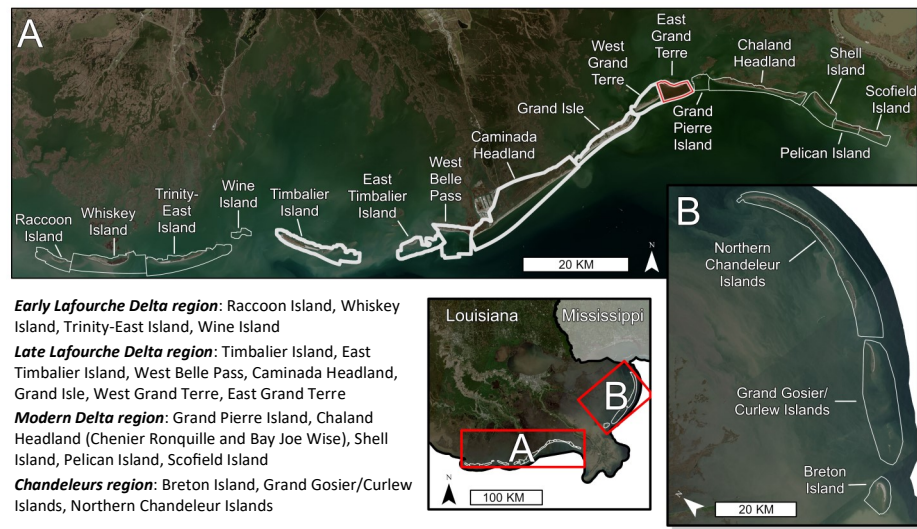
Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsplillrestoration.noaa.gov/project?id=306>.



April, 2026

Location



Oblique imagery



Oblique image from 2023 showing East Grand Terre.

Restoration history

- Sediment placement (4.6 million cubic yards [MCY]) to increase island height and width by stabilizing 1,575 acres of barrier island habitat in 2009–2010 (BA-30-EB)

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Ivan (H3)	2004	170 km
Katrina (H3)	2005	27 km
Zeta (H3)	2020	71 km
Ida (H4)	2021	39 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

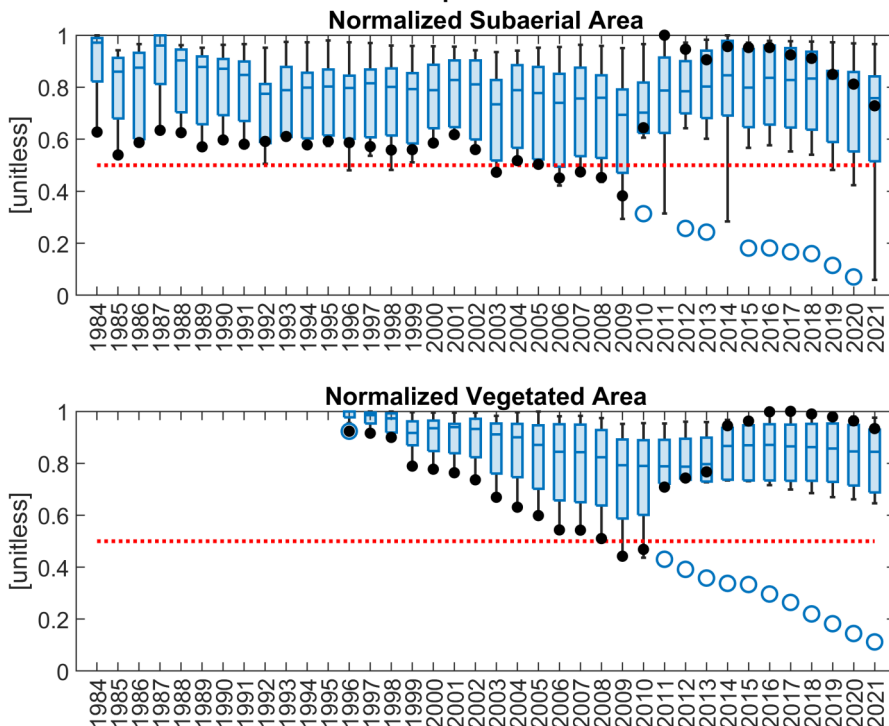
Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?

East Grand Terre Compared to Late Lafourche Delta



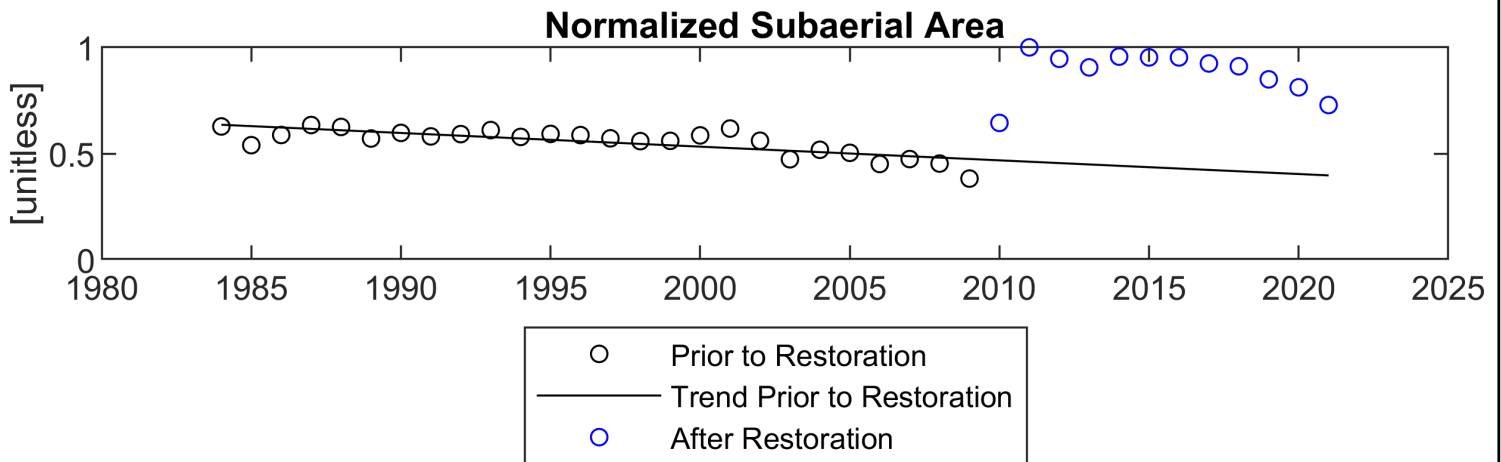
Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Subaerial area and vegetated area slowly declined from 1986–2010, with a higher rate of loss during the stormy period of the 2000s. Restoration in 2009 led to increases in subaerial area and vegetated area. Subaerial land has since decreased steadily.

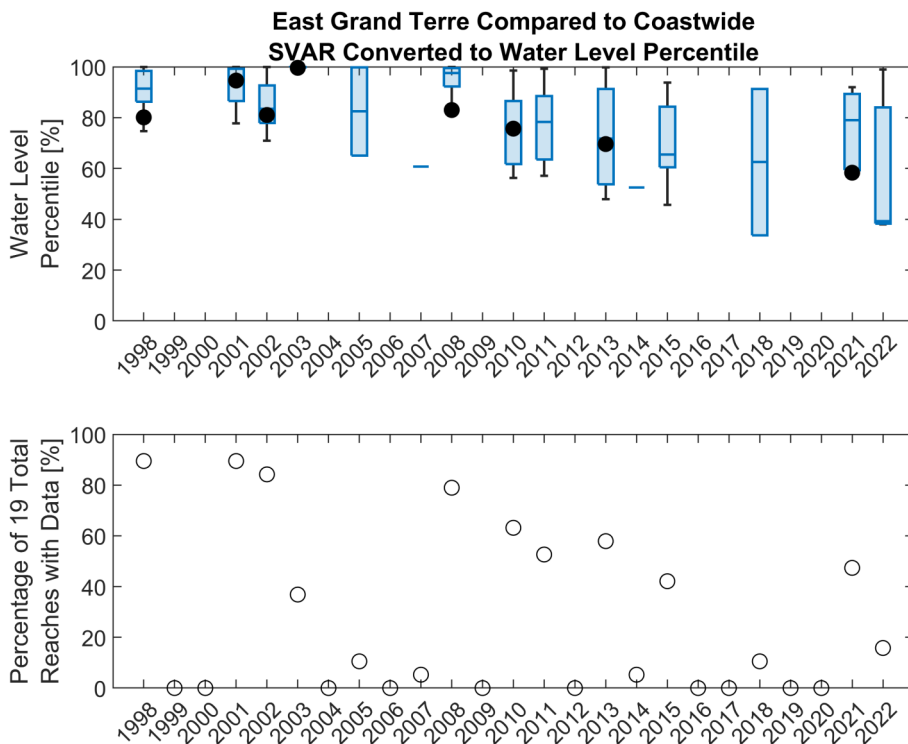
Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?



Results: Island area had a slow but steady decline prior to a significance increase due to restoration in 2009. Area has declined since then, with what appears to be a slight acceleration in loss rate since ~2018.

What do data tell us about resistance to storms?



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

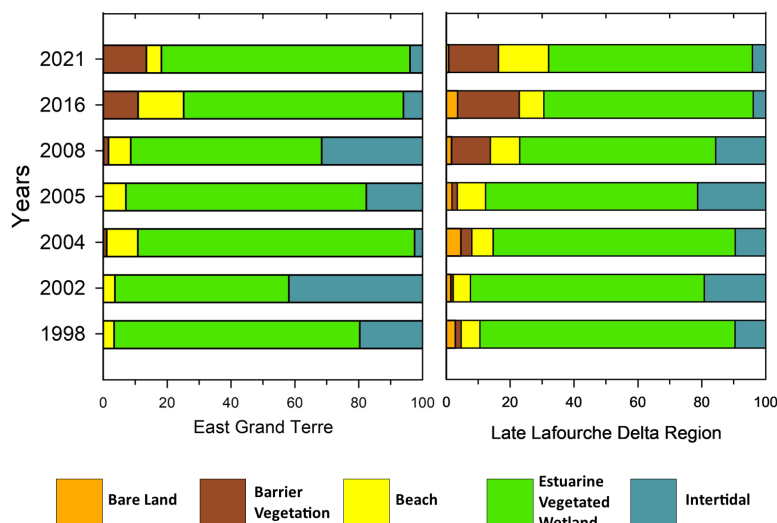
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: SVAR at East Grand Terre has generally been between the 50th and 90th water level percentile. The value of SVAR has been relatively stable since the storms of the early 2000s, but has not kept pace with sea-level rise, and is now at a historical low relative to water levels.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

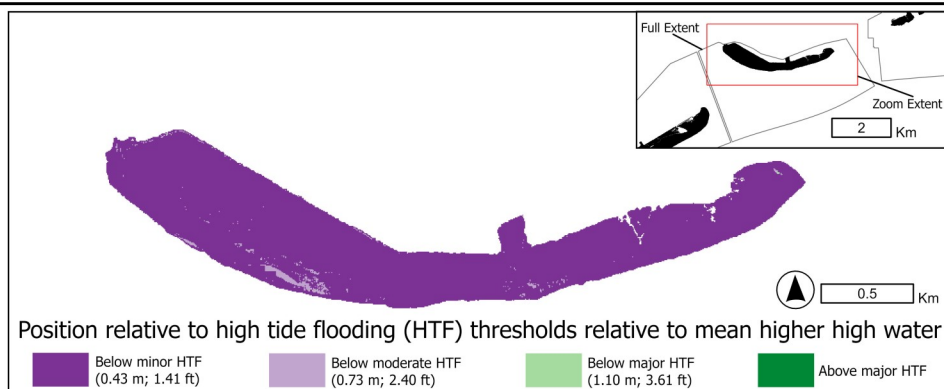


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	≈	≈
Vegetated & Low (Estuarine Vegetated Wetland)	+	≈
Nonvegetated & High (Bare Land/Beach)	-	+
Nonvegetated & Low (Intertidal)	≈	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUZJ>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P18X4JJ8>

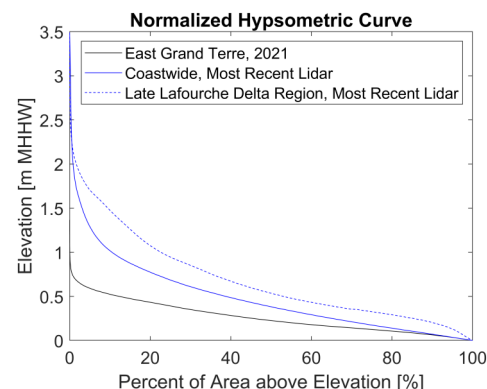
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	98.30	78.60	79.20
Below moderate	1.62	11.40	11.06
Below major	0.03	7.88	7.85
Above major	0	2.10	1.89



Hypsometric curve

Distribution of elevation relative to island area:

	Elevation (m relative to mean higher high water [MHHW])		
Percentile	Reach	Region	Coastwide
95	0.036	0.041	0.036
75	0.126	0.176	0.176
50	0.226	0.391	0.381
25	0.391	0.711	0.686
5	0.591	1.296	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the

Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NG0>.

Grand Gosier/Curlew Islands Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

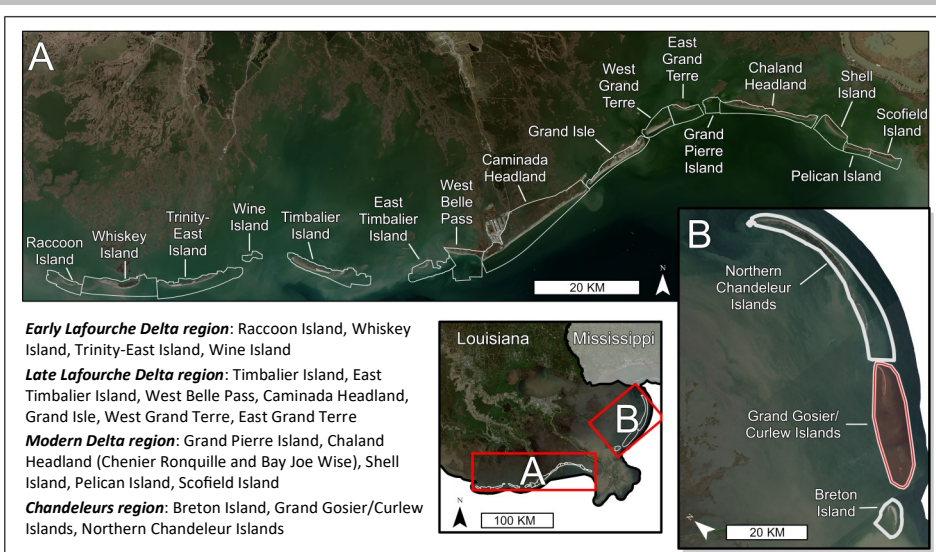
Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsplillrestoration.noaa.gov/project?id=306>.



Location



Oblique imagery



Oblique image from 2023 showing Grand Gosier/Curlew Islands.

Restoration history

- None

Storm history (1985–2021)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Ivan (H3)	2004	111 km
Katrina (H3)	2005	52 km
Zeta (H3)	2020	108 km
Ida (H4)	2021	120 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

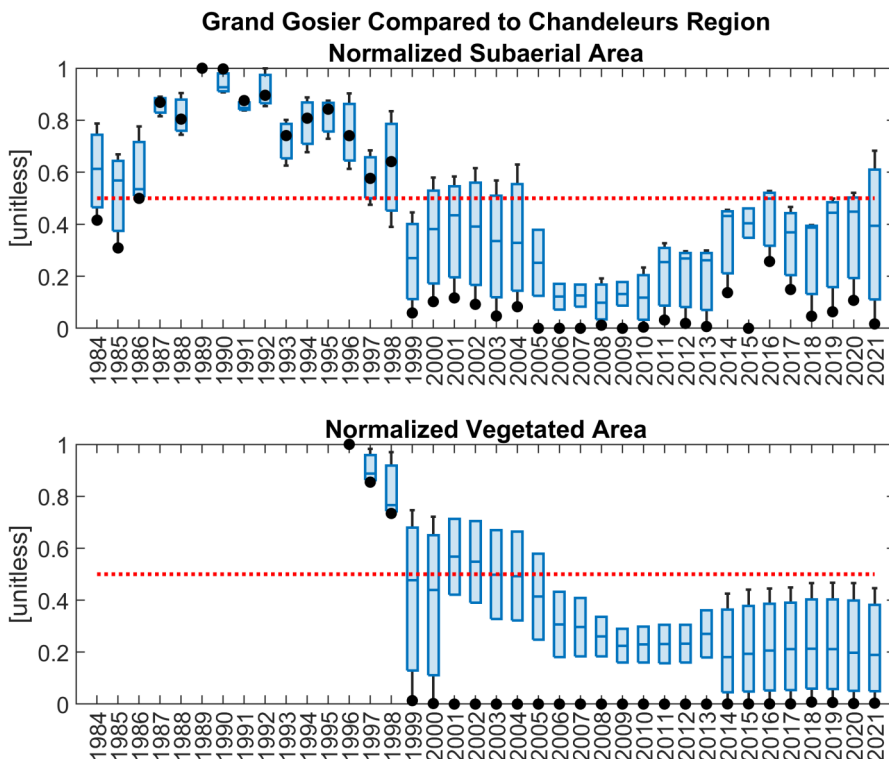
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

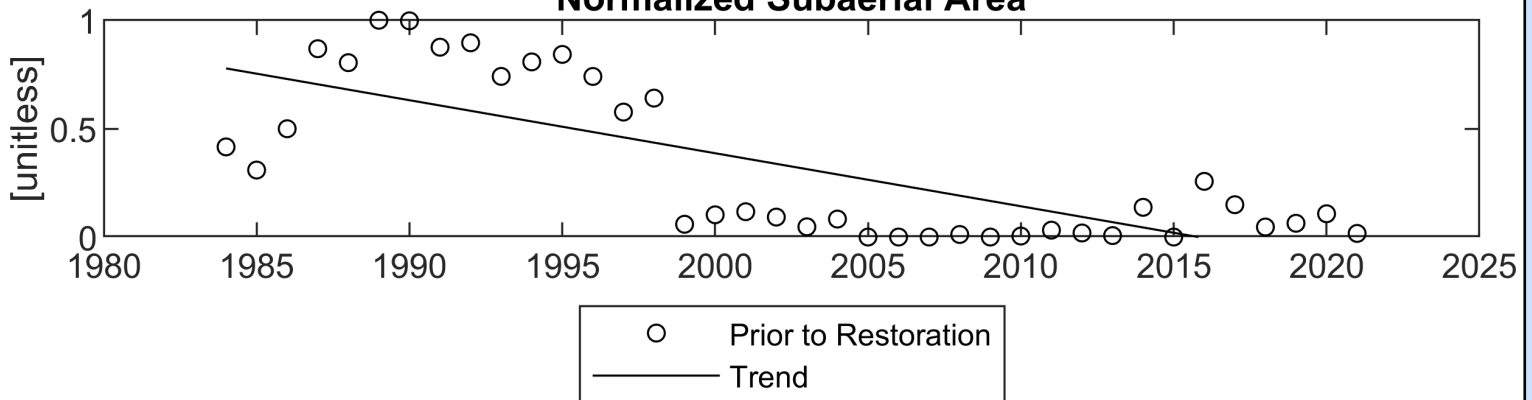
Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Resilience peaked in the early 1990s, dropping sharply from 1995–1999. The area was only impacted by minor hurricanes during this period, notably Category 2 Georges in 1998. The island has now transitioned to an intermittent shoal, with no vegetation and limited subaerial area since 2000.

Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?

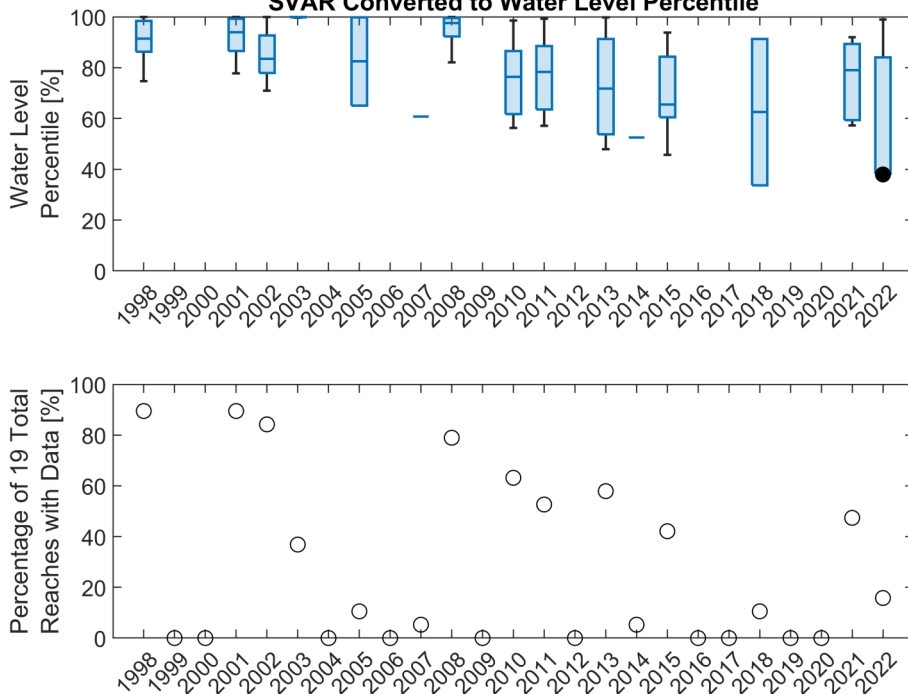
Normalized Subaerial Area



Results: Subaerial area declined steadily after 1990, dropping sharply in 1998–1999. The island became almost completely subaqueous and has remained that way.

What do data tell us about resistance to storms?

Grand Gosier Compared to Coastwide SVAR Converted to Water Level Percentile



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

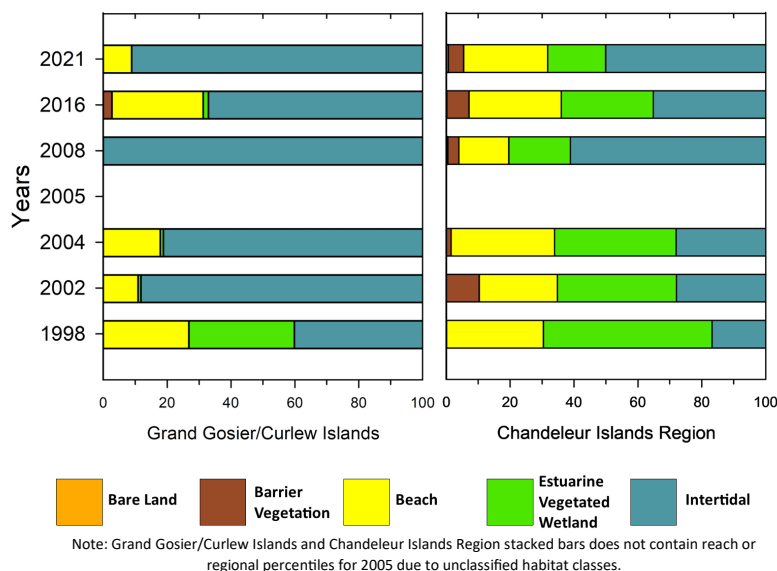
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: There is only one lidar survey from which SVAR can be calculated for Grand Gosier, which was taken in 2022. SVAR was between the 25th and 50th percentile of water level, reflecting the transition to an intermittently submerged shoal.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

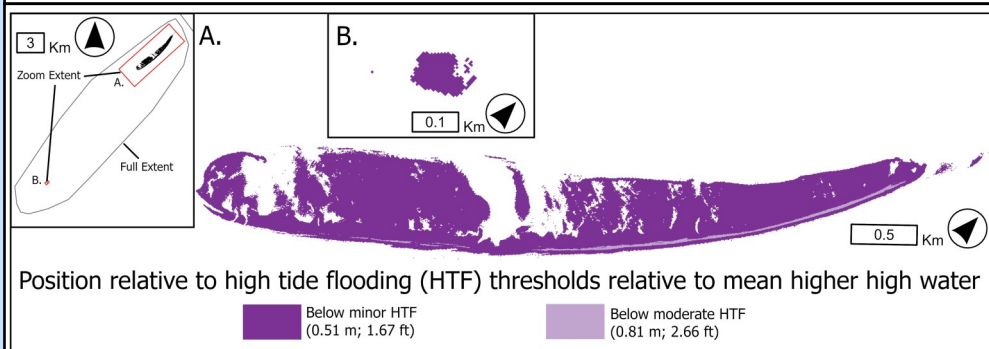


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	≈	+
Vegetated & Low (Estuarine Vegetated Wetland)	≈	-
Nonvegetated & High (Bare Land/Beach)	-	≈
Nonvegetated & Low (Intertidal)	+	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUJZ>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P19VSXXH>

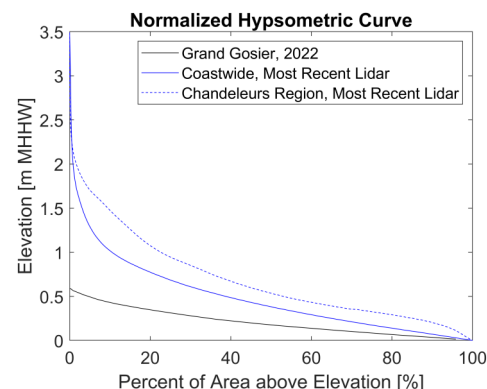
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	97.50	78.30	79.20
Below moderate	2.52	12.20	11.06
Below major	0	8.24	7.85
Above major	0	1.20	1.89



Hypsometric curve

Distribution of elevation relative to island area:

	Elevation (m relative to mean higher high water [MHHW])		
Percentile	Reach	Region	Coastwide
95	0.016	0.021	0.036
75	0.086	0.141	0.176
50	0.176	0.331	0.381
25	0.311	0.556	0.686
5	0.496	1.071	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NG0>.

Grand Isle Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

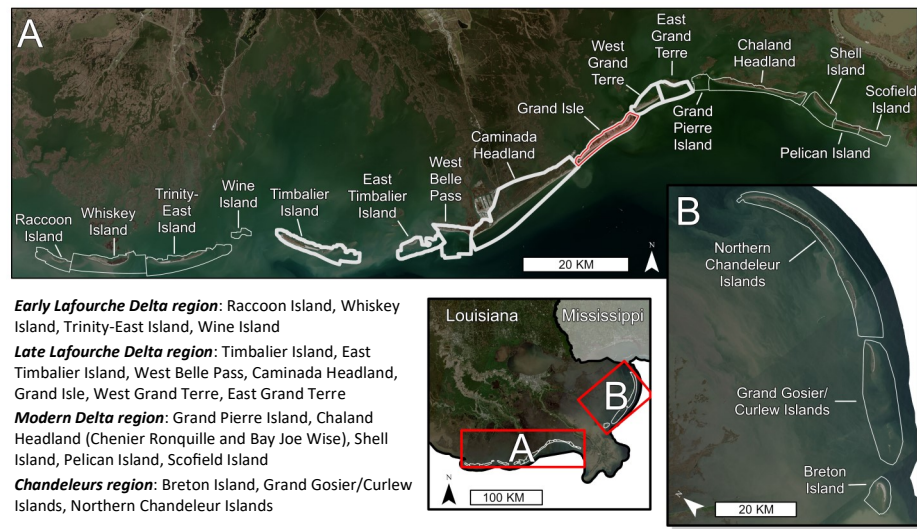
Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsplillrestoration.noaa.gov/project?id=306>.



April, 2026

Location



Oblique imagery



Oblique image from 2023 showing Grand Isle.

Restoration history

- Much of Gulf side of Grand Isle has been stabilized with rock jetties, breakwater systems, and rock shore protection installed through multiple projects from 1958 to the present (BA-50, BA-0187, BA-0155, BA-0168, BA-0233)
- Many coastal protection and sediment placement projects have been constructed on Grand Isle; large dredge projects were completed in 2021 (BA-0210) and 2025

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Lili (H3)	2002	187 km
Katrina (H3)	2005	39 km
Zeta (H3)	2020	59 km
Ida (H4)	2021	25 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

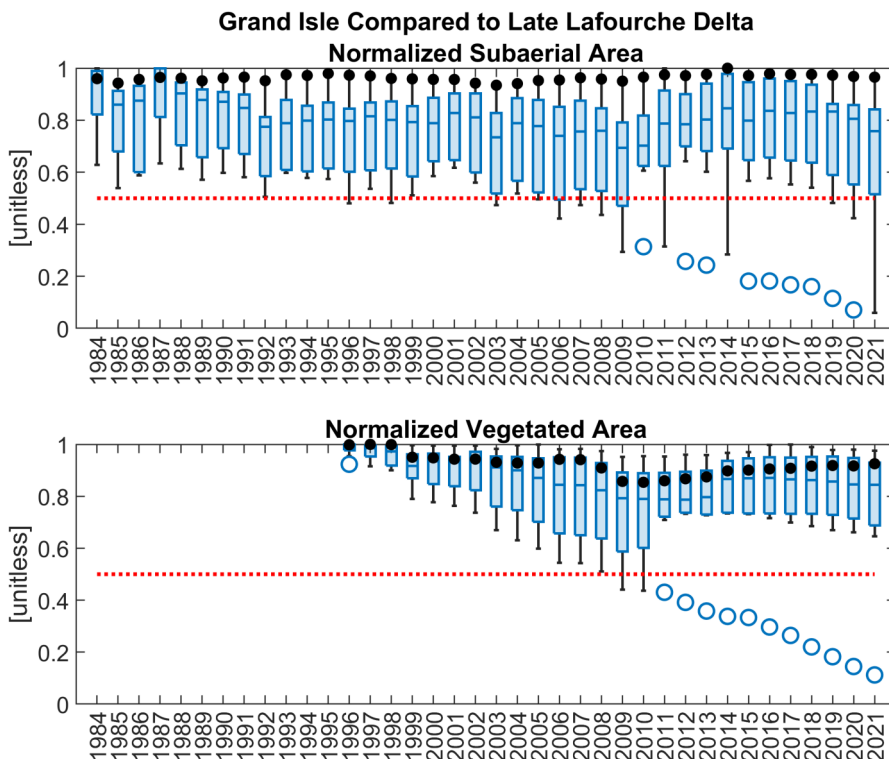
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetated cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



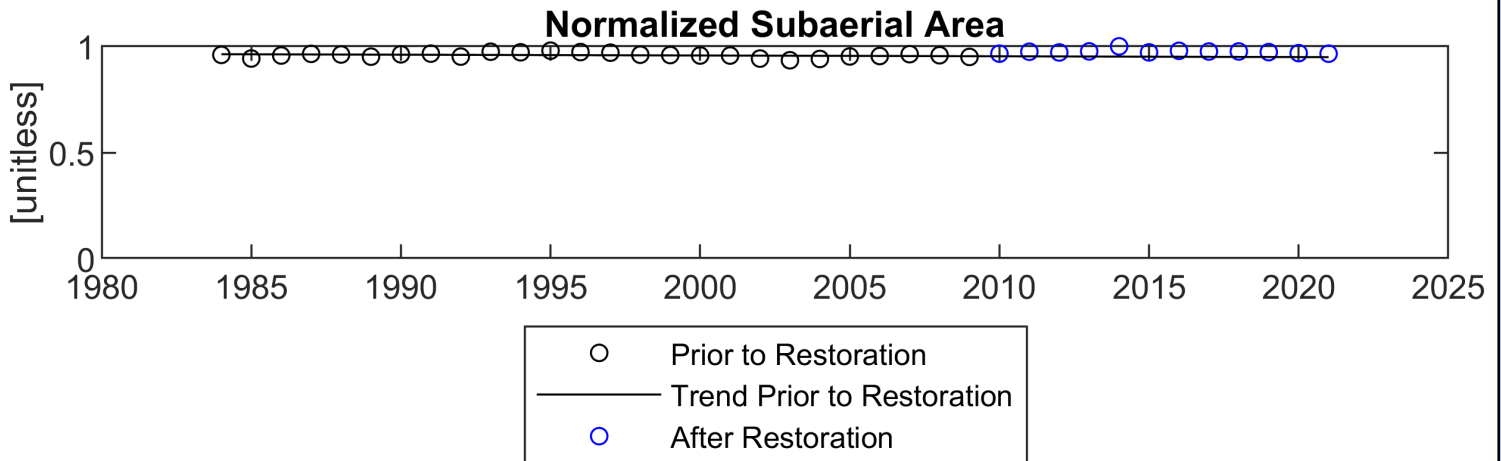
Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Resilience metrics at Grand Isle have been consistent over time, with subaerial area changing by less than 5% over the period of 1985–2021. The vegetated area at Grand Isle is low compared to subaerial land, reflecting its status as an occupied barrier. This metric has also been consistent over time.

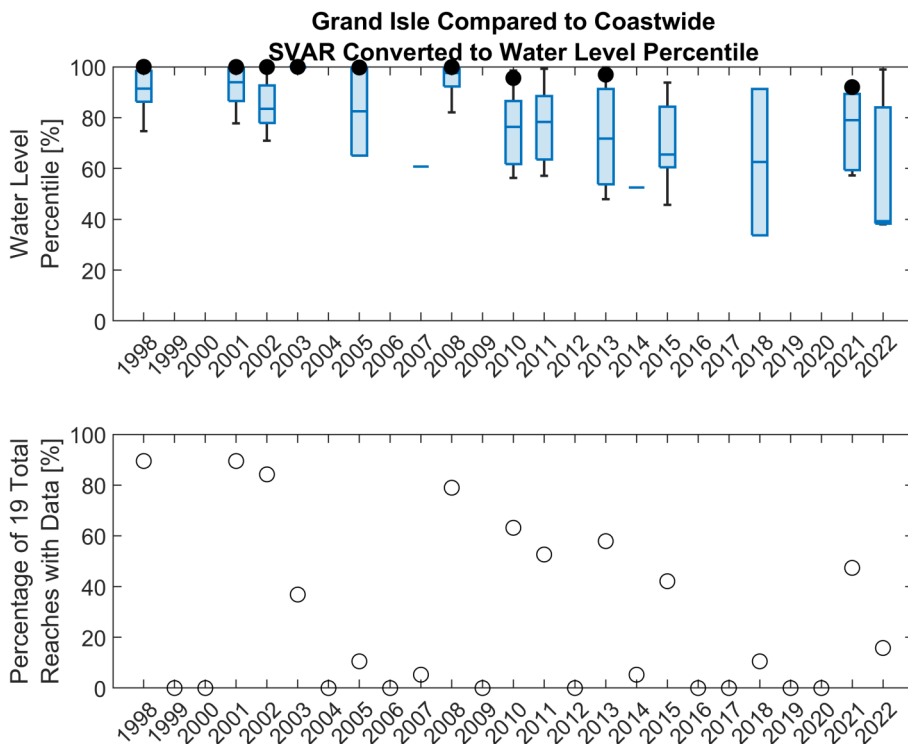
Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?



Results: Subaerial area has stayed steady since 1984. Without restoration, the island has maintained subaerial land cover.

What do data tell us about resistance to storms?



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

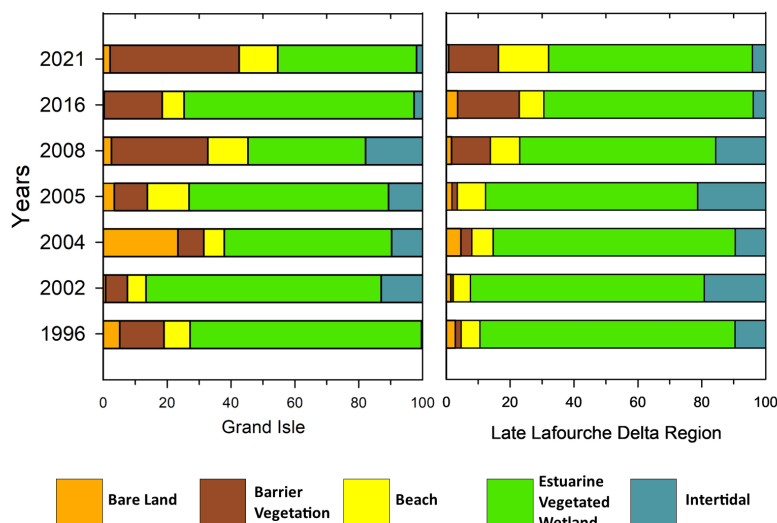
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: SVAR for Grand Isle exceeded the 90th percentile of water level for all available surveys. SVAR was close to the 100th percentile prior to 2010, but this may be due to lower lidar quality not filtering woody vegetation and structures. SVAR was consistent from 2013–2021, dropping slightly relative to water level percentiles due to sea-level rise.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

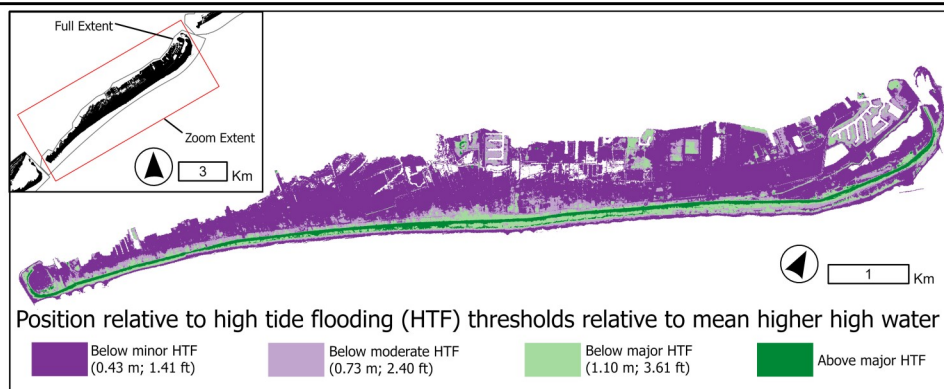


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	+	≈
Vegetated & Low (Estuarine Vegetated Wetland)	-	≈
Nonvegetated & High (Bare Land/Beach)	+	+
Nonvegetated & Low (Intertidal)	≈	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUZI>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P18X4JJ8>

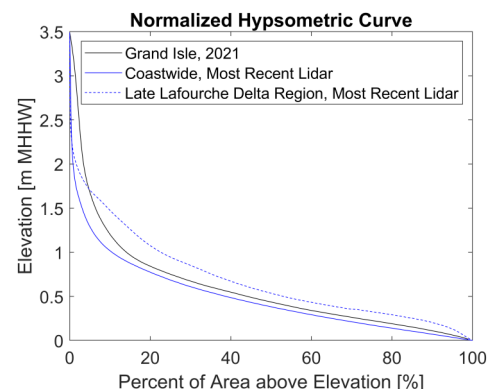
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	68.10	78.60	79.20
Below moderate	15.10	11.40	11.06
Below major	10.90	7.88	7.85
Above major	5.96	2.10	1.89



Hypsometric curve

Distribution of elevation relative to island area:

	Elevation (m relative to mean higher high water [MHHW])		
Percentile	Reach	Region	Coastwide
95	0.061	0.041	0.036
75	0.226	0.176	0.176
50	0.436	0.391	0.381
25	0.751	0.711	0.686
5	1.681	1.296	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NGO>.

Grand Pierre Island Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

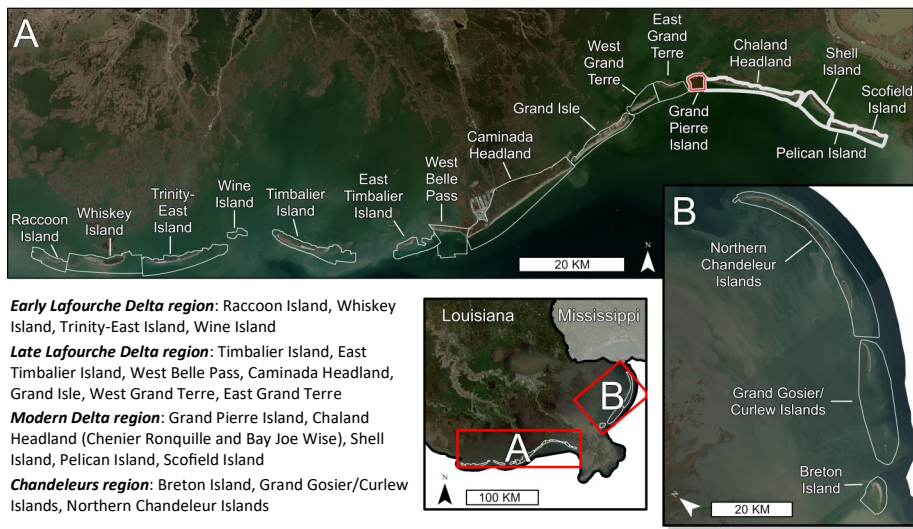
Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsillrestoration.noaa.gov/project?id=306>.



Location



Oblique imagery



Oblique image from 2023 showing Grand Pierre Island.

Restoration history

- None

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Ivan (H3)	2004	166 km
Katrina (H3)	2005	23 km
Zeta (H3)	2020	76 km
Ida (H4)	2021	43 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

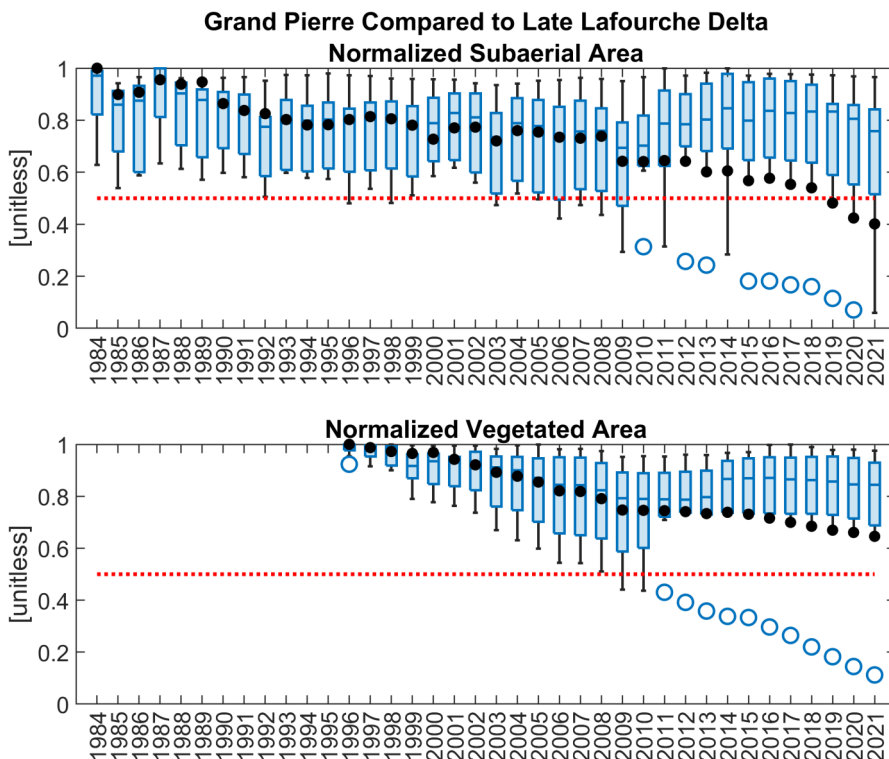
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

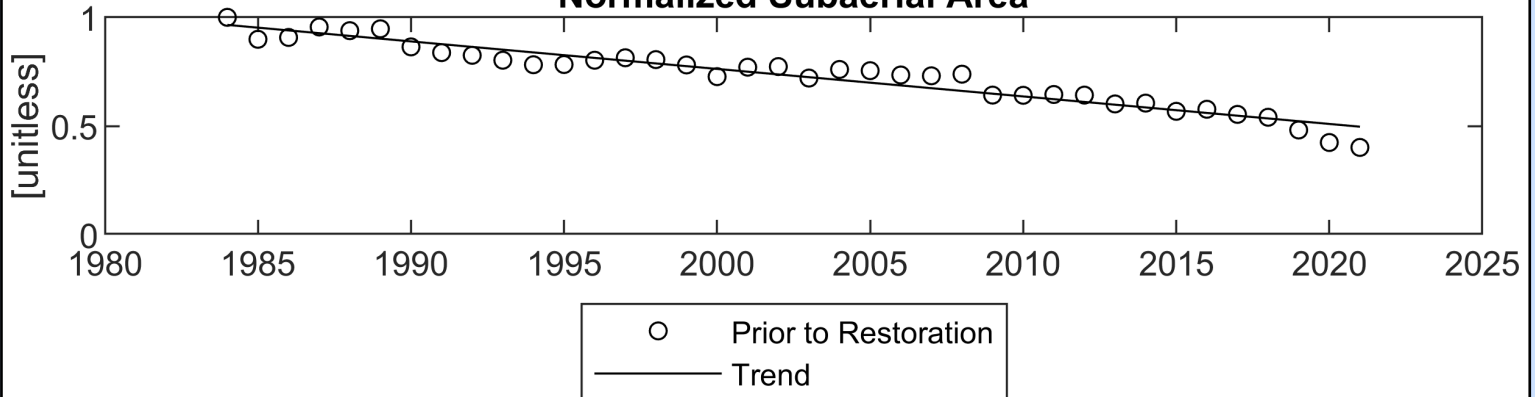
Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Resilience at Grand Pierre has steadily declined since the late 1980s. The subaerial area in 2021 was less than 50% of the area at its peak in 1985. Inspection of satellite imagery indicates a decline in area in 2020–2021 is associated with widening breach that initially developed during Hurricane Zeta. Vegetated area began to decline approximately ten years after subaerial area, but has decreased steadily since 1995.

Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?

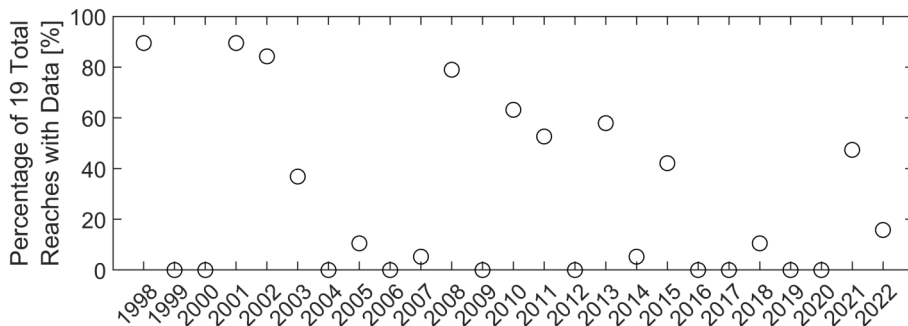
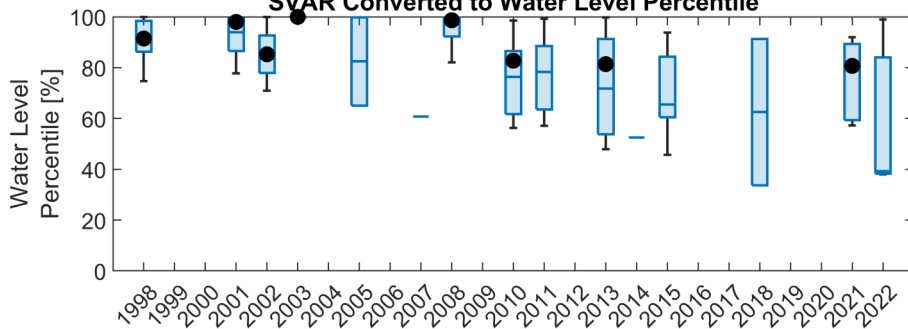
Normalized Subaerial Area



Results: Subaerial area has steadily declined from 1984 to 2021, with an apparent increase in loss rate starting in 2019.

What do data tell us about resistance to storms?

Grand Pierre Compared to Coastwide SVAR Converted to Water Level Percentile



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

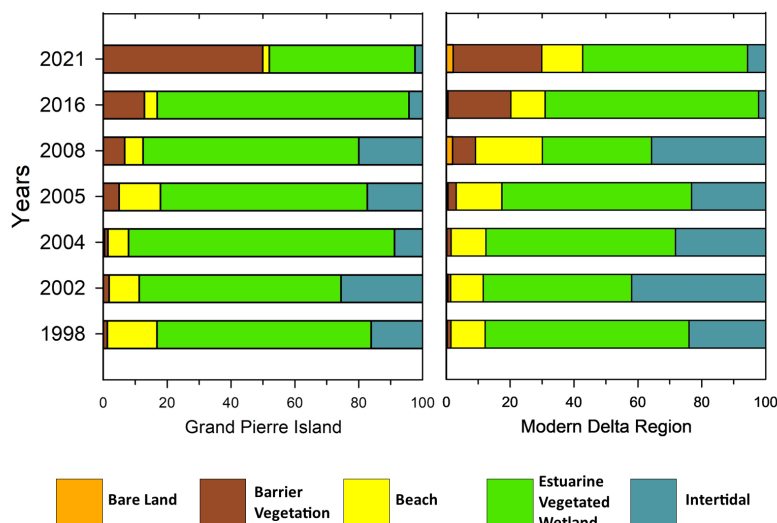
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: SVAR has been relatively consistent over time at Grand Pierre, with minor oscillations over time. However, maintaining SVAR does not allow the island to keep pace with sea-level rise, and SVAR has fallen below historical values at about the 90th percentile of water level.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*



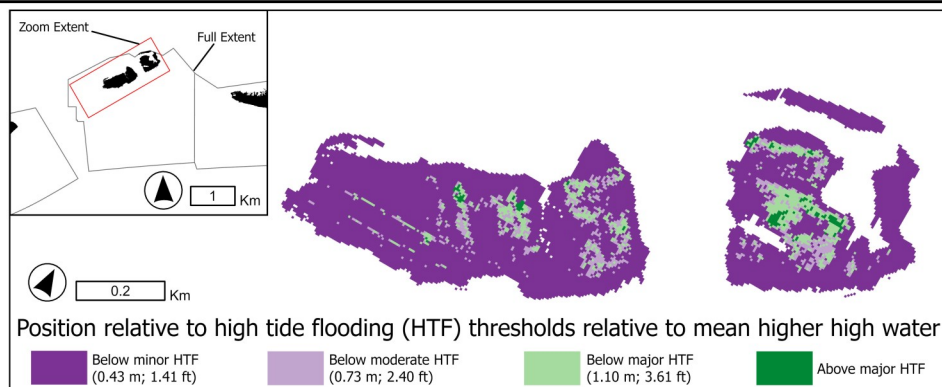
Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	+	+
Vegetated & Low (Estuarine Vegetated Wetland)	-	-
Nonvegetated & High (Bare Land/Beach)	≈	≈
Nonvegetated & Low (Intertidal)	≈	≈

Percentage point difference: +, > 5; -, < -5; and ≈, -5–5

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUJZ>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P1ZQP7SN>

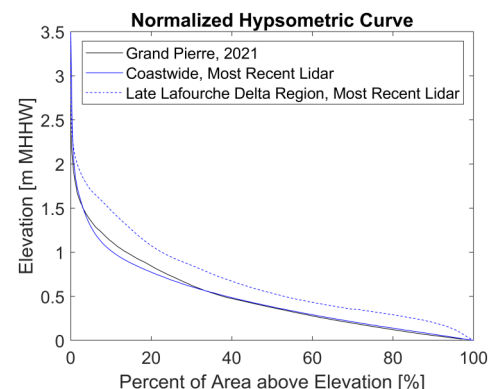
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	83.50	90.60	79.20
Below moderate	7.90	6.46	11.06
Below major	7.46	2.79	7.85
Above major	1.14	0.20	1.89



Hypsometric curve

Distribution of elevation relative to island area:

	Elevation (m relative to mean higher high water [MHHW])		
Percentile	Reach	Region	Coastwide
95	0.026	0.031	0.036
75	0.156	0.141	0.176
50	0.371	0.311	0.381
25	0.731	0.556	0.686
5	1.356	0.946	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NGO>.

Northern Chandeleur Islands Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

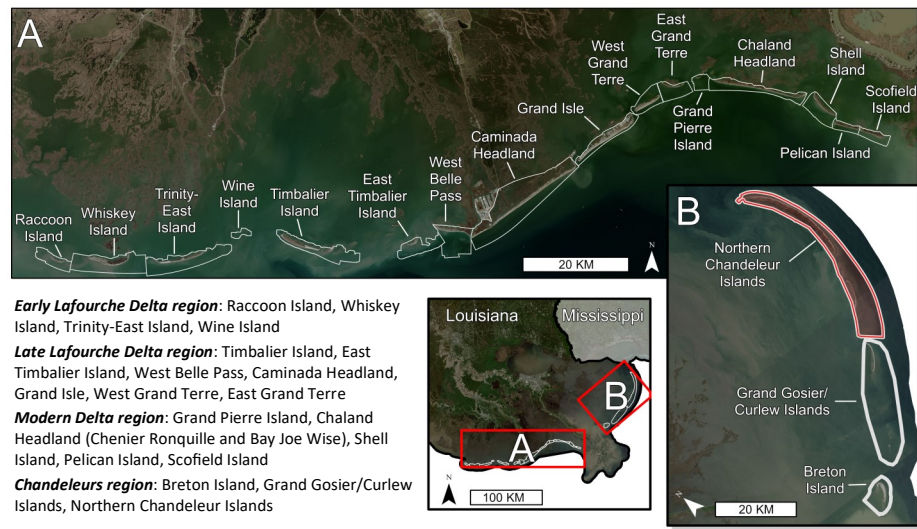
Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsplillrestoration.noaa.gov/project?id=306>.



Location



Oblique imagery



Oblique image from 2023 showing Northern Chandeleur Islands.

Restoration history

- Vegetative plantings for 364 acres in 2001 (PO-27)
- Emergency berm constructed using 5.9 million cubic yards (MCY) of sand in 2010 (LA-0163)

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Ivan (H3)	2004	90 km
Katrina (H3)	2005	80 km
Zeta (H3)	2020	174 km
Ida (H4)	2021	162 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

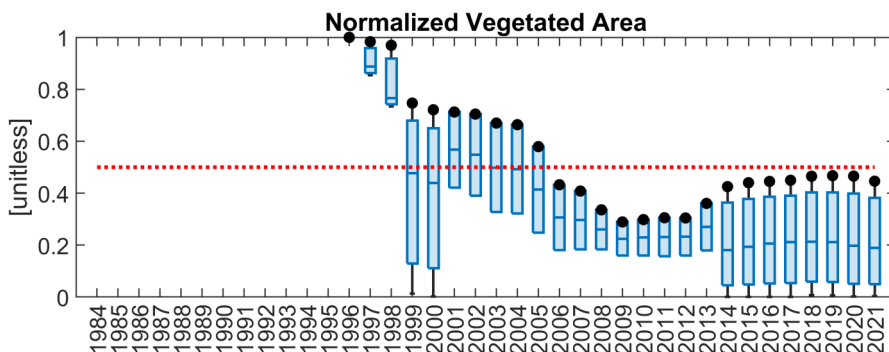
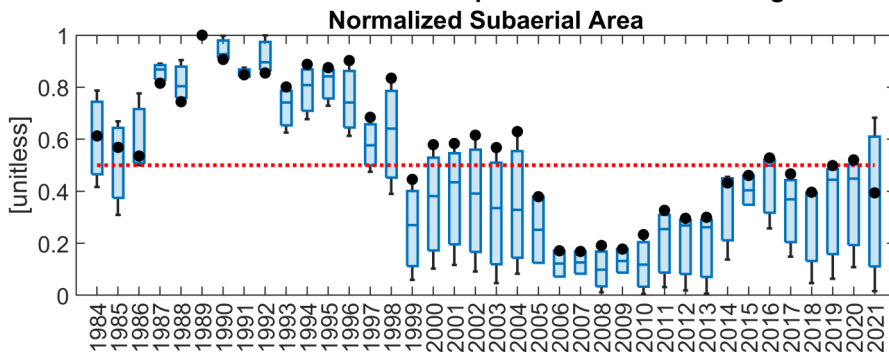
Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?

Northern Chandeleurs Compared to Chandeleurs Region



Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

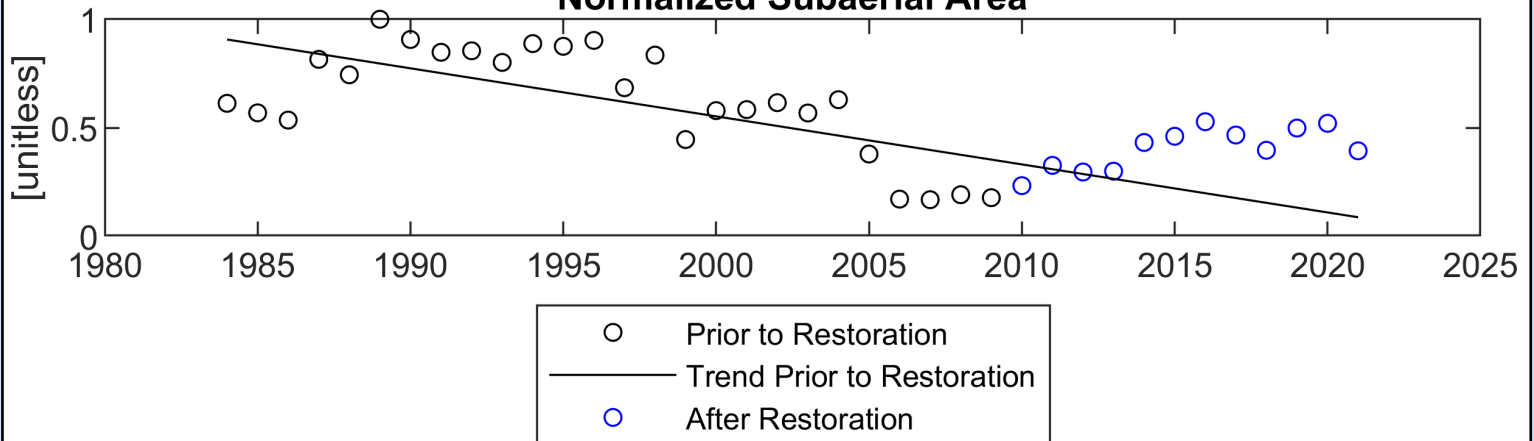
Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Subaerial and vegetated area at the Northern Chandeleur Islands steadily declined from peak values in the 1990s through 2005, with significant loss associated with the hurricanes of the early and mid-2000s. There was some recovery starting in 2010 with the construction of an emergency berm, with values relatively consistent at around 50% of their historic high from 2015–2021.

Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?

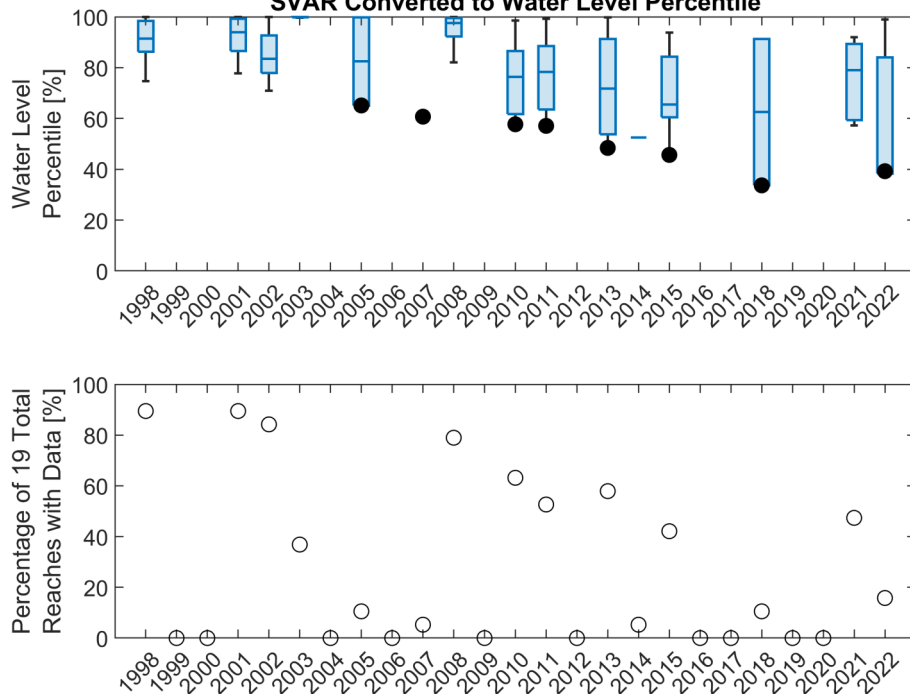
Normalized Subaerial Area



Results: Subaerial area declined steadily through the early 2000s, with modest recovery occurring since that time.

What do data tell us about resistance to storms?

Northern Chandeleurs Compared to Coastwide SVAR Converted to Water Level Percentile



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

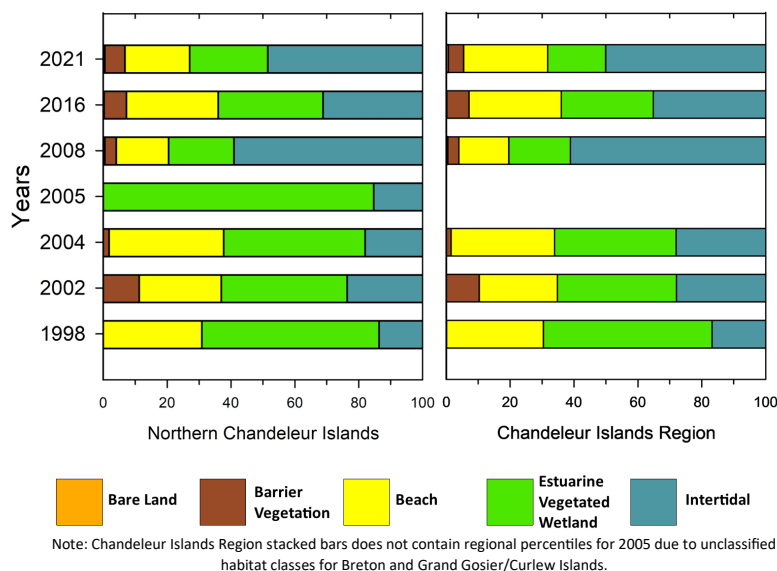
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: SVAR was low but fairly consistent from 2005 through the early 2020s, with the emergency berm having limited impact on this metric. As a result, SVAR has not kept paced with sea-level rise, and fell to between the 25th and 50th percentile of water level.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

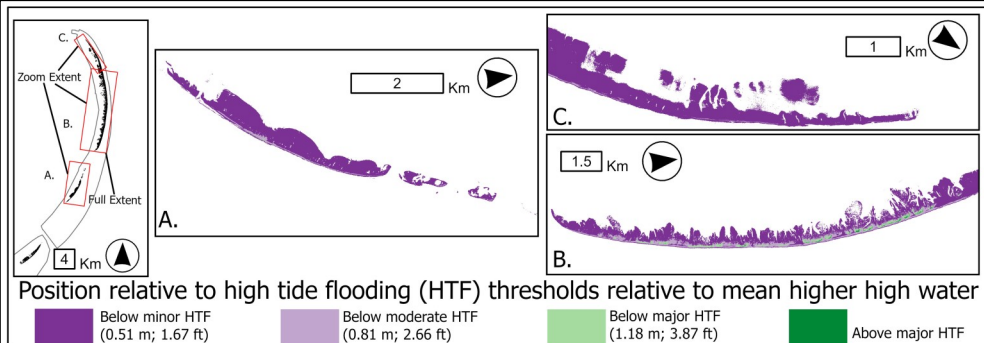


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	≈	+
Vegetated & Low (Estuarine Vegetated Wetland)	-	-
Nonvegetated & High (Bare Land/Beach)	-	≈
Nonvegetated & Low (Intertidal)	+	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUZI>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P19VXXH>

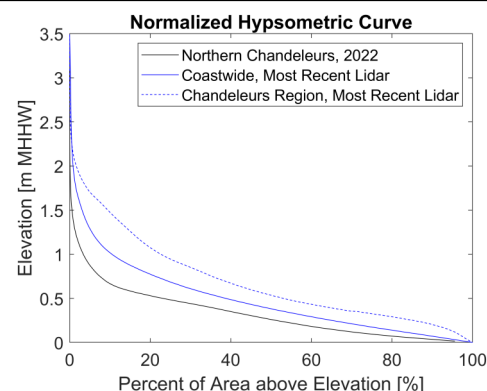
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	83.50	78.30	79.20
Below moderate	12.20	12.20	11.06
Below major	3.81	8.24	7.85
Above major	0.49	1.20	1.89



Hypsometric curve

Distribution of elevation relative to island area:

	Elevation (m relative to mean higher high water [MHHW])		
Percentile	Reach	Region	Coastwide
95	0.016	0.021	0.036
75	0.096	0.141	0.176
50	0.261	0.331	0.381
25	0.486	0.556	0.686
5	0.876	1.071	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the

Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NGQ>.

Pelican Island Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level (*pages 2–3*). This information tells us how the reach compares to other reaches in the region.

Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach.

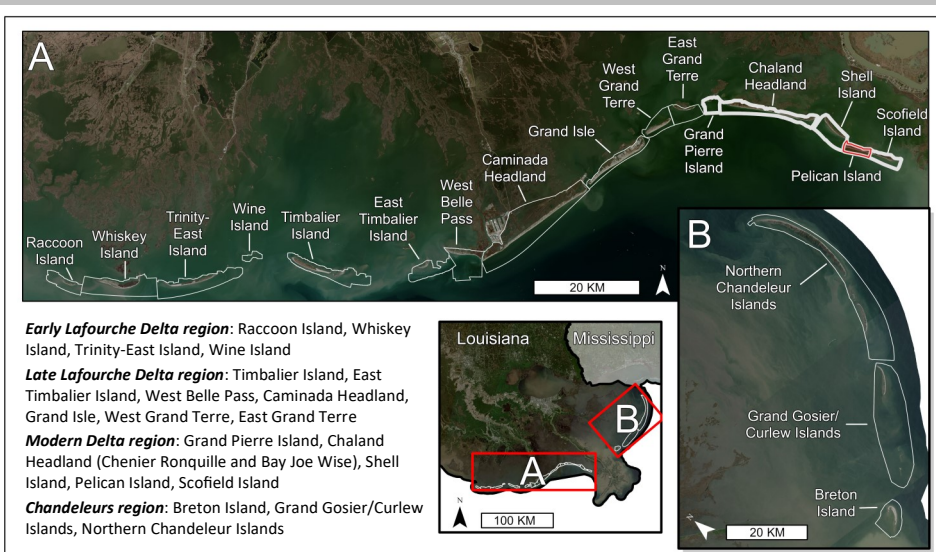
Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsplillrestoration.noaa.gov/project?id=306>.



April, 2026

Location



Oblique imagery



Oblique image from 2023 showing Pelican Island.

Restoration history

- Emergency berm placed offshore of 1.3 million cubic yards (MCY) of sand after the Deep Horizon oil spill in 2010 (LA-163)
- Sediment placement (6.4 MCY) to increase island height and width by creating 590 acres of restored habitat in 2011–2013 (BA-38-2)

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Ivan (H3)	2004	141 km
Katrina (H3)	2005	6 km
Zeta (H3)	2020	99 km
Ida (H4)	2021	62 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

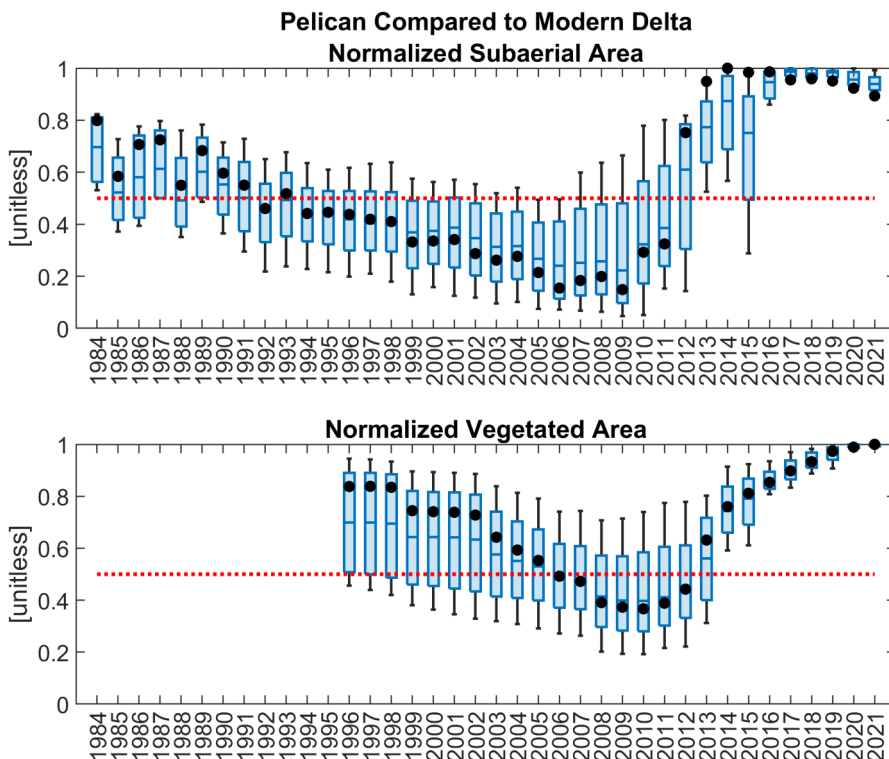
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

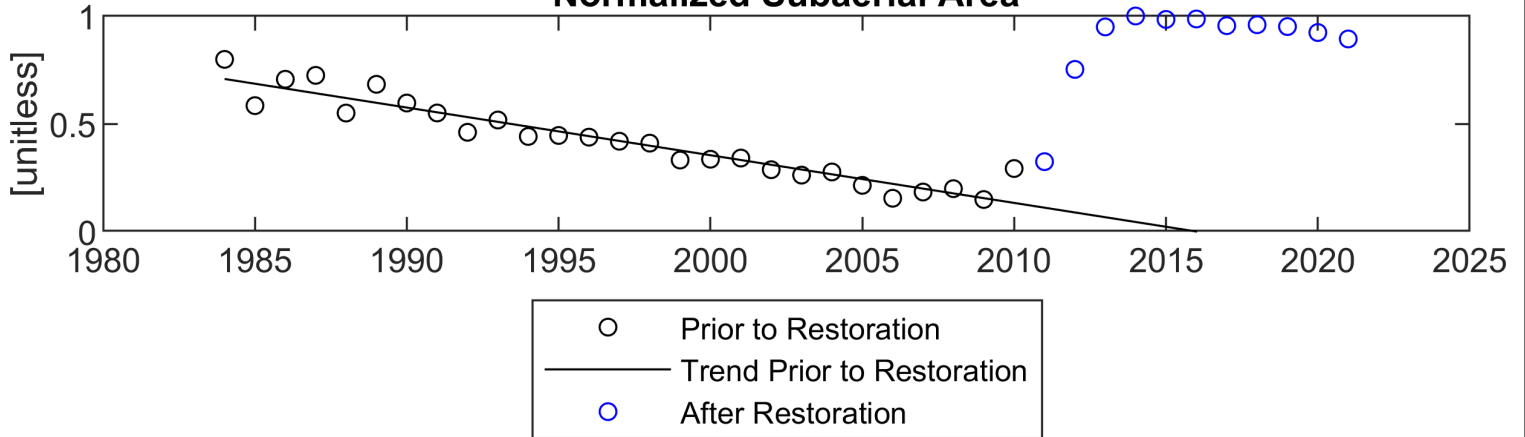
Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Pelican Island lost subaerial land area from 1985 through the mid 2000s. Sediment placement and restoration activities between 2010 and 2013 led to increased subaerial land area, which has subsequently begun to decline again. Vegetated area was gradually declining, but has increased following restoration.

Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?

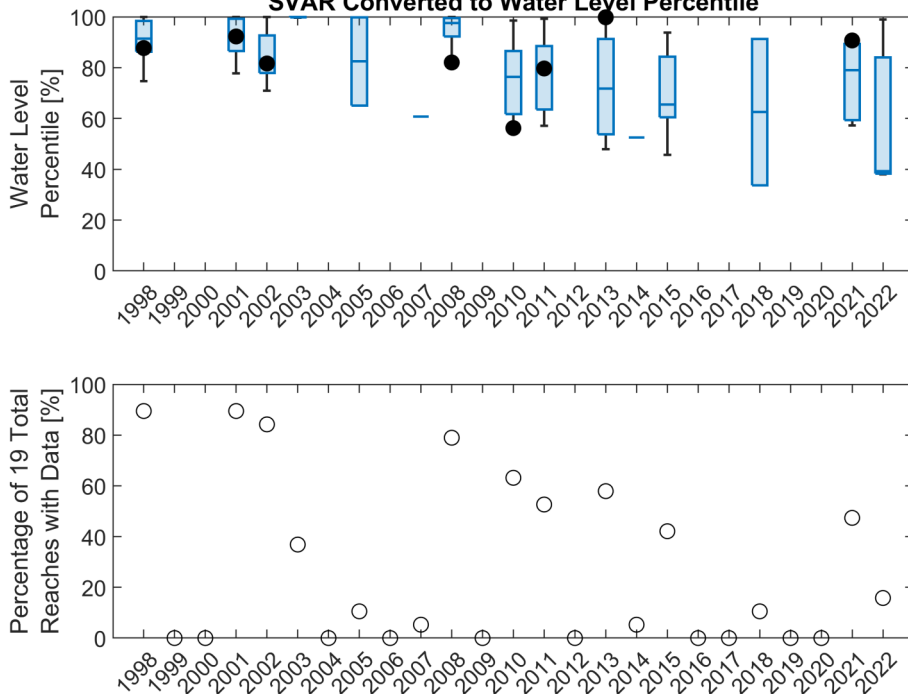
Normalized Subaerial Area



Results: Subaerial area was undergoing steady decline prior to increasing dramatically with restoration in 2010, which subsequently altered the trajectory of the reach.

What do data tell us about resistance to storms?

Pelican Compared to Coastwide SVAR Converted to Water Level Percentile



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

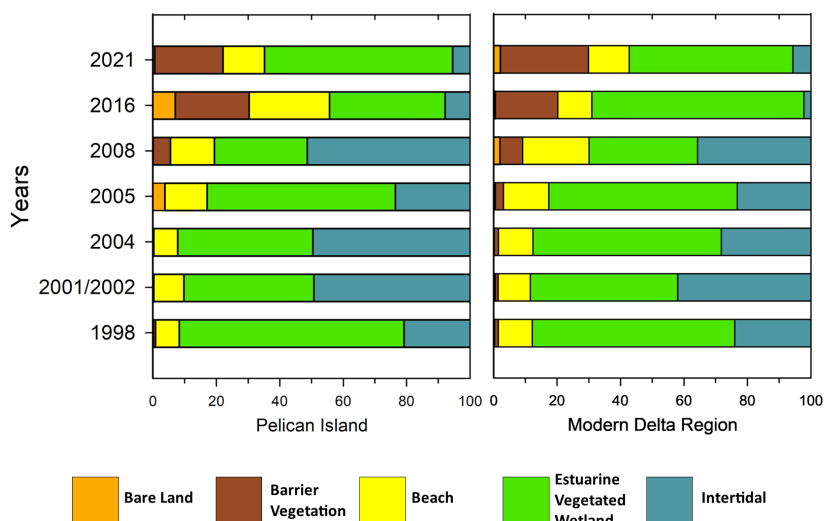
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: SVAR was at or slightly below the 90th percentile of water level in the early 2000s, decreasing relative to water level until restoration in 2010–2013 brought SVAR above the 99th percentile of water level. SVAR has decreased since that post-restoration peak.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

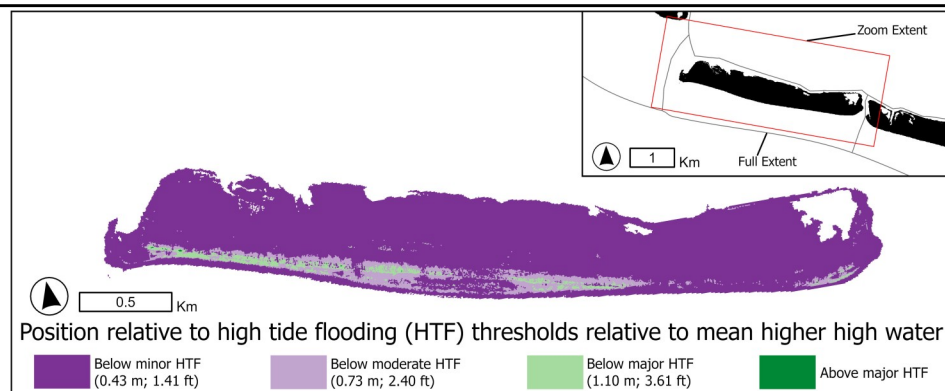


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	≈	+
Vegetated & Low (Estuarine Vegetated Wetland)	+	-
Nonvegetated & High (Bare Land/Beach)	-	≈
Nonvegetated & Low (Intertidal)	≈	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUZI>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P1ZQP7SN>

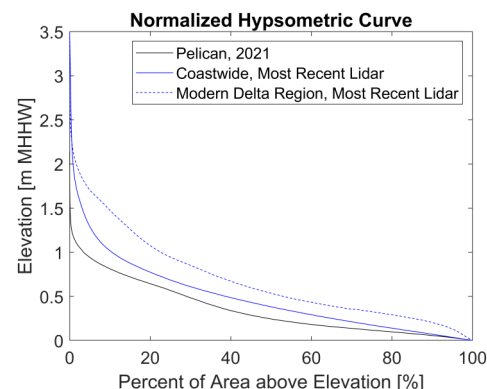
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	89.08	90.60	79.20
Below moderate	8.26	6.46	11.06
Below major	2.63	2.79	7.85
Above major	0.02	0.20	1.89



Hypsometric curve

Distribution of elevation relative to island area:

	Elevation (m relative to mean higher high water [MHHW])		
Percentile	Reach	Region	Coastwide
95	0.031	0.031	0.036
75	0.116	0.141	0.176
50	0.246	0.311	0.381
25	0.566	0.556	0.686
5	0.941	0.946	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NGO>.

Raccoon Island Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

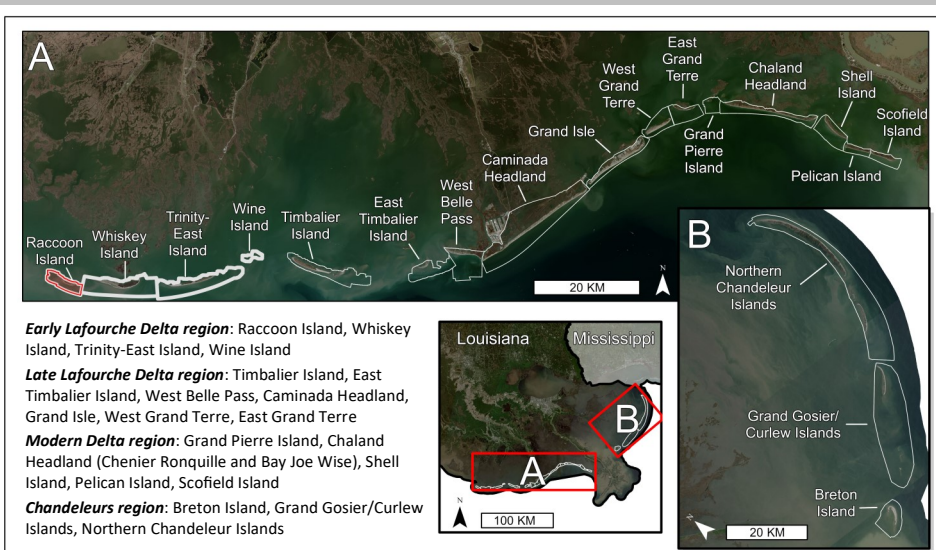
Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsillrestoration.noaa.gov/project?id=306>.



April, 2026

Location



Oblique imagery



Oblique image from 2023 showing Raccoon Island.

Restoration history

- Sediment placement of dredged sand (1.5 million cubic yard [MCY]) to repair storm damage/close breaches and vegetation planting to create habitats in 1993–1994 (TE-106)
- Rock breakwaters to reduce shoreline retreat and promote sediment accretion were added in 1997 (TE-29) and 2006–2008 (TE-48A)
- Sediment placement of mixed sediment (60 acres) to create marsh in 2012–2013 (TE-48B)

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Andrew (H4)	1992	48 km
Lili (H3)	2002	105 km
Katrina (H3)	2005	110 km
Rita (H3)	2005	110 km
Zeta (H3)	2020	100 km
Ida (H4)	2021	45 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

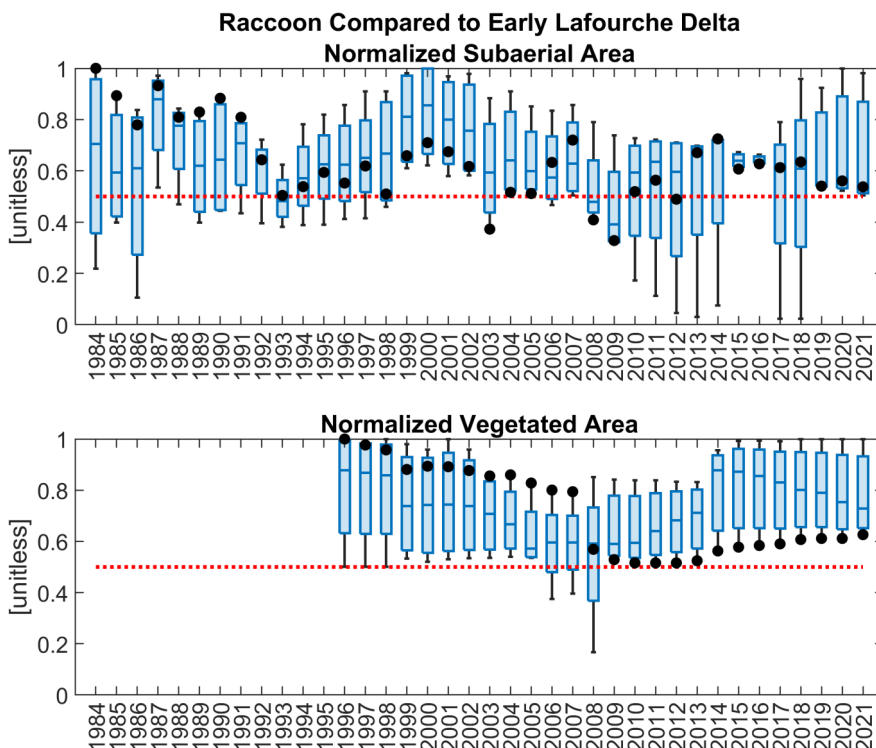
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



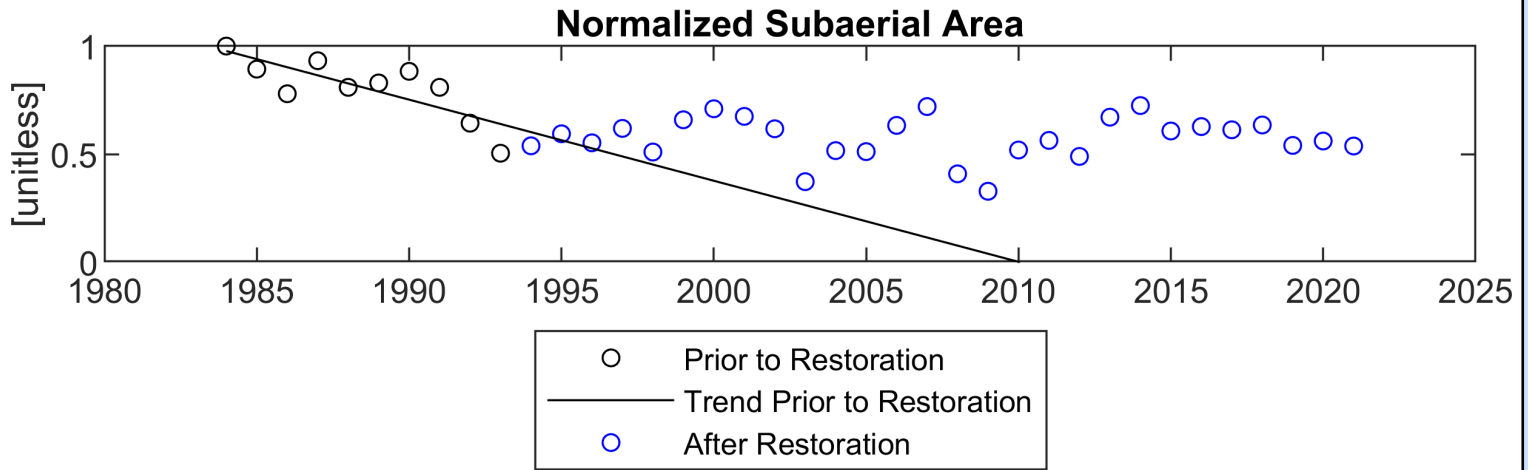
Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: The maximum subaerial land was in 1984, then gradually decreased until stabilizing in 1993 when sediment was placed on the island. The vegetated area also gradually decreased from the 1990s until Hurricanes Katrina and Rita in the mid-2000s. The marsh creation project in 2012–2013 has not fully vegetated and vegetation has shown only minor increases since the late 2000s.

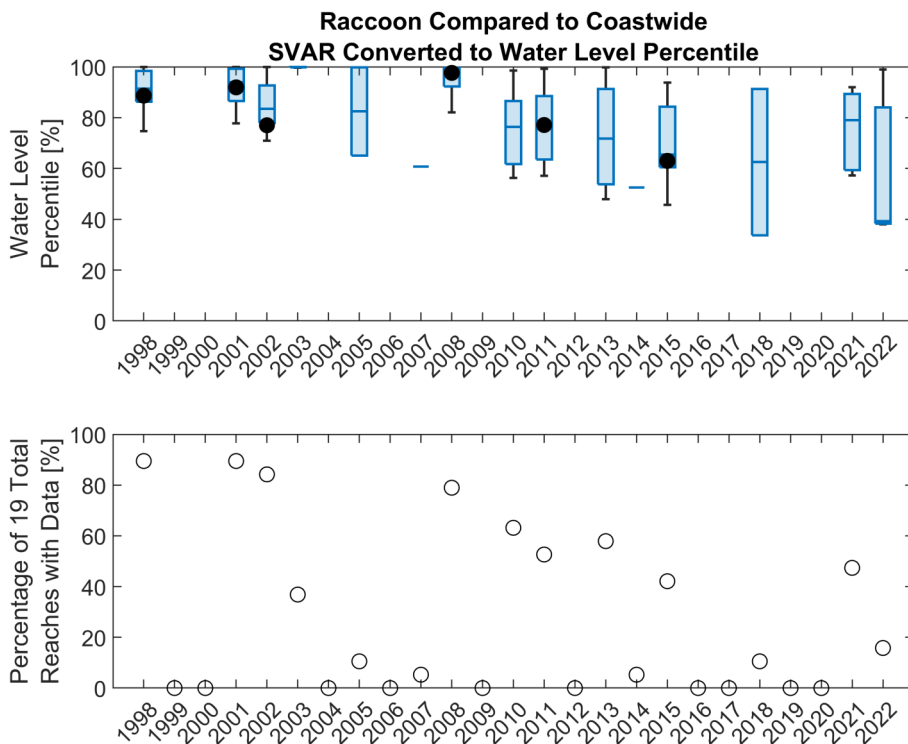
Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?



Results: Prior to restoration there was a decreasing trend in subaerial area, but since restoration the subaerial area has stabilized.

What do data tell us about resistance to storms?



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

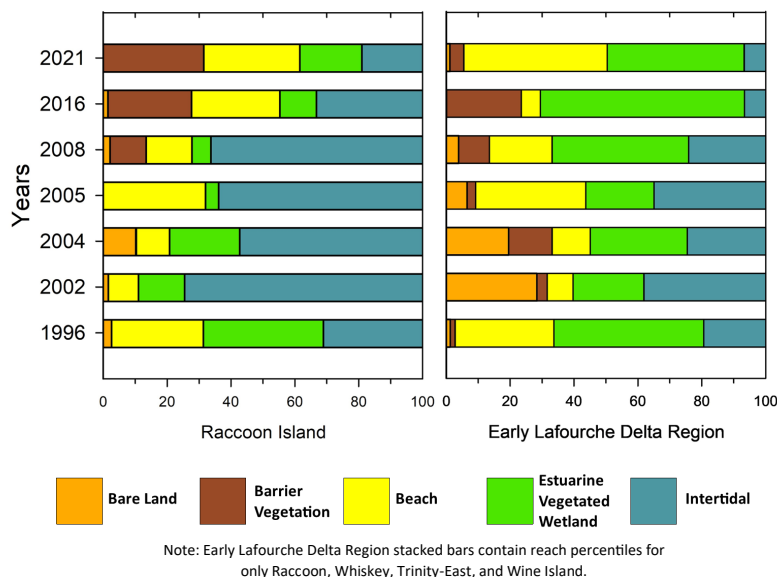
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Other than a high in 2008, SVAR at has generally been between the 50th and 90th water level percentile. SVAR was steady from 2010–2015, and therefore fell relative to water level percentile as a result of sea-level rise.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

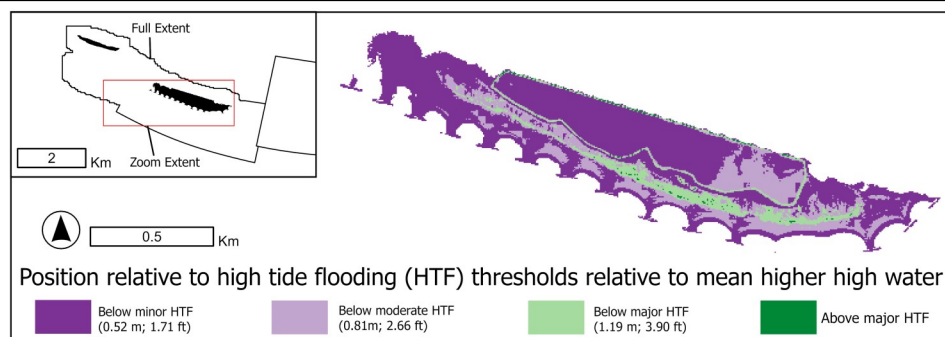


Zone	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	+	-
Vegetated & Low (Estuarine Vegetated Wetland)	+	-
Nonvegetated & High (Bare Land & Beach)	≈	+
Nonvegetated & Low (Intertidal)	-	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUZI>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P13ECWEM>

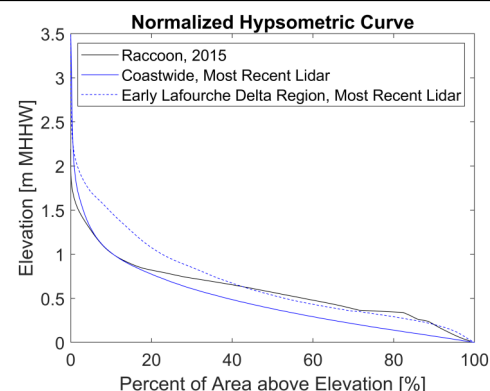
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	70.70	65.30	79.20
Below moderate	21.00	13.90	11.06
Below major	7.77	15.50	7.85
Above major	5.75	5.30	1.89



Hypsometric curve

Distribution of elevation relative to island area:

	Elevation (m relative to mean higher high water [MHHW])		
Percentile	Reach	Region	Coastwide
95	0.086	0.131	0.036
75	0.356	0.326	0.176
50	0.566	0.536	0.381
25	0.771	0.946	0.686
5	1.271	1.706	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J. -F., Cottam, A., Gorelick, N., and Belward, A. S. (2016). High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS) (2022). Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NG0>.

Scofield Island Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

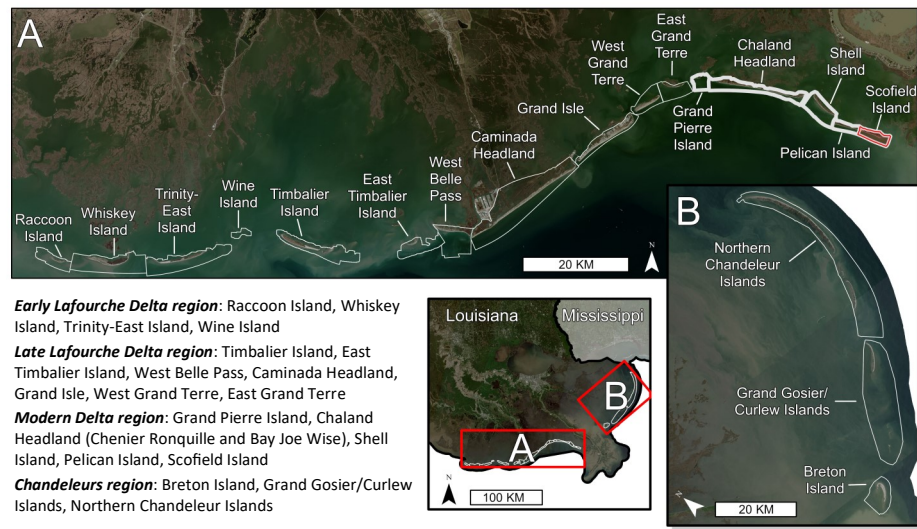
Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsplillrestoration.noaa.gov/project?id=306>.



Location



Oblique imagery



Oblique image from 2023 showing Scofield Island.

Restoration history

- Emergency berm placed offshore of 0.9 million cubic yards (MCY) of sand after the Deep Horizon oil spill in 2010 (LA-163)
- Sediment placement (4.7 MCY) to increase island height and width by creating 598 acres of restored habitat in 2012–2013 (BA-40)

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Ivan (H3)	2004	136 km
Katrina (H3)	2005	9 km
Zeta (H3)	2020	103 km
Ida (H4)	2021	66 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

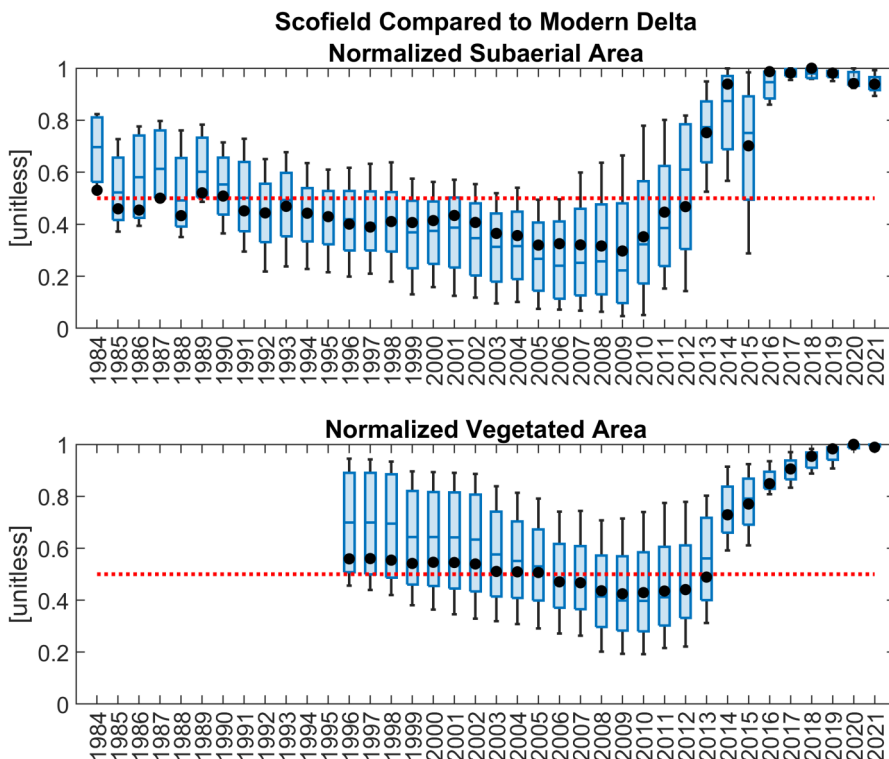
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

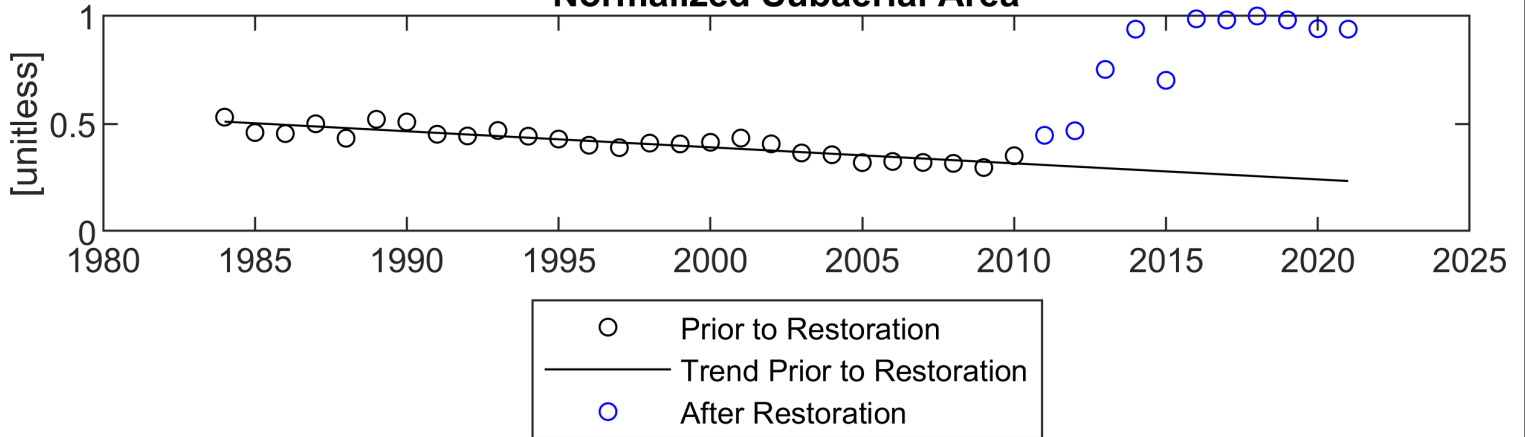
Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Scofield Island had modest declines in subaerial land area from 1985 through 2010 when sediment placement occurred. The vegetated area followed a similar pattern from 1996 to 2010. Sediment placement to restore the island subaerial land area and, later, vegetated area led the metrics to their highest level over the period of analysis. Both metrics have had only slight declines in the years since.

Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?

Normalized Subaerial Area

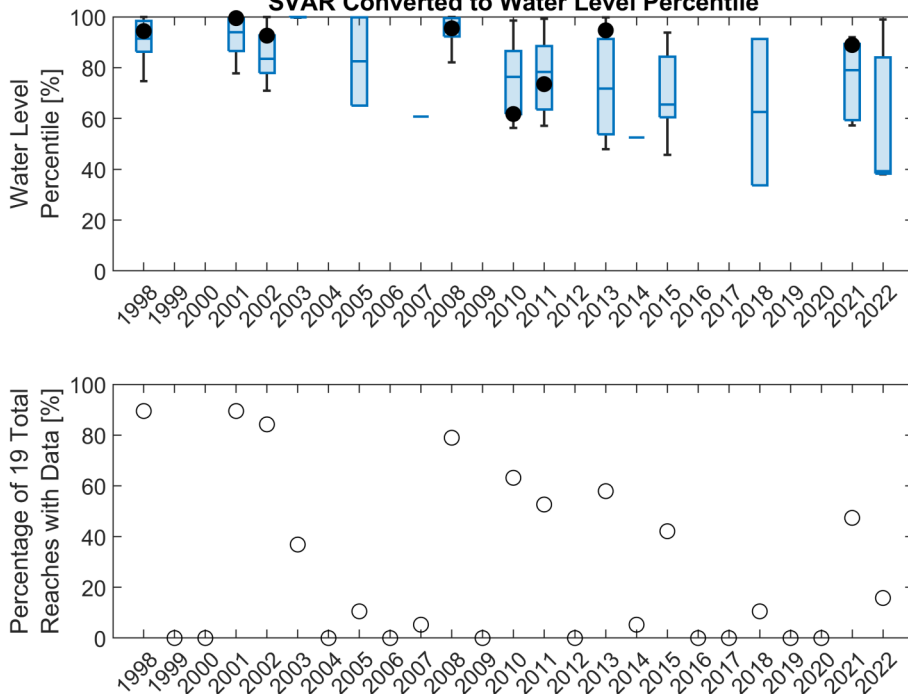


Results: Subaerial area decreased steadily prior to a dramatic increase with restoration in 2010, which has subsequently altered the trajectory of the reach.

What do data tell us about resistance to storms?

Scofield Compared to Coastwide

SVAR Converted to Water Level Percentile



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

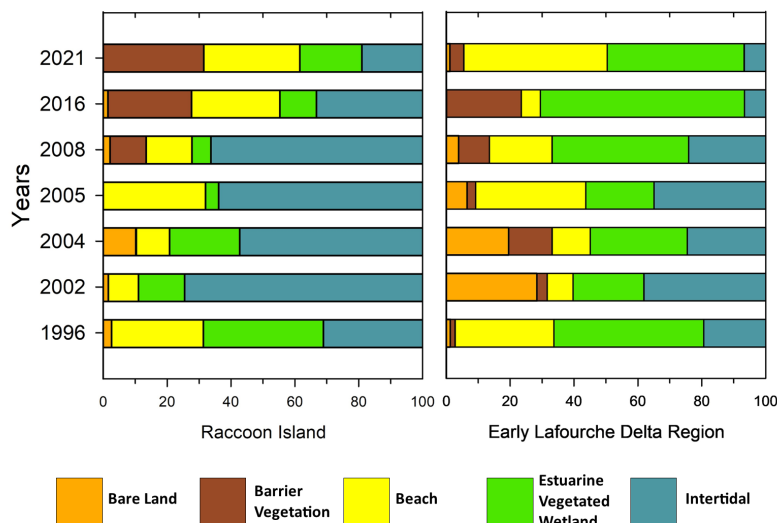
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: SVAR was consistently above the 90th percentile of water level through the early 2000s, falling below that benchmark by 2010. Sediment placement restored the island to be above the 95th percentile water level, where it still remained in 2021.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

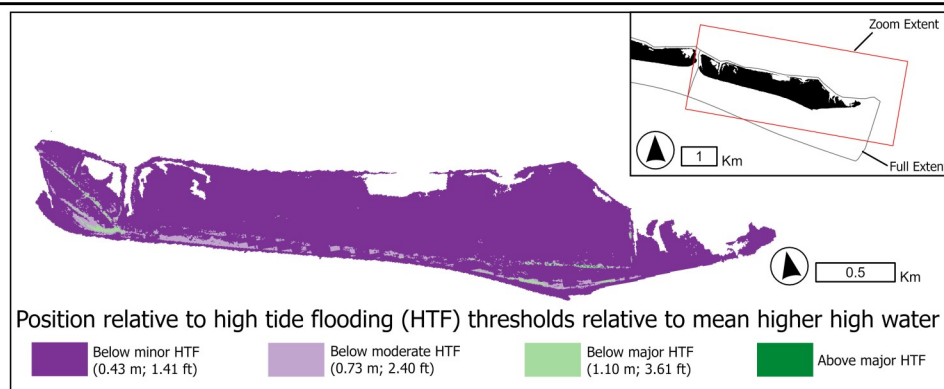


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	≈	+
Vegetated & Low (Estuarine Vegetated Wetland)	+	-
Nonvegetated & High (Bare Land/Beach)	-	≈
Nonvegetated & Low (Intertidal)	-	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5-5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes 3 or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUZI>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P1ZQP7SN>.

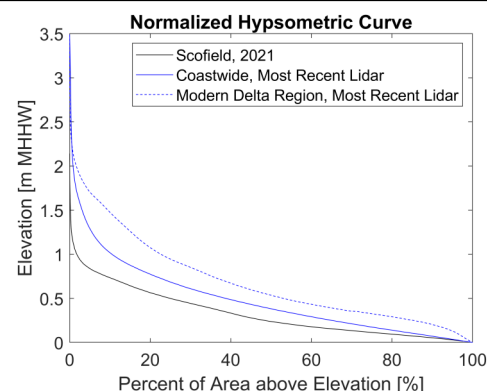
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	94.70	90.60	79.20
Below moderate	4.21	6.46	11.06
Below major	1.00	2.79	7.85
Above major	0.04	0.20	1.89



Hypsometric curve

Distribution of elevation relative to island area:

	Elevation (m relative to mean higher high water [MHHW])		
Percentile	Reach	Region	Coastwide
95	0.031	0.031	0.036
75	0.116	0.141	0.176
50	0.236	0.311	0.381
25	0.501	0.556	0.686
5	0.836	0.946	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NG0>.

Shell Island Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

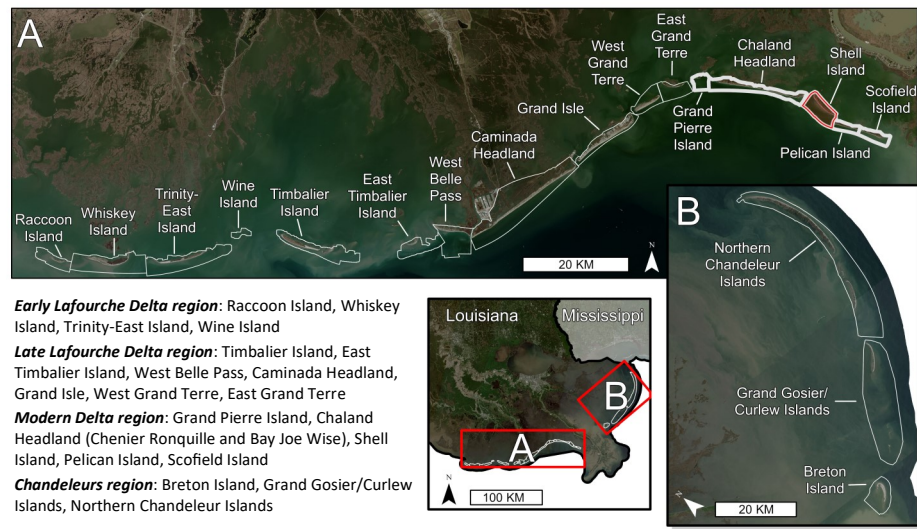
Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsplillrestoration.noaa.gov/project?id=306>.



Location



Oblique imagery



Oblique image from 2023 showing Shell Island.

Restoration history

- Emergency berm placed offshore of 0.8 million cubic yards (MCY) of sand after the Deepwater Horizon oil spill in 2010 (LA-163)
- Sediment placement (3.0 MCY) to increase island height and width by creating 277 acres of dune/beach/marsh habitat in 2013 (BA-110)

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Ivan (H3)	2004	145 km
Katrina (H3)	2005	4 km
Zeta (H3)	2020	95 km
Ida (H4)	2021	59 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

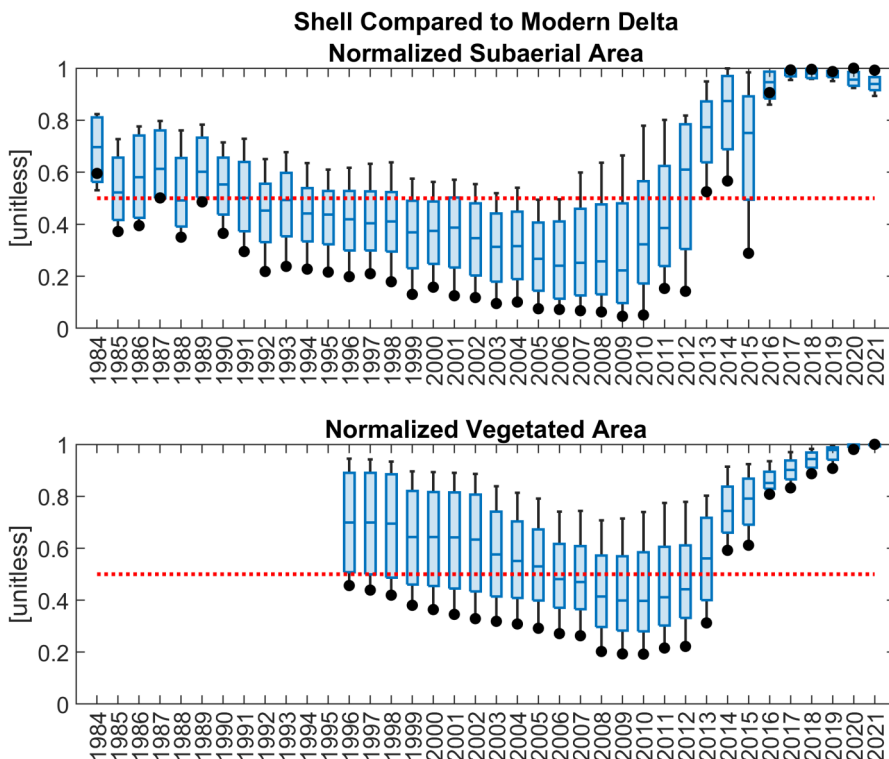
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

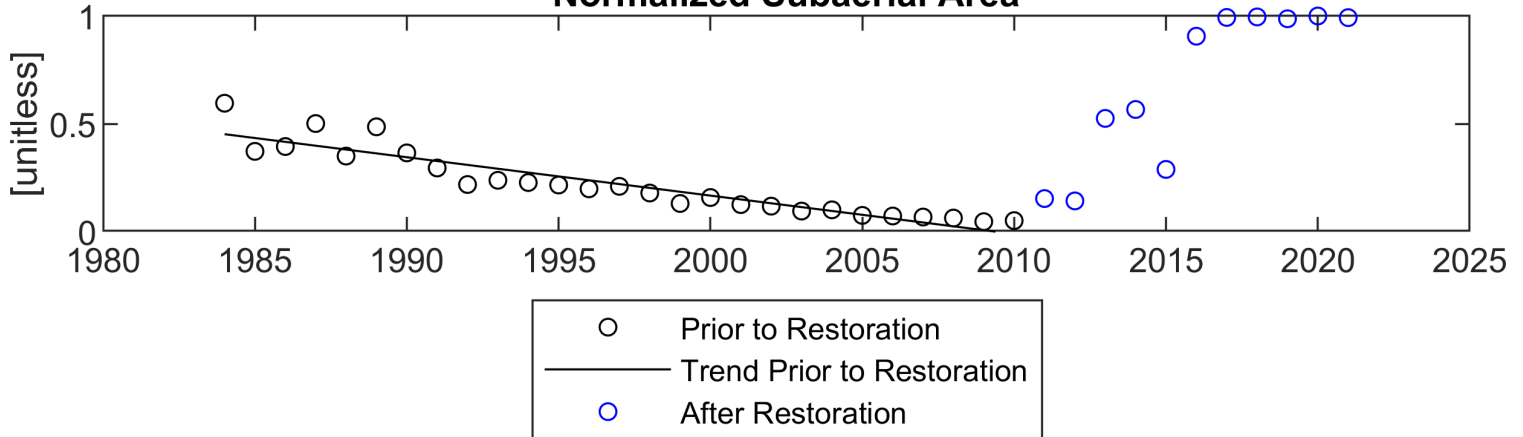
Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Subaerial land area decreased steadily from highs in the 1980s and 1990s to a low in 2010. Vegetated area followed a similar trend. Restoration activities in 2010–2018 dramatically increased the islands subaerial and vegetated areas, which remain at the highest levels observed over the period of record.

Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?

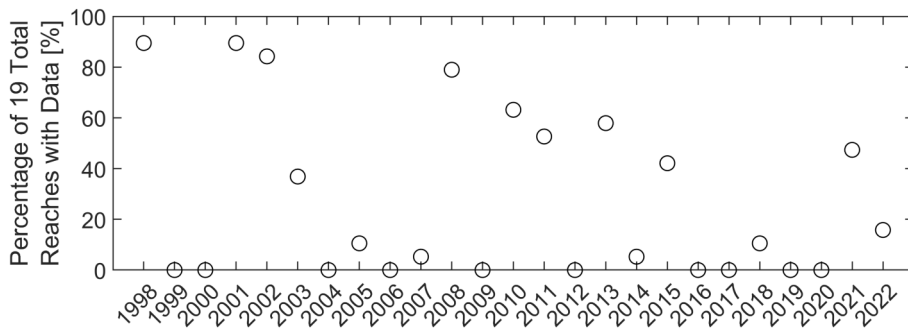
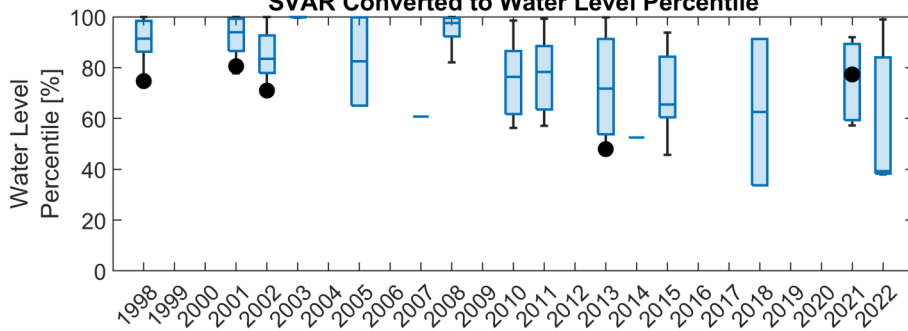
Normalized Subaerial Area



Results: Subaerial area decreased steadily prior to increasing dramatically since restoration in 2013 altered the trajectory of the reach.

What do data tell us about resistance to storms?

Shell Compared to Coastwide SVAR Converted to Water Level Percentile



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

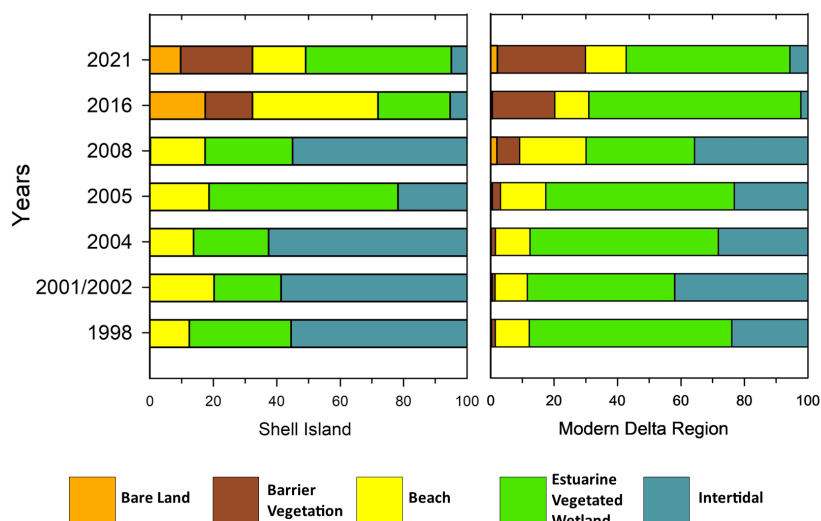
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: SVAR at Shell Island has been relatively consistent over time compared to water level, remaining between the 50th and 90th percentiles. Sediment placement has, however, allowed SVAR to keep pace with sea-level rise over time.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

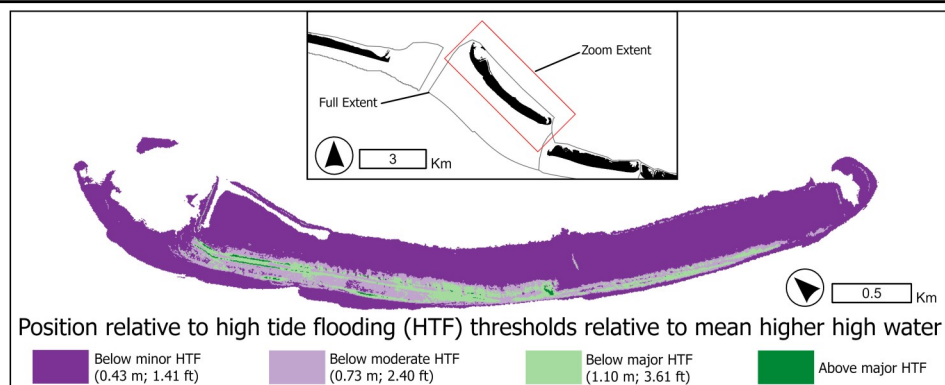


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	+	+
Vegetated & Low (Estuarine Vegetated Wetland)	+	-
Nonvegetated & High (Bare Land/Beach)	-	≈
Nonvegetated & Low (Intertidal)	≈	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUJZ>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P1ZQP7SN>

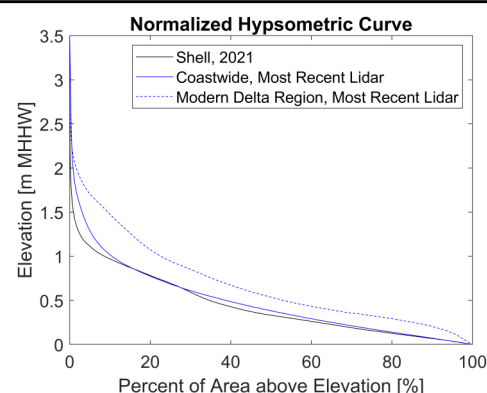
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	78.50	90.60	79.20
Below moderate	12.90	6.46	11.06
Below major	8.06	2.79	7.85
Above major	0.55	0.20	1.89



Hypsometric curve

Distribution of elevation relative to island area:

	Elevation (m relative to mean higher high water [MHHW])		
Percentile	Reach	Region	Coastwide
95	0.036	0.031	0.036
75	0.156	0.141	0.176
50	0.336	0.311	0.381
25	0.696	0.556	0.686
5	1.116	0.946	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NGO>.

Timbalier Island Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

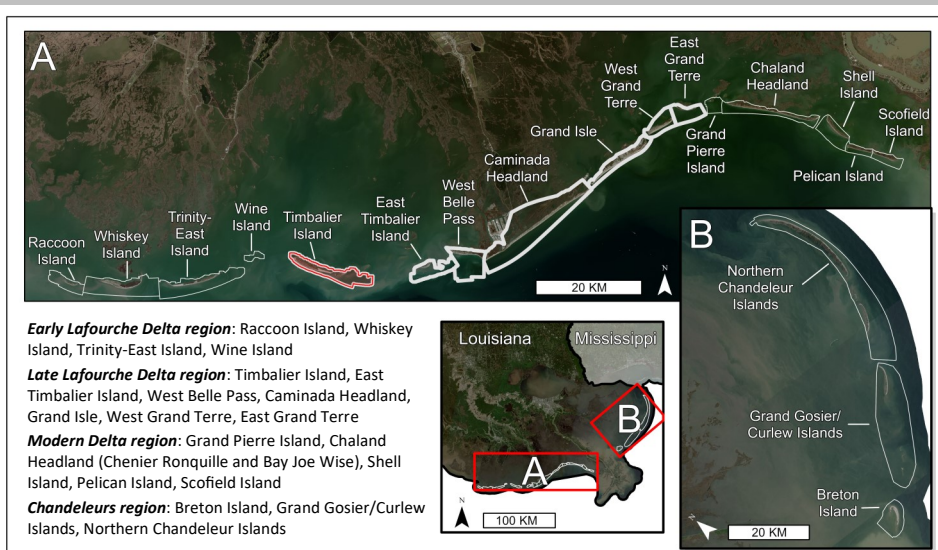
Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsillrestoration.noaa.gov/project?id=306>.



Location



Oblique imagery



Oblique image from 2023 showing Timbalier Island.

Restoration history

- Sand fences and compatible vegetation planting in 1996 (TE-18) to retain sand and buffer wind/wave energy
- Sediment placement (4.6 million cubic yards [MCY]) in 2004 (TE-40) to increase the height of the island and nourish the marsh on the island’s eastern end to create 273 acres of habitats
- Sediment placement (9.0 MCY) focused on the center of the island to create 1,080 acres of total habitats in 2022 (TE-143); note the area/volume may span multiple reaches

Storm history (1985–2021)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Lili (H3)	2002	139 km
Katrina (H3)	2005	92 km
Zeta (H3)	2020	17 km
Ida (H4)	2021	18 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

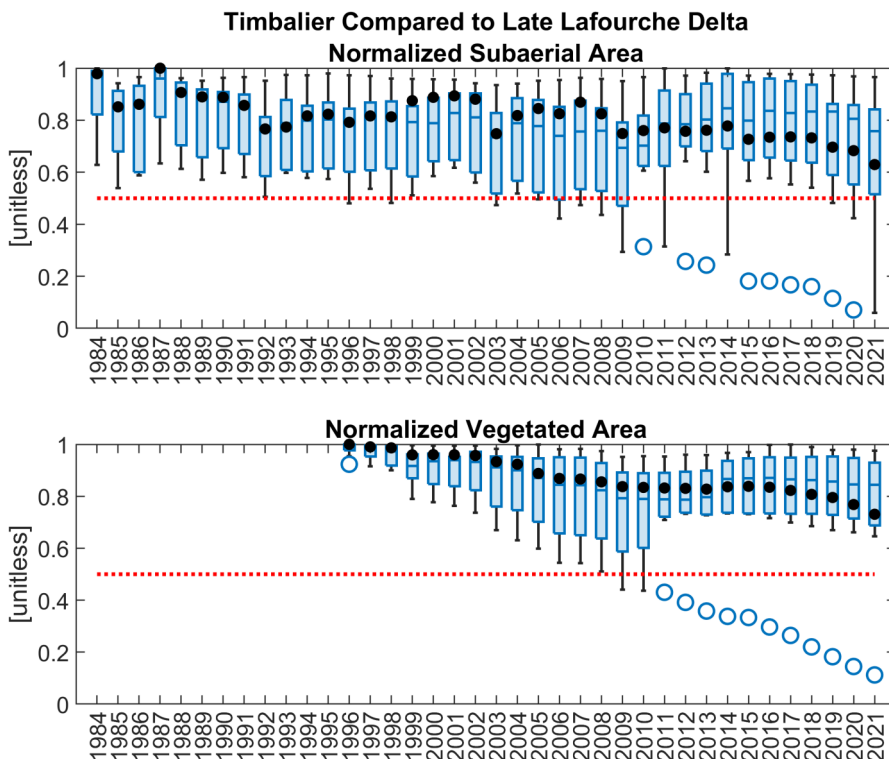
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



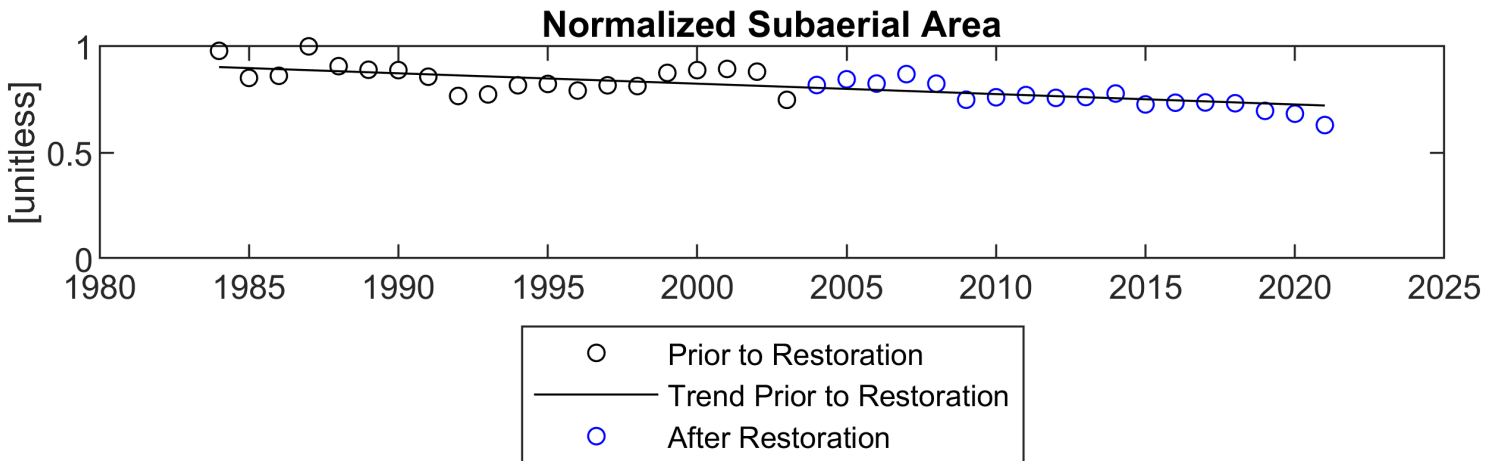
Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: The maximum subaerial area occurred in the mid-1980s and has gradually decreased over the observation period. The restoration in 2004 showed a slight increase in subaerial land, but island resilience has gradually decreased since that restoration action. The vegetated area has mirrored the trend for subaerial land with a gradual decrease over time.

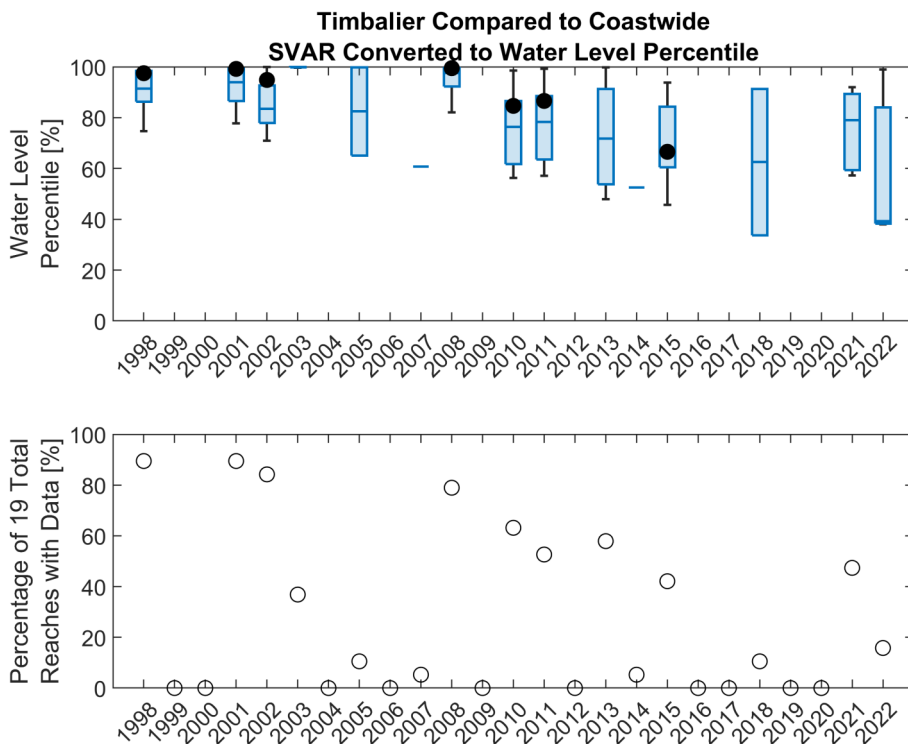
Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?



Results: Subaerial area has undergone a slow but steady decline since 1985. Sediment placement in 2004 had a limited impact, while the most recent restoration (in 2022) was after the analysis period.

What do data tell us about resistance to storms?



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

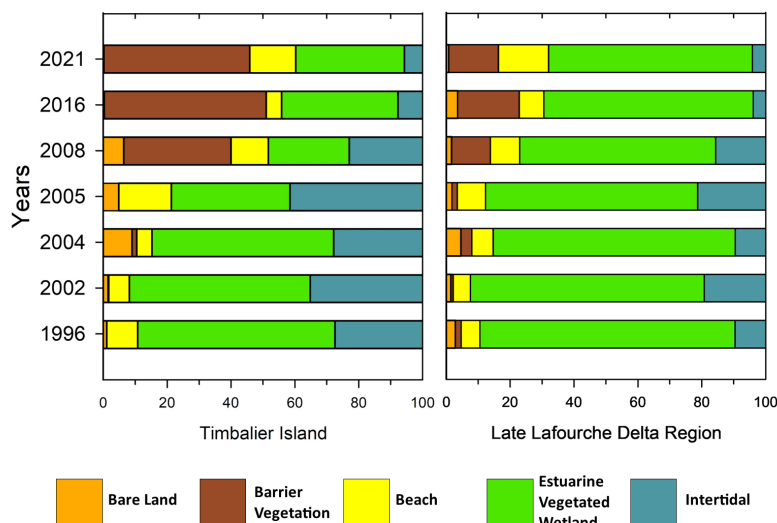
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Recent observations show SVAR has typically fallen between the 50th and 90th water level percentile. SVAR has generally tracked with sea-level rise, but there is evidence of lower resistance with the 2015 SVAR value being only slightly above the 50th water level percentile.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

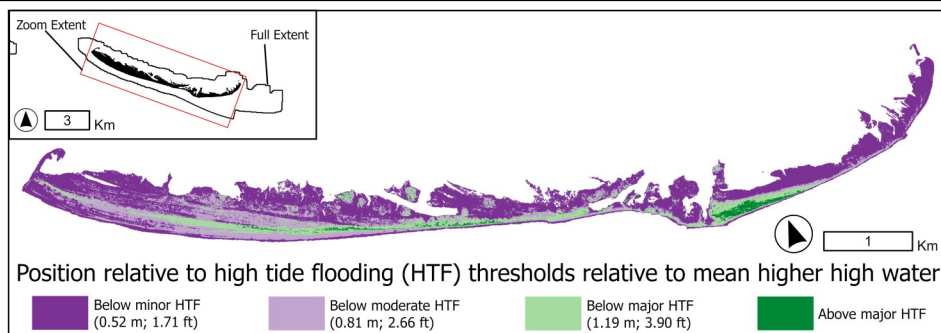


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	-	≈
Vegetated & Low (Estuarine Vegetated Wetland)	≈	≈
Nonvegetated & High (Bare Land/Beach)	+	+
Nonvegetated & Low (Intertidal)	≈	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUZJ>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P18X4JJ8>

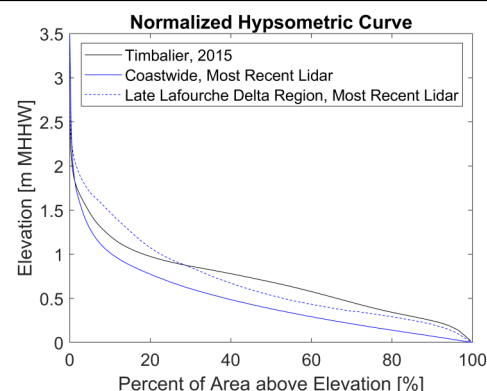
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	60.80	78.60	79.20
Below moderate	23.70	11.40	11.06
Below major	13.03	7.88	7.85
Above major	2.53	2.10	1.89



Hypsometric curve

Distribution of elevation relative to island area:

Elevation (m relative to mean)			
Percentile	Reach	Region	Coastwide
95	0.171	0.041	0.036
75	0.396	0.176	0.176
50	0.686	0.391	0.381
25	0.911	0.711	0.686
5	1.471	1.296	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NGQ>.

Trinity-East Island Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

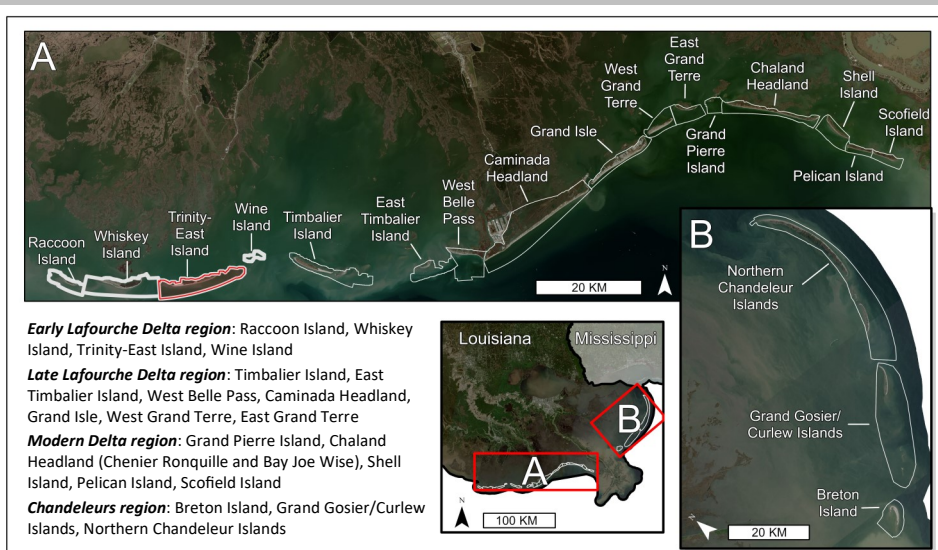
Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsplillrestoration.noaa.gov/project?id=306>.



Location



Oblique imagery



Oblique image from 2023 showing Trinity-East Island.

Restoration history

- Two sediment placements to build beach, dune, and elevated marsh (3.9 million cubic yards [MCY] & 4.8 MCY) in 1998–1999 to increase the width and height of the island by 353 acres. Vegetation planted to stabilize sand and minimize transport (TE-20 & TE-24)
- Sediment placement (1.0 MCY) in 2007 to close a breach and vegetation was planted (TE-37)
- Sediment placement (9.0 MCY) focused on the center of the island to create 1,080 acres in 2022 (TE-143); note, the area/volume may span multiple reaches

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Lili (H3)	2002	125 km
Katrina (H3)	2005	112 km
Zeta (H3)	2020	20 km
Ida (H4)	2021	35 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

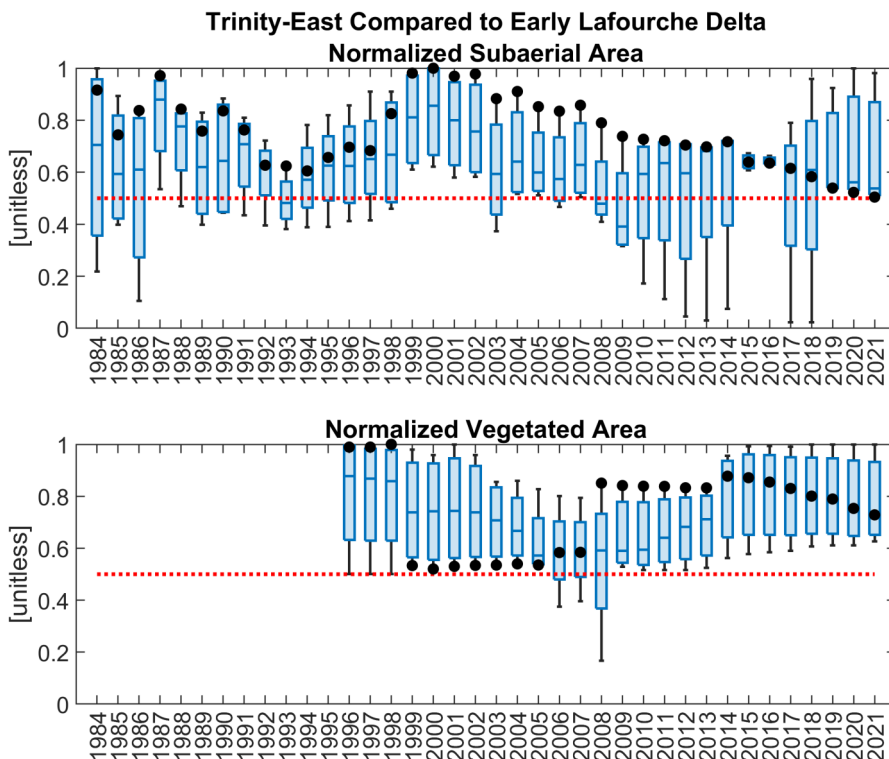
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



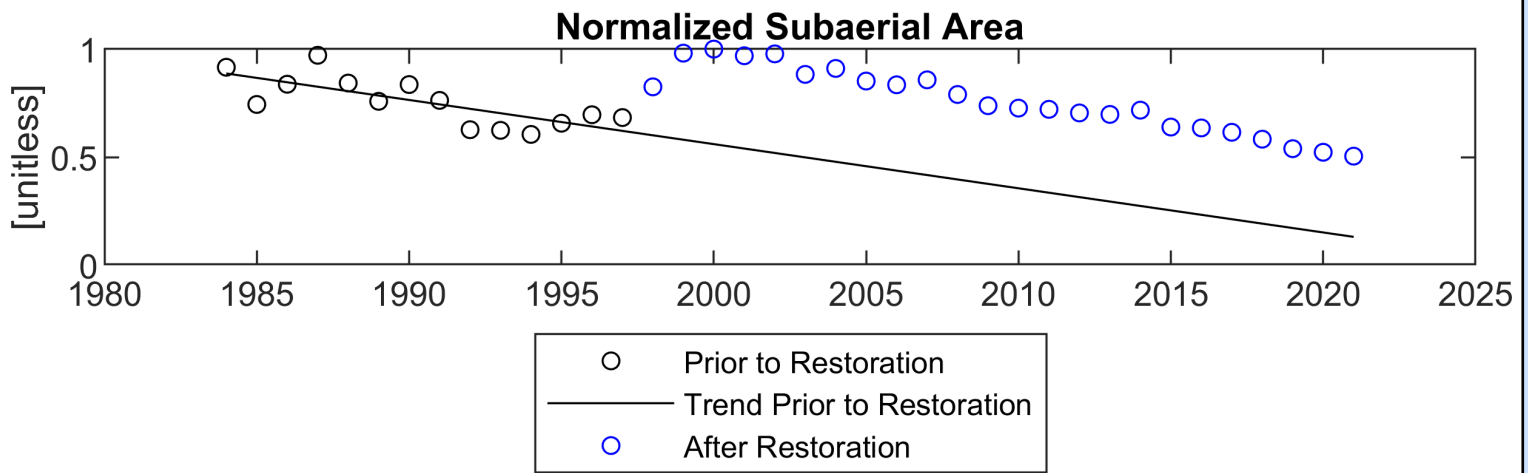
Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Total subaerial area was high in the mid-1980s before declining to the mid-1990s. The subaerial area was highest after the 1998–1998 restoration. After this point, there was a gradual decline of subaerial land through 2021. Vegetated area sharply dropped in the late 1990s, some of which could have been a result of sediment placement. Vegetated area increased several years after the restoration and has been fairly stable since then.

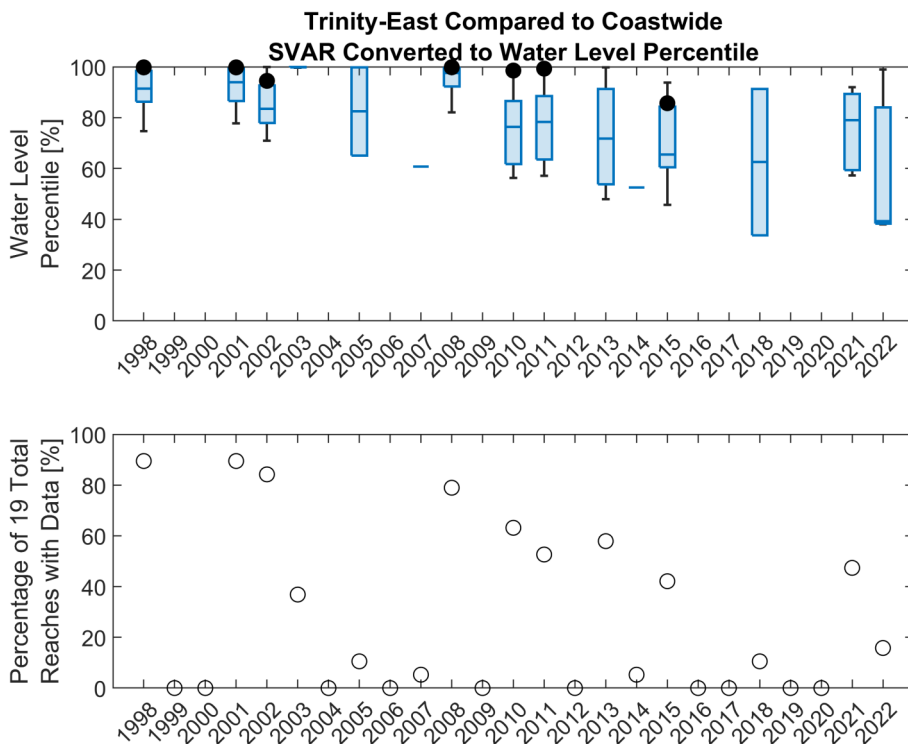
Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?



Results: Subaerial area decreased prior to restoration in 1998–1999. That sediment placement increased subaerial area, but the loss rate has been similar pre- and post-restoration.

What do data tell us about resistance to storms?



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

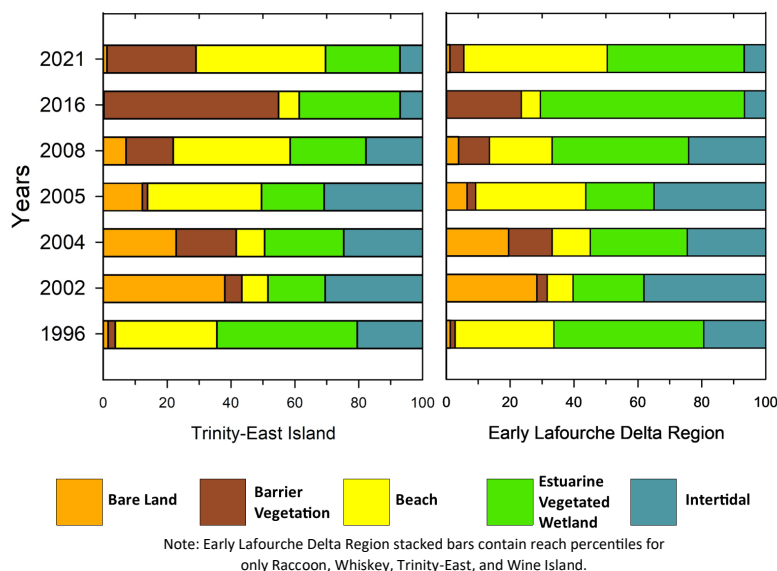
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: SVAR was above the 95th to 99th percentile of water level through the early 2010s, with a high in 2008. There was a gradual decline after then, which combined with sea-level rise brought SVAR below the 90th percentile of water level in 2015.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

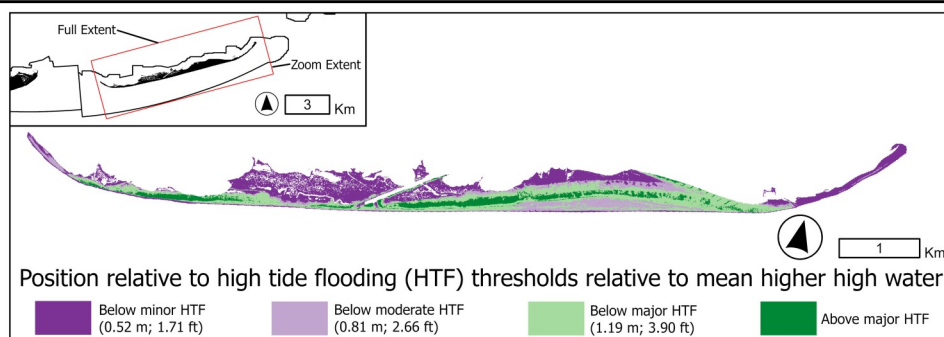


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	-	-
Vegetated & Low (Estuarine Vegetated Wetland)	-	-
Nonvegetated & High (Bare Land/Beach)	+	+
Nonvegetated & Low (Intertidal)	≈	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUZI>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P13ECWEM>

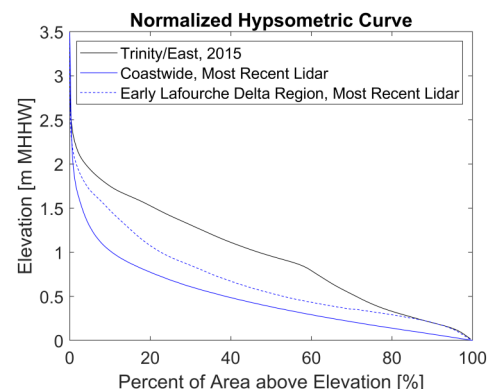
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	39.80	65.30	79.20
Below moderate	16.47	13.90	11.06
Below major	31.48	15.50	7.85
Above major	12.24	5.30	1.89



Hypsometric curve

Distribution of elevation relative to island area:

Elevation (m relative to mean)			
Percentile	Reach	Region	Coastwide
95	0.136	0.131	0.036
75	0.416	0.326	0.176
50	0.956	0.536	0.381
25	1.411	0.946	0.686
5	1.941	1.706	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NGQ>.

West Belle Pass Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

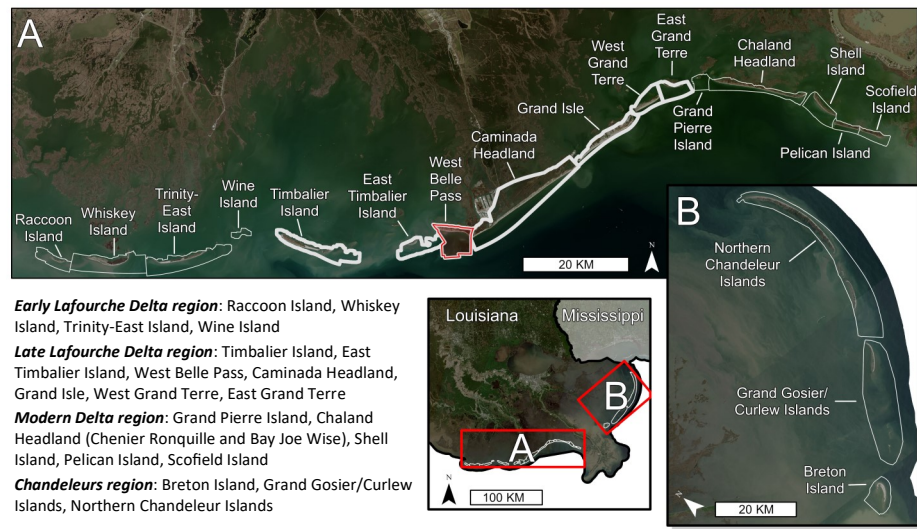
Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsplillrestoration.noaa.gov/project?id=306>.



April, 2026

Location



Oblique imagery



Oblique image from 2023 showing West Belle Pass.

Restoration history

- Sediment placement (4.8 million cubic yards [MCY]) in 2011–2012 (TE-52) added sand (beach & dune) and clay (marsh) to increase island width and height by 320 acres
- Sediment placement (9.0 MCY) focused on the center of the island to create 1,080 acres of total habitats in 2022 (TE-143); note, the area/volume may span multiple reaches

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Lili (H3)	2002	157 km
Katrina (H3)	2005	68 km
Zeta (H3)	2020	36 km
Ida (H4)	2021	5 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

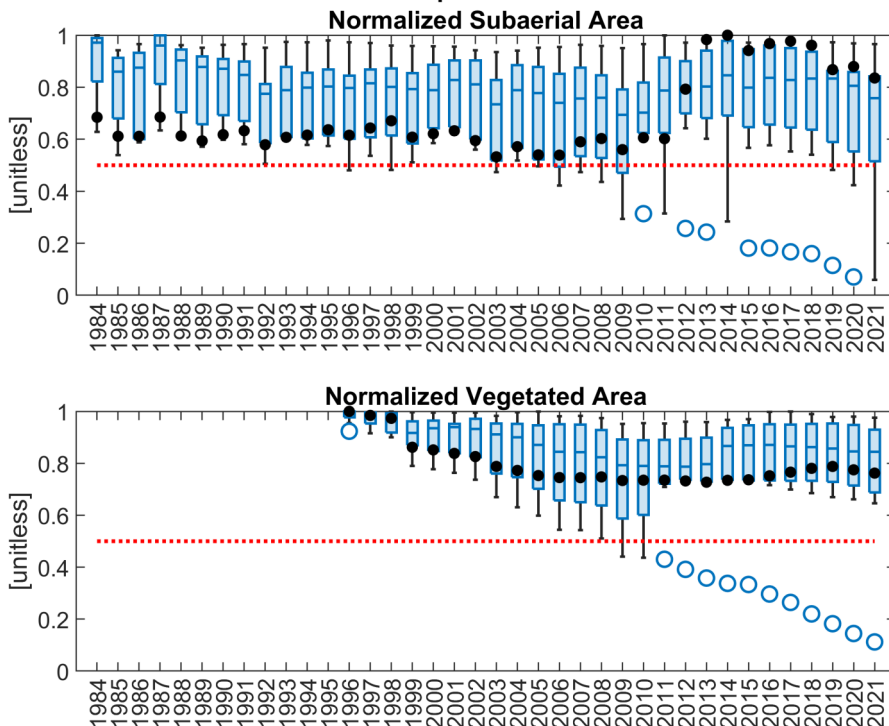
Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?

West Belle Pass Compared to Late Lafourche Delta



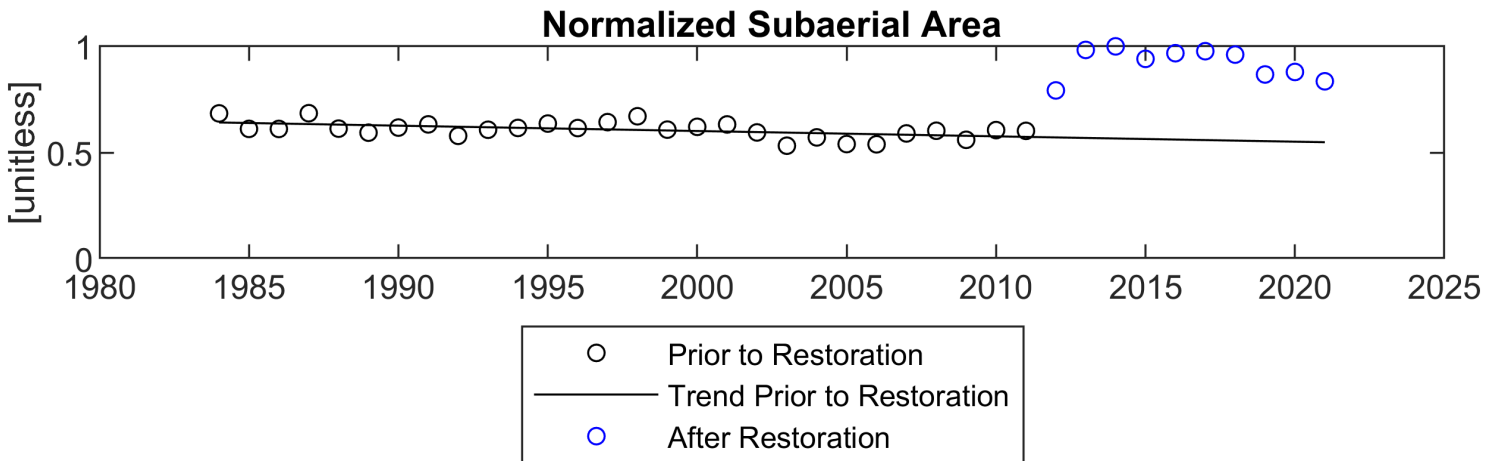
Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetation area can provide information on resilience.

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Restoration in 2011–2012 increased subaerial land area over the extent in the 1980s. This increase resulted in the maximum or near maximum subaerial area occurring from 2013–2018, before a loss of area beginning in 2019. Vegetation area was highest in the mid-1990s and been generally consistent over time.

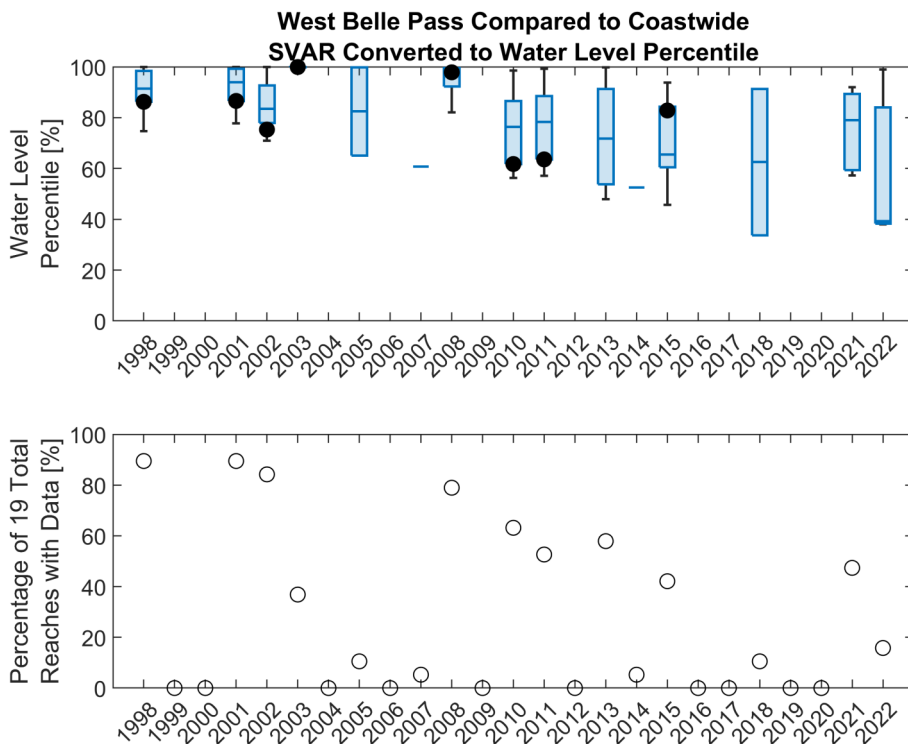
Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?



Results: Subaerial area exhibited a slight loss from the mid-1980s through the restoration in 2011–2012 that increased area while not impacting the overall trend with time.

What do data tell us about resistance to storms?



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

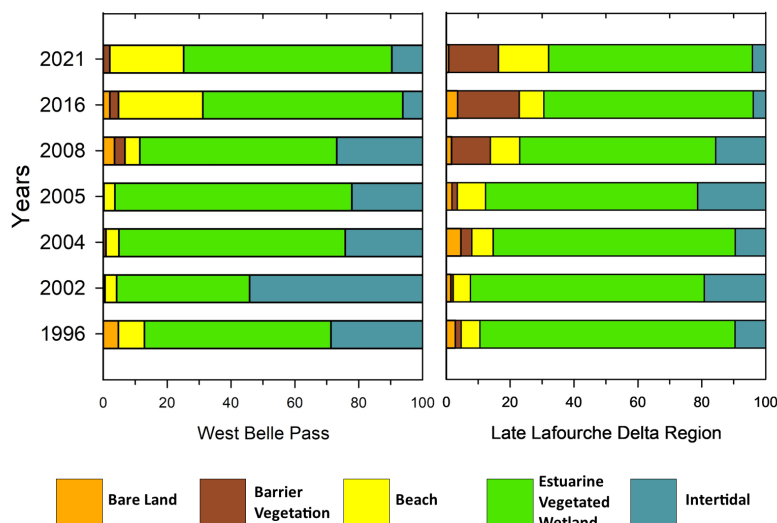
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Besides a high in 2003, SVAR has typically varied between the 50th and 90th percentile of water level. Sediment placement in the 2010s helped West Belle Pass keep pace with sea-level rise. New lidar could evaluate if the 2022 restoration helped maintained this trend.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

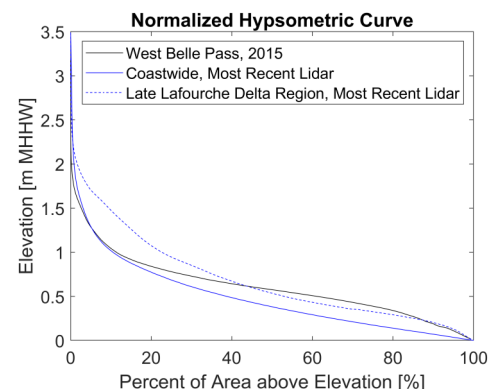
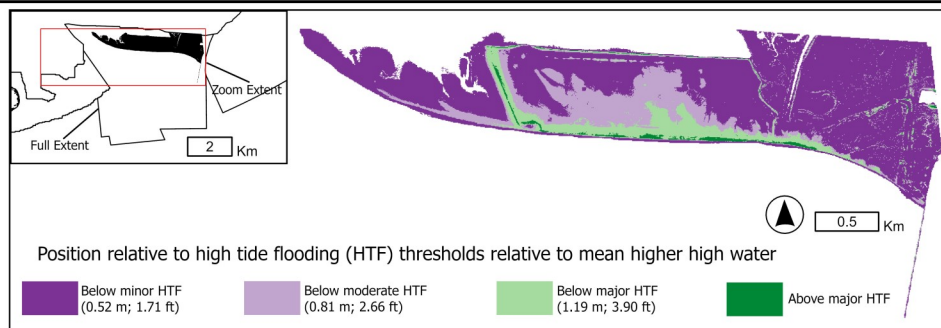


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	≈	≈
Vegetated & Low (Estuarine Vegetated Wetland)	≈	≈
Nonvegetated & High (Bare Land/Beach)	-	+
Nonvegetated & Low (Intertidal)	≈	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUJL>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P18X4J8>

Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	70.80	78.60	79.20
Below moderate	18.09	11.40	11.06
Below major	9.62	7.88	7.85
Above major	1.48	2.10	1.89

Hypsometric curve

Distribution of elevation relative to island area:

	Elevation (m relative to mean higher high water [MHHW])		
Percentile	Reach	Region	Coastwide
95	0.111	0.041	0.036
75	0.391	0.176	0.176
50	0.576	0.391	0.381
25	0.781	0.711	0.686
5	1.286	1.296	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NG0>.

West Grand Terre Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

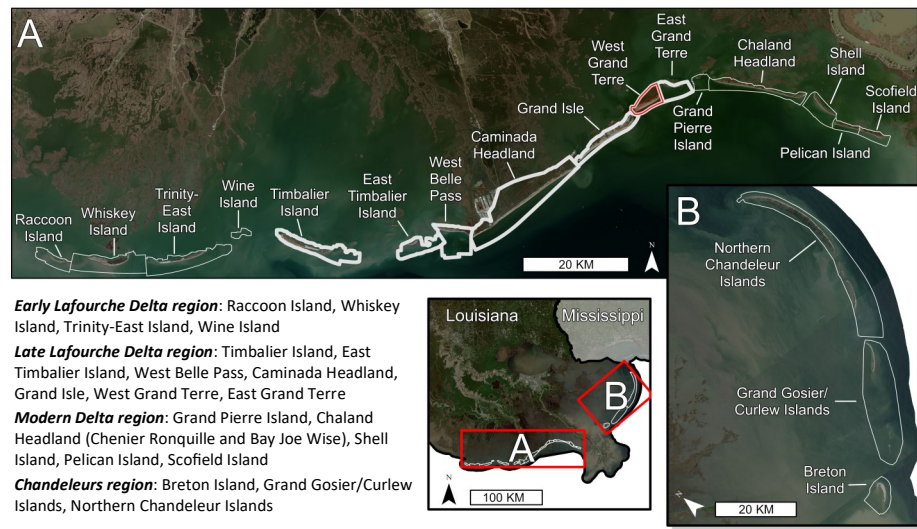
Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsplillrestoration.noaa.gov/project?id=306>.



April, 2026

Location



Oblique imagery



Oblique image from 2023 showing West Grand Terre.

Restoration history

- Dredged placement and plantings (BA-28), 1996–2001
- Rock dike built in 2003 to protect Gulf shoreline of island
- Sediment placement to increase island height and width in 2020–2023 (BA-0197)
- Rock breakwaters expanded at southern end of island in 2020–2023 (BA-0197)

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Lili (H3)	2002	195 km
Ivan (H3)	2004	173 km
Katrina (H3)	2005	32 km
Zeta (H3)	2020	66 km
Ida (H4)	2021	34 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

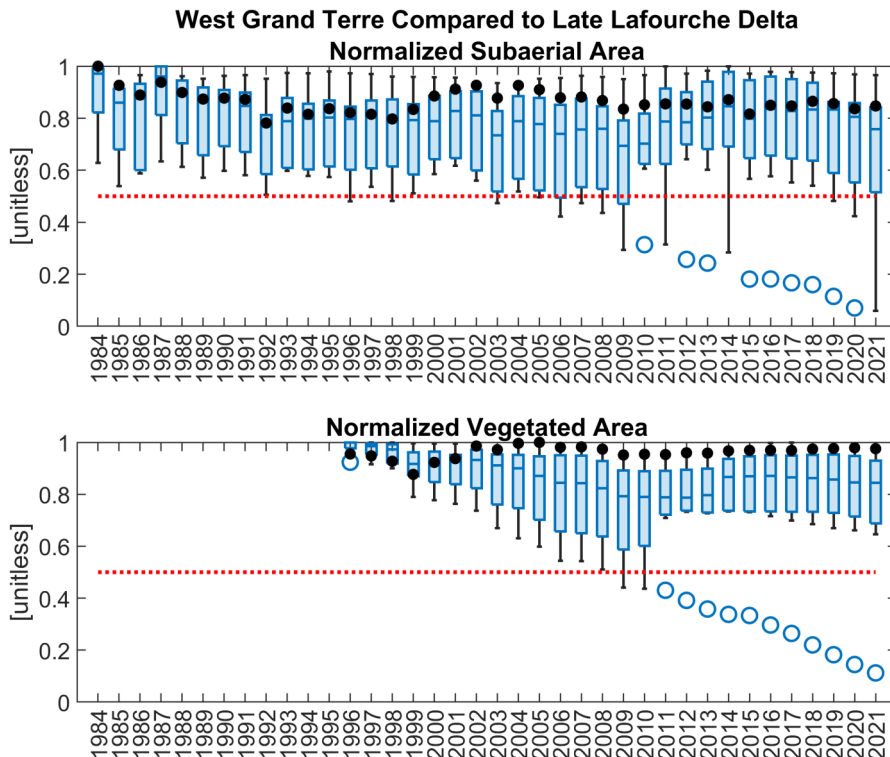
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



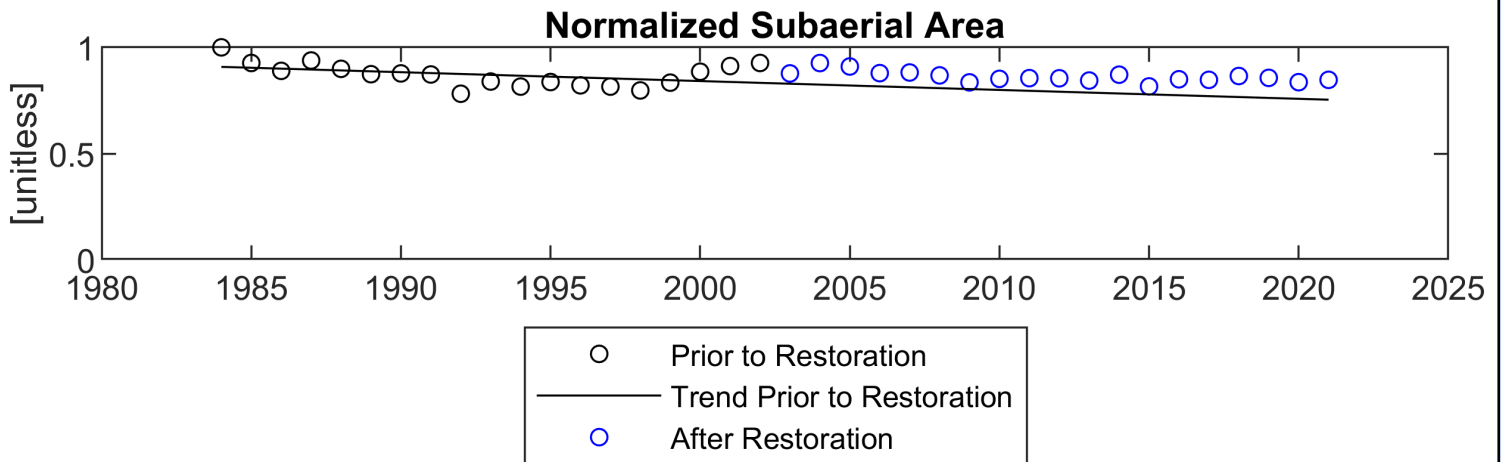
Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Subaerial and vegetated area at West Grand Terre declined steadily in the 1980s and 1990s until placement of dredged material and vegetative planting in 1996–2001. After an initial decline in subaerial area, both subaerial and vegetated area stabilized after placement. Restoration in 2020–2022 is too recent to see an effect during the time period analyzed.

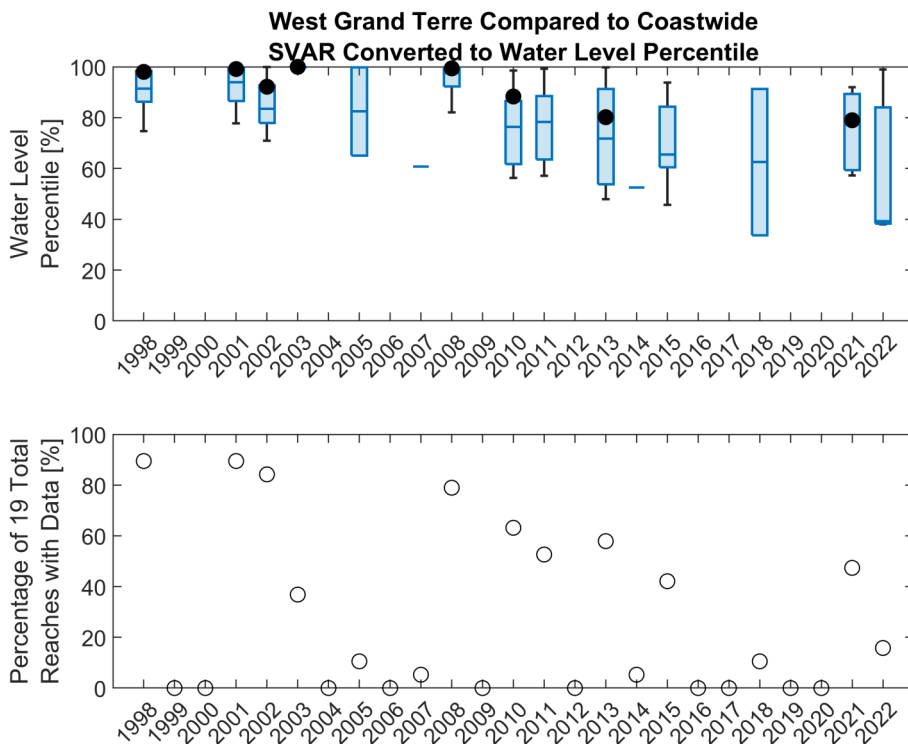
Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?



Results: Subaerial area has stayed steady post restoration, indicating land has been maintained.

What do data tell us about resistance to storms?



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

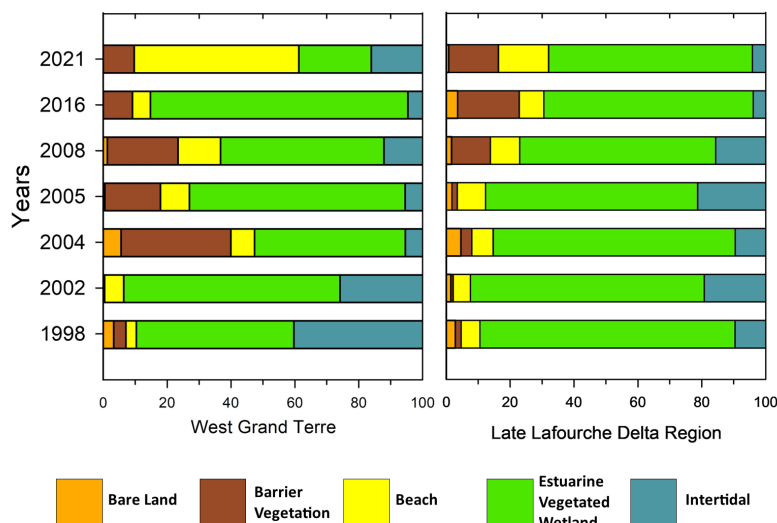
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: SVAR was at or above the 90th percentile of water level from the late 1990s through the early 2000s. SVAR declined while water level rose from 2008–2012, dropping SVAR below the 90th percentile. Restoration in 2020–2022 did help SVAR keep pace with sea-level rise.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

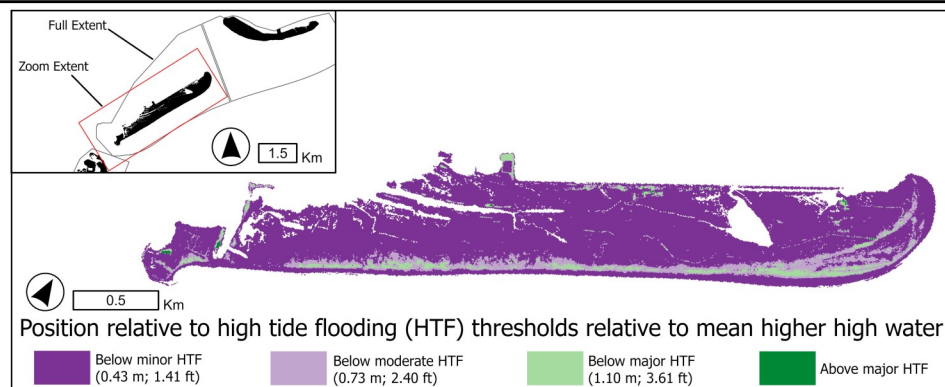


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	≈	≈
Vegetated & Low (Estuarine Vegetated Wetland)	-	≈
Nonvegetated & High (Bare Land/Beach)	+	+
Nonvegetated & Low (Intertidal)	+	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5–5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUZJ>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P18X4J18>

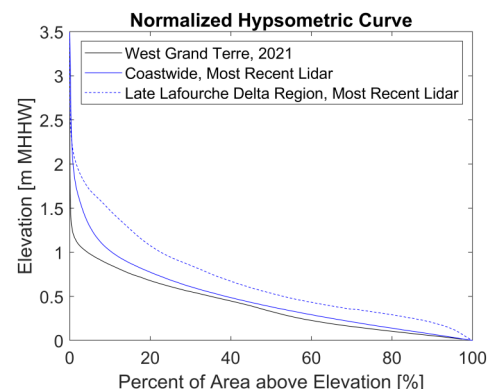
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	84.80	78.60	79.20
Below moderate	10.80	11.40	11.06
Below major	4.26	7.88	7.85
Above major	0.14	2.10	1.89



Hypsometric curve

Distribution of elevation relative to island area:

	Elevation (m relative to mean higher high water [MHHW])		
Percentile	Reach	Region	Coastwide
95	0.031	0.041	0.036
75	0.131	0.176	0.176
50	0.331	0.391	0.381
25	0.611	0.711	0.686
5	0.981	1.296	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the

Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via

<https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NGO>.

Whiskey Island Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

Tier 1 resilience and resistance metrics that are benchmarked to the region-level or coast-wide level (*pages 2–3*). This information tells us how the reach compares to other reaches.

Tier 2 analysis metrics for the reach (*page 4*) that provide detailed and supporting information on the state of the reach with comparisons to the region and rest of the coast.

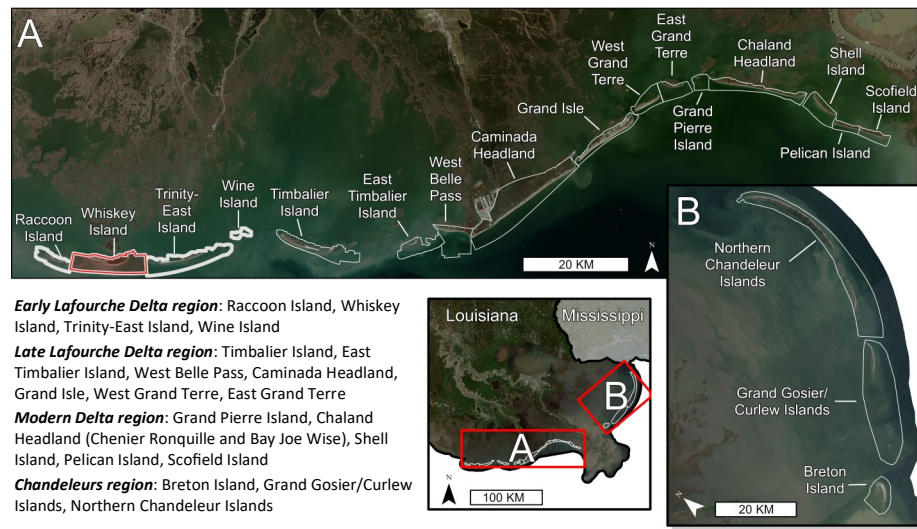
Acknowledgements

This effort was completed under the project titled “Characterizing the Barrier Island Geomorphic State” funded by the Louisiana Trustee Implementation Group. For more information see, <https://gulfsplillrestoration.noaa.gov/project?id=306>.



April, 2026

Location



Oblique imagery



Oblique image from 2023 showing beach/dune restoration on Whiskey Island.

Restoration history

- Sediment placement of 2.9 million cubic yards (MCY) of sand was used to increase the island's width and height in 1998–1999; planted smooth cordgrass vegetation in a 523 acres marsh creation (TE-27)
- Marsh restoration of 316 acres in 2009 (TE-50; 2.76 MCY) and created a small sand dune
- Large-scale beach, dune, and back-barrier restoration in 2018, creating 954 acres of habitats (TE-100; 10.5 MCY)
- Planting of dune and marsh vegetation (TE-53)

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Andrew (H4)	1992	48 km
Lili (H3)	2002	105 km
Katrina (H3)	2005	110 km
Rita (H3)	2005	110 km
Zeta (H3)	2020	100 km
Ida (H4)	2021	45 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

For barrier systems, the concept of “resilience” and “resistance” — and even the definition of stable states — is difficult to define given their highly dynamic nature.

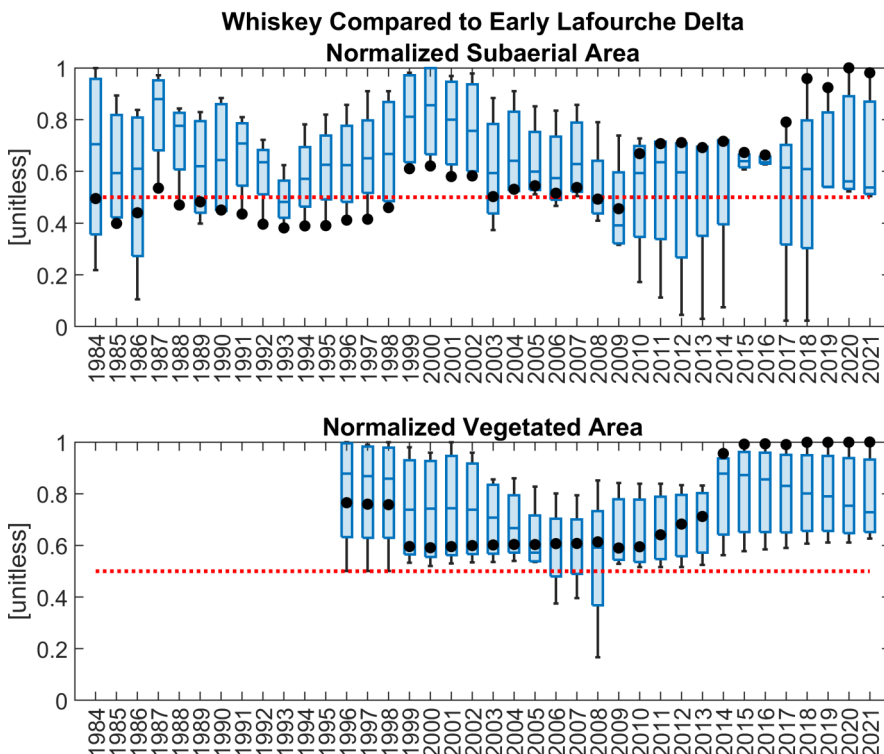
Resilience is defined here on a spectrum relative to becoming subaqueous, where a more resilient barrier is one with a greater capacity to remain subaerial on yearly to decadal time scales.

Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

Tier	Metric	Metric type
1	Subaerial land	Resilience
1	Vegetation cover	Resilience
1	Subaerial volume to area ratio	Resistance
2	Habitat coverage from high-resolution maps	Resilience
2	High tide flooding analysis	Resistance
2	Hypsometric curve	Resistance

What do data tell us about resilience?



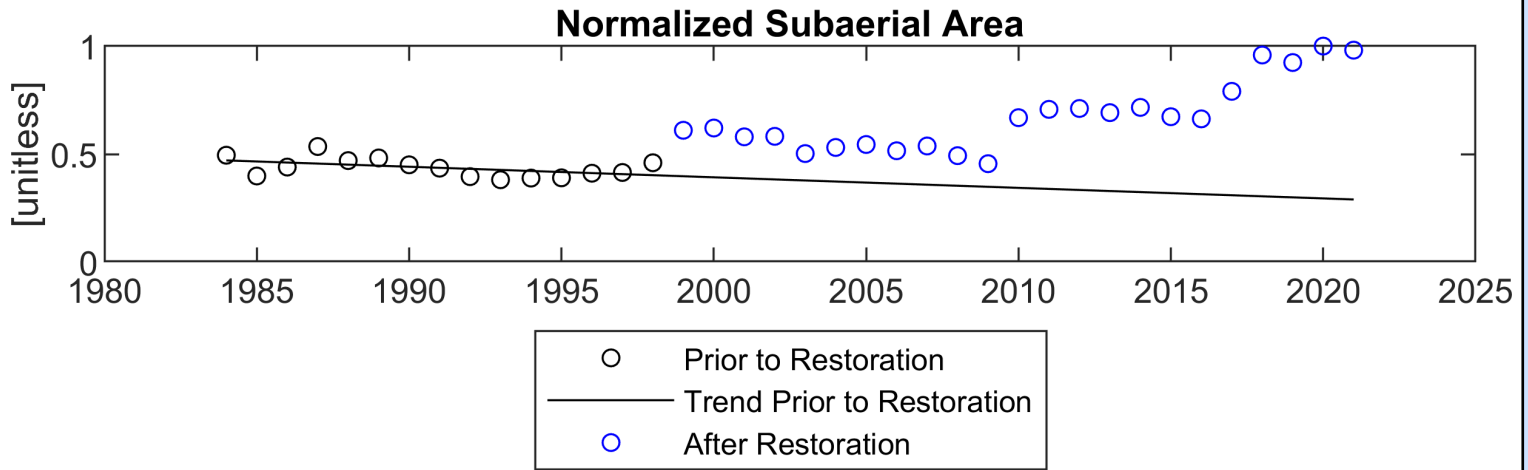
Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: Restoration in 1998 increased subaerial land area, but much of this gain was lost by 2009 after major storms in 2002 and 2005. Land area did not stabilize until after the 2018 restoration. The high for vegetated area occurred in 2015 and has been generally consistent since.

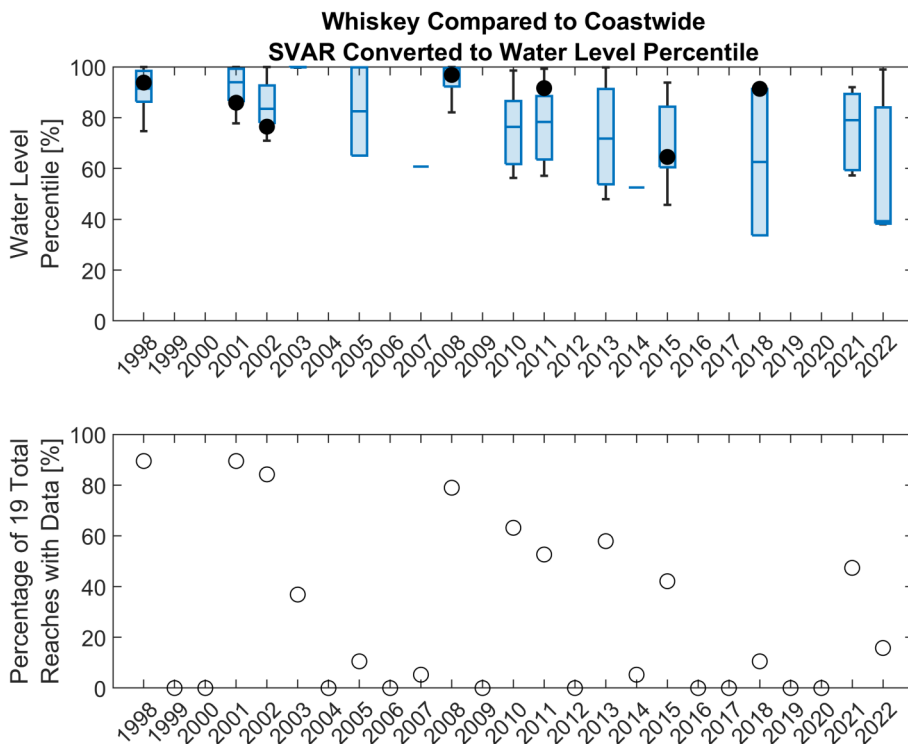
Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?



Results: The island had a decreasing area prior to restoration; restoration in 1998 increased the area while the rate of loss remained similar. Subsequent restoration appears to have decreased the loss rate of the island.

What do data tell us about resistance to storms?



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

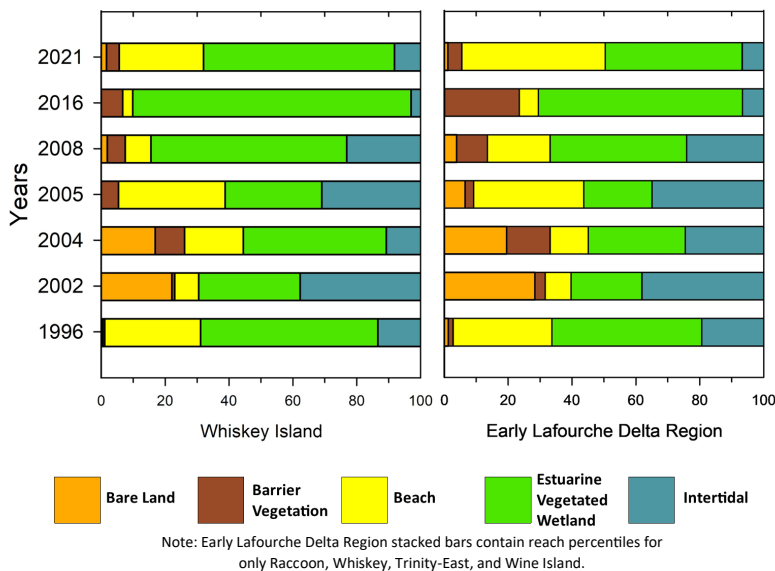
Metric interpretation: Subaerial volume to area ratio (SVAR) provides information on the average elevation above a specific threshold (i.e., 0 m NAVD88). The higher SVAR is relative to water levels indicates higher resistance. Insight into resilience can be obtained from exploring how SVAR tracks water levels over time (i.e., which include relative sea-level rise).

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: SVAR was at a high in 2008 and gradually decreased over the next decade. Resilience during this time increased initially, but continued erosion led to reduced resilience and resistance until restoration in 2018.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

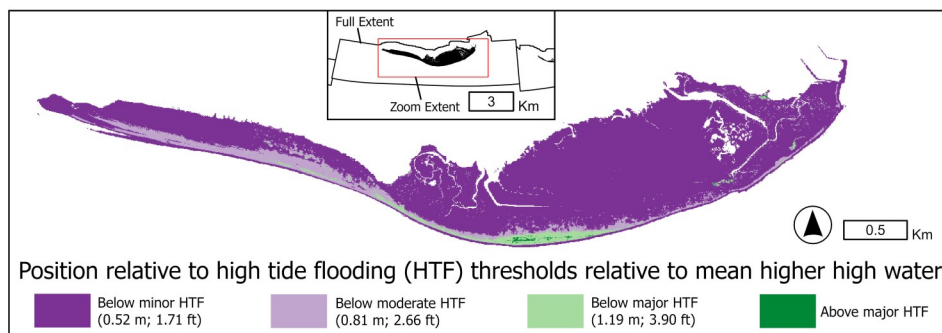


Class	2021 compared to prior year at reach level	2021 compared to the region level
Vegetated & High (Barrier Vegetation)	≈	-
Vegetated & Low (Estuarine Vegetated Wetland)	-	-
Nonvegetated & High (Bare Land/Beach)	+	+
Nonvegetated & Low (Intertidal)	+	≈
Percentage point difference: +, > 5; -, < -5; and ≈, -5-5		

Habitat diversity is important for an island's resilience and resistance and helps to maintain a functional and sustainable ecosystem. Habitat diversity can be found by observing the proportions of habitat classes in a given year. Things to consider is whether the reach/region is dominated by a single class or two (e.g., lower diversity) or whether the area includes three or more classes that are roughly equal in size (i.e., higher diversity), how habitat diversity has changed over time, and how the habitat diversity of a reach compares to the region.

1996–2005 habitat maps: <https://doi.org/10.5066/P13VTUZI>; 2008–2016 habitat maps: <https://doi.org/10.3133/ofr20201030>; 2021 habitat maps: <https://doi.org/10.5066/P13ECWEM>

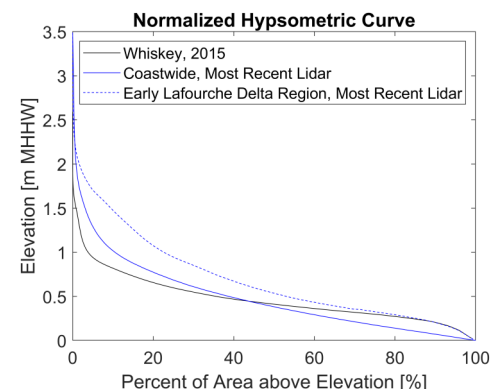
Elevation Metrics (2015 data for reach, most recent data for region/coastwide)



Inundation analysis

Percent of the land in the reach relative to the National Oceanographic and Atmospheric Administration's thresholds:

Inundation class	Reach (%)	Region (%)	Coastwide (%)
Below minor	87.00	65.30	79.20
Below moderate	9.81	13.90	11.06
Below major	3.02	15.50	7.85
Above major	0.21	5.30	1.89



Hypsometric curve

Distribution of elevation relative to island area:

Elevation (m relative to mean)			
Percentile	Reach	Region	Coastwide
95	0.131	0.131	0.036
75	0.296	0.326	0.176
50	0.411	0.536	0.381
25	0.596	0.946	0.686
5	0.941	1.706	1.291

Types of Input Data

Oblique imagery: Oblique imagery collected by the University of New Orleans (<https://cims.coastal.louisiana.gov/outreach/Projects/Bicm>).

Restoration history: Coastal Protection and Restoration Authority (CPRA) (2026). Barrier Island Status Report: Draft Fiscal Year 2027 Annual Plan. Coastal Protection and Restoration Authority of Louisiana (CPRA), Baton Rouge, LA, 71p.

Hurricanes: Landsea, C. W., & Franklin, J. L. (2013). Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Monthly Weather Review, 141(10), 3576–3592. <https://doi.org/10.1175/MWR-D-12-00254.1>.

Elevation data: Digital elevation models from airborne light detection and ranging (lidar) that are publicly available via the U.S. Interagency Elevation Inventory (<https://coast.noaa.gov/inventory/>) or available via request to the Louisiana Coastal Protection and Restoration Authority.

Subaerial land area: Pekel, J.-F., Cottam, A., Gorelick, N., and Belward, A.S., 2016, High-resolution mapping of global surface water and its long-term changes: Nature, v. 540, p. 418–422. Updated data through 2021 available via <https://global-surface-water.appspot.com/>.

Land cover data: U.S. Geological Survey (USGS), 2022, Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 Science Products for the Conterminous United States: USGS data release, <https://doi.org/10.5066/P9C46NGO>.

Wine Island Geomorphic State Report Card

Louisiana Trustee Implementation Group Barrier Island Geomorphic State Project

Introduction

Found along the estuarine-marine interface, barrier islands are shaped by processes (e.g., climate change, sea-level rise, subsidence, overwash, dune erosion). With a changing climate, natural resource managers need information on barrier island resilience and resistance to storms under current conditions and how it relates to past conditions. This information can help drive restoration decisions for these important resources.

What is included in this report card?

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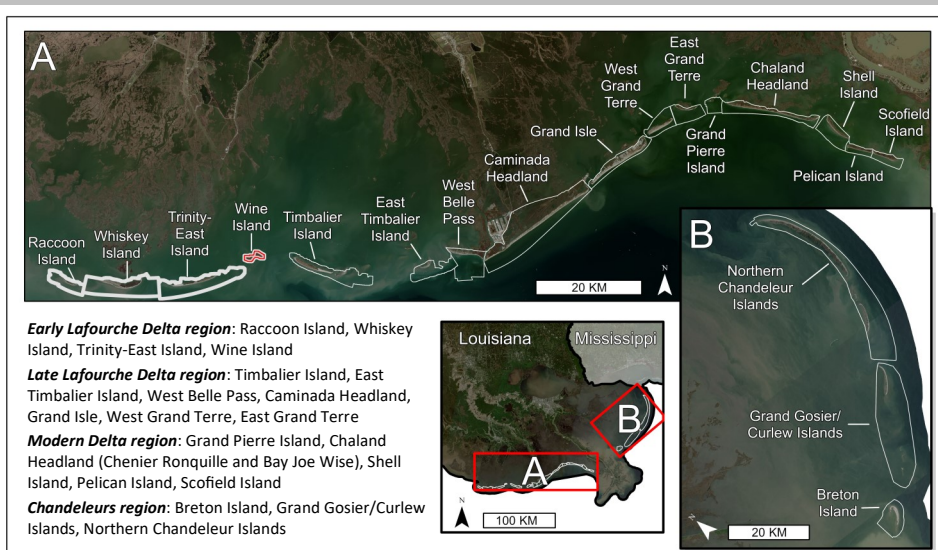
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Acknowledgements

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Location



Oblique imagery



Oblique image from 2023 showing Wine Island (submerged).

Restoration history

- Rock containment added in 1991
- Aerial seedings created 20+ acres of wetlands (1995)
- Wine Island has not been the site of a fully designed and executed restoration project, but sediment has been pumped from nearby Houma Navigation Canal (HNC) during several periods including 1993–1994 (0.6 million cubic yards [MCY]); 1994 (0.2 MCY); 1994 (0.5 MCY); and 2007 (0.5 MCY)

Storm history (1985–2022)

A total of six major hurricanes (i.e., category ≥ 3) have passed within 200 km. Other storms may have impacted the reach that were a lower category or were further afield. H3, category 3 hurricane; H4, category 4 hurricane.

Name (Category)	Year	Distance
Lili (H3)	2002	134 km
Katrina (H3)	2005	101 km
Zeta (H3)	2020	12 km
Ida (H4)	2021	24 km

Tier 1 Metrics Benchmarked Regionally and Coastwide

Resilience and Resistance

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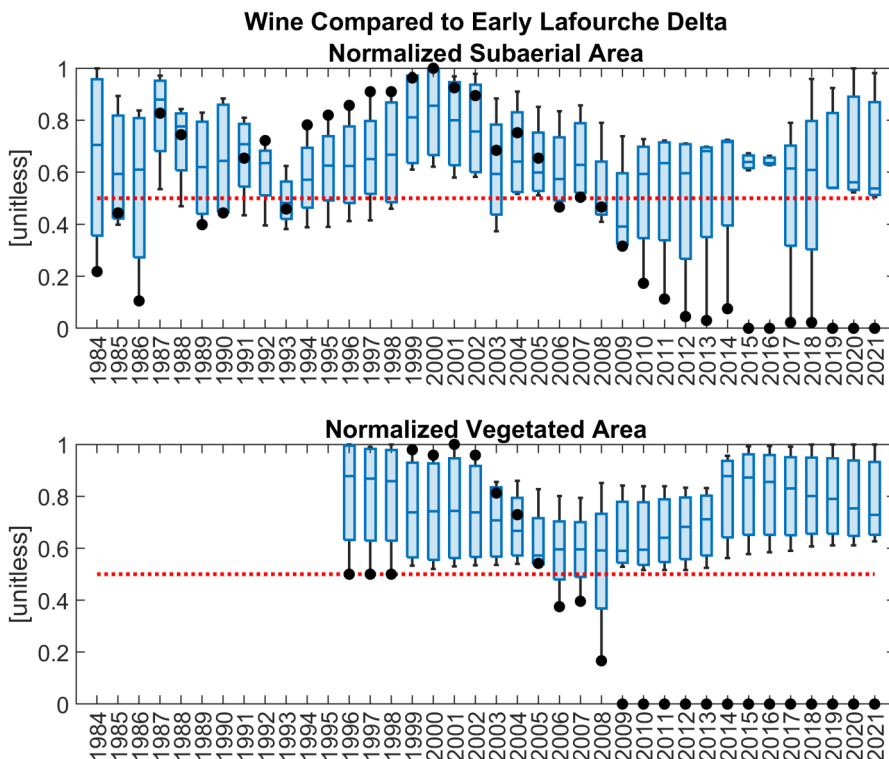
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Resistance is defined here as the capacity to maintain geologic and geomorphic form and ecological function on a time scale of days to weeks in the face of hurricanes and other storms. Exploring resistance metrics overtime can provide information about resilience.

Two types of metrics were developed for this effort. **Tier 1 screening metrics** (*this page and page 3*) that can be readily calculated from available data, are easily interpretable as an evaluation of barrier condition, and provide a high-level snapshot of overall barrier resilience and resistance; and **Tier 2 analysis metrics** (*page 4*) that required specialized analysis and interpretation and are more applicable to answering specific questions managers may have about barrier state.

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2	Hypsometric curve	Resistance

What do data tell us about resilience?



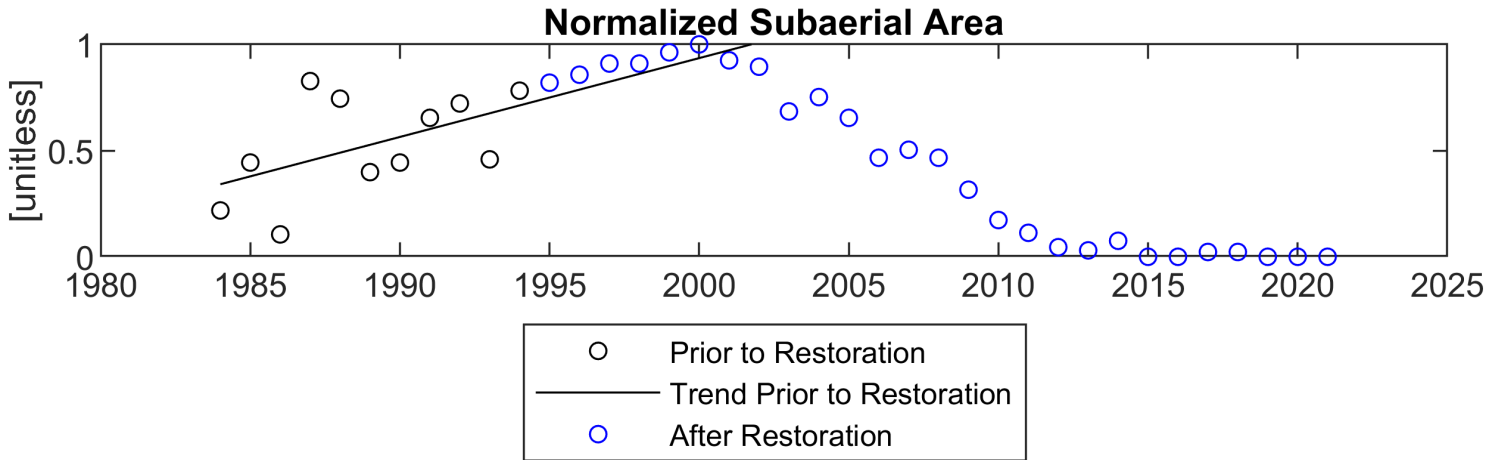
Metric interpretation: Exploring trends in normalized (normalized to maximum value for all dates) for subaerial land area and vegetated area can provide information on resilience.

Questions to consider: How is coverage changing over time? How does subaerial land coverage compare to maximum value or period where restoration actions were completed? How do the reach-level data (black dots) compare to the region (box plots)?

Results: There was a gradual and slight increase in subaerial area from the mid-1990s, with the maximum occurring around 2000. After that, land and vegetated area both dropped, likely as a result of storms in the early 2000s. Since then, Wine Island has had virtually no land area, reflecting that it has lost all resilience and is not often completely subaqueous.

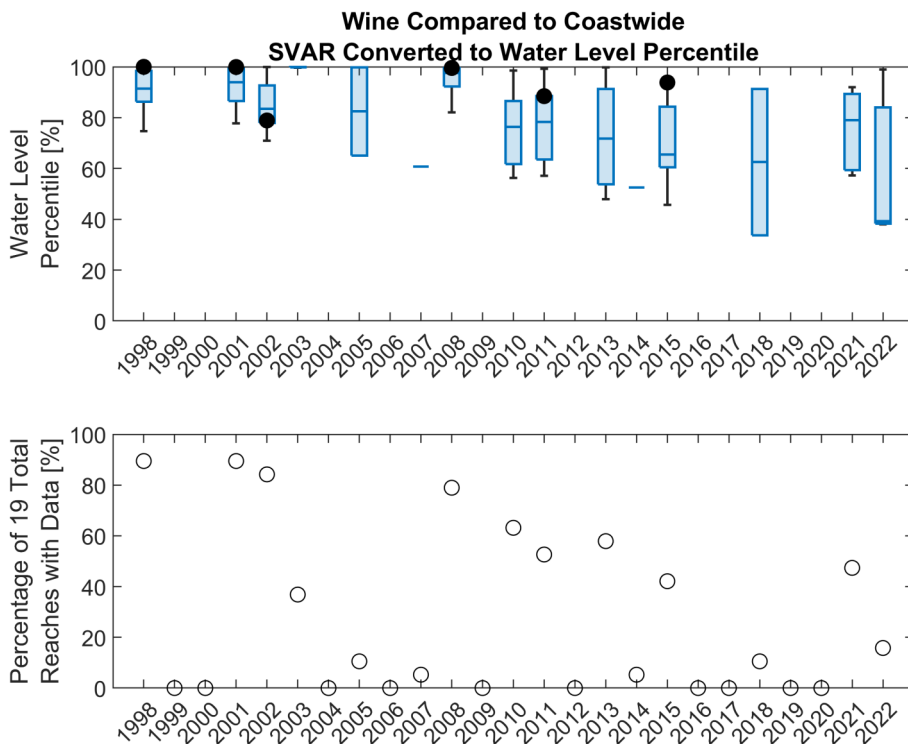
Tier 1 Metrics Benchmarked Regionally and Coastwide

What was the natural trajectory of subaerial area for the reach prior to the earliest restoration?



Results: Subaerial land decreased steadily and sharply from 2000 through the mid-2010s, when the barrier became intermittently subaqueous. It has remained that way in the time period since.

What do data tell us about resistance to storms?



Note: Technological advancements led to elevation data quality increasing in the late 2000s and early 2010s.

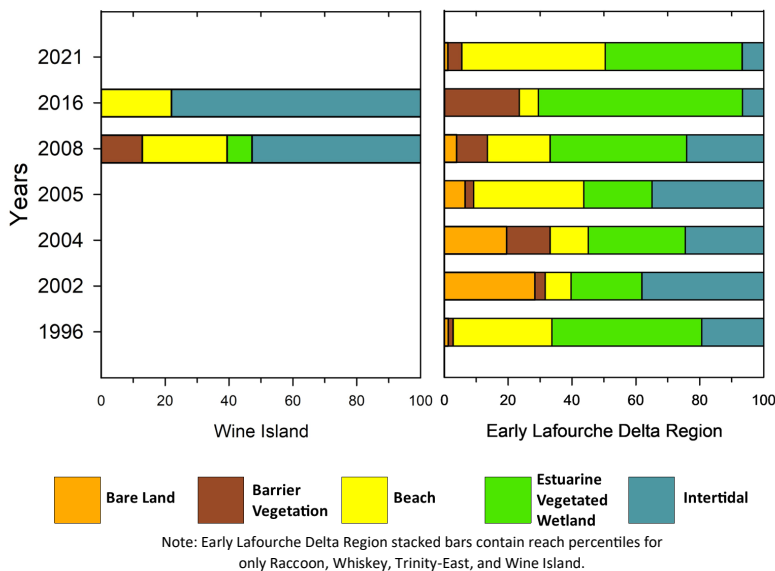
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Results: SVAR at Wine Island ranged from the 50th percentile to over the 99th percentile through the mid-2010s. During the last lidar survey (2015), the small remaining subaerial portion was relatively high compared to sea level, but this may reflect detection of the rock features.

Tier 2 — Detailed Information About the State of the Reach

Habitat Data (general habitat classes from the Barrier Island Comprehensive Monitoring Program)*

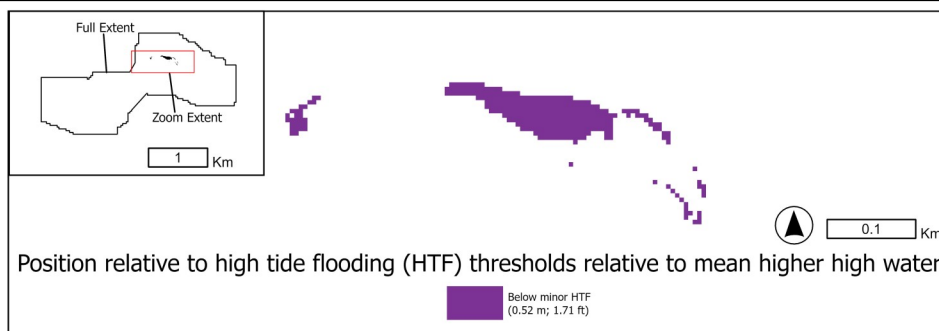


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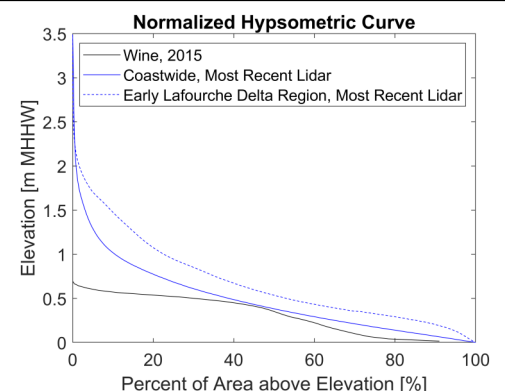
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