Shore & Beach

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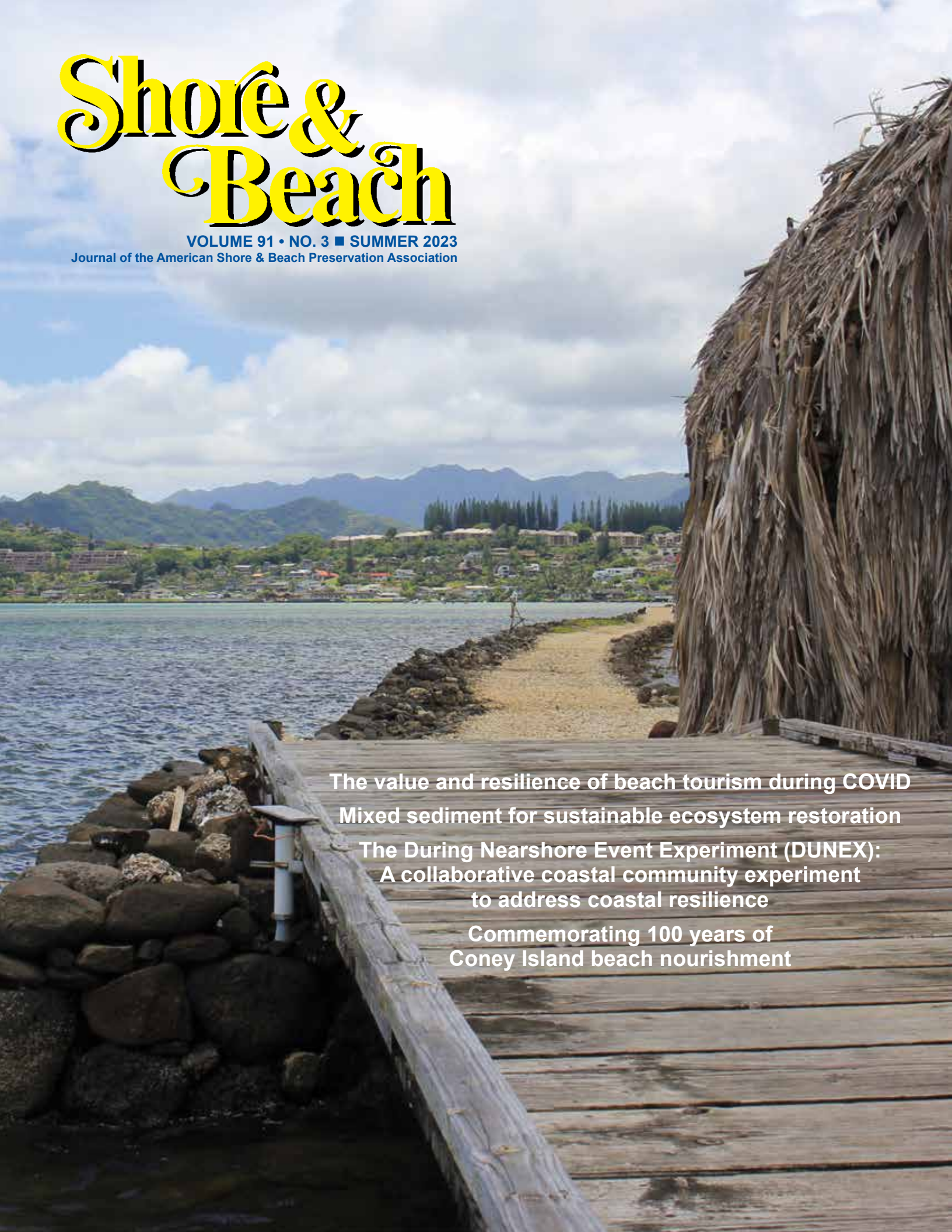

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A Hohonu water level sensor at He'eia Fishpond, an ancient Hawaiian fishpond on O'ahu. Similar sensors have been installed by ASBPA in the Southeast United States. (Photo courtesy of Hohonu.)

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FROM THE EDITOR'S DESK:

Finding the missing pieces of the coastal puzzle

By

Lesley C. Ewing, Ph.D., editor-in-chief

For much of my coastal career, changes to the ocean and shore were framed by flooding and erosion, with storms, sea level rise and tsunamis being the major drivers. A lot more is changing than those factors and this summer has made some other factors front-page news. Triple-digit ocean water temperatures are extreme, as are multiple days with inland temperatures over 110 or 120 degrees.

In June I went to the United Nations for World Ocean's Day for discussions of some global concerns and, while I was there, New York City had the worst air quality of any city in the world due to Canadian wildfires hundreds of miles away. Like news reports on storms, these phenomena are discussed as current news and many reporters now connect these events to the larger concerns with climate change. Pull on one thread and the unraveling spreads in unexpected ways and to unexpected areas. Spikes in ocean temperatures raise concerns about the severity and intensity of hurricane season, leading possibly to extensive flooding and erosion — but what unexpected results will there be for future beach tourism, water-borne diseases, geomorphic changes, or efficacy of living shorelines?

Much of our knowledge about coasts comes from observations, measurements, identification of trends, correlations between observations and measurements, and trends and looking for gaps or missing pieces of the puzzle. Some puzzle pieces take a long time to find, and some may never be found. A tsunami is an example of a missing piece that took centuries to find. The Japanese have centuries of water level records related to tsunamis; the 1700 record of a tsunami was called The Orphan Tsunami until the geologic survey of the Cascadia Subduction Zone linked together its indicators or seismic activity, indigenous stories of a large flood, sediment cores from marshes in northern California, and water records in Japan. One mystery has been solved, but many more exist. Data collections, coastal observations and discussions of trends are important steps for better understand coastal conditions.

"The During Nearshore Event Experiment (DUNEX): A collaborative community experiment to address coastal resilience," is a major multi-disciplinary effort to better understand nearshore processes under storm conditions. The paper by Jessamin Straub, Mary Cialone, Britt Raubenheimer, Jenna Brown, Nicole Elko, and Katherine Brodie describes the development of DUNEX through agency and community coordination on scientific goals and use of clear focus on community resilience. Some research findings are provided, but analyses are ongoing, and many findings will be covered in future reports and articles.

Flooding is and will remain a major threat to low-lying coastal areas and information about real-time or near real-time water levels can help communities with flood resilience. The Coastal Forum article, "U.S. coastal communities' need for water level observations" by Nicole Elko, Debra Hernandez, and Kristen Yarincik report the results of a survey of U.S. coastal stakeholders about the availability of and need for water level stations. Over 40% the respondents were not aware of any available water level data, but interest in such data is widespread. For the Southeast Water Level Network alone, over 175 stations are proposed to be installed to address these needs.

More data and observations will be important, but engineers often must design and implement projects with the best information available. Syed Khalil, Richard Raynie, Beth Forrest and Tershara Matthews discussed the ongoing need for sediment in "Mixed sediment for sustainable ecosystem restoration in Louisiana," where they provide information on prior nourishment volumes and projected future sediment volumes needed to both restore emergent vegetation habitats and create new land areas to offset some historic losses. Their paper also notes that sand is not always the preferred sediment for these efforts, and that mixed sediment is often better. They also compare ecosystem restoration needs with available sediment.

The articles by Delaney Dolan, Tiffany Briggs, and Nicole Elko, and by James Houston, provide reminders about the value of beaches and why continued research on their special areas is needed. In "Commemorating 100 years of beach nourishment on Coney Island, New York," Doran *et al.* provide an overview of the first and longest-running program of beach nourishment undertaken to create a public beach. In addition to creating a recreational beach that everyone could use, property values increased and taxable revenues were enough to cover the project cost. Houston's paper, "The value and resilience of beach tourism during the COVID pandemic," provides data on beach useable during the pandemic and highlights differences in beach tourism from other traditional tourism. All travel and tourism dropped precipitously in March 2020, at the start of the COVID pandemic. By mid-2020, beach use (mainly by domestic visitors) had recovered and expanded in subsequent years. The differences in beach tourism from other U.S. tourism during the pandemic highlights the importance of beaches to coastal economics.

Some papers in this issue address efforts to provide some of the missing puzzle pieces to understand coastal processes and time and spatial scales that can help coastal communities become more resilience. Other papers are reminders of the historic and current importance of beaches for coastal communities. As members of ASBPA, readers of *Shore & Beach*, and coastal advocates, thank you for all you do for the coast.

The value and resilience of beach tourism during the COVID pandemic

By

James R. Houston

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ABSTRACT

The coronavirus disease (COVID) had a greater impact on travel and tourism (T&T) than on any other industry sector, causing the worst downturn in world and U.S. history. The downturn in U.S. T&T caused a $937 billion drop in Gross Domestic Product (GDP) and a 7.1 million job loss in 2020 and a $708 billion GDP drop and 6.3 million job loss in 2021. Trillion dollar government programs saved the sector from complete collapse. Although overall T&T in the U.S. was hard hit in 2020 and did not recover greatly in 2021, beach tourism had a very different response to COVID. Some beaches were closed for months during the first half of 2020, but beach tourism largely recovered by the middle of 2020 as people decided the safest recreation during COVID was outdoors in the sun and fresh air of beaches or parks. Scientists have since come to the same conclusion. The number of international visitors remained low as air transportation remained largely dormant, but the number of domestic tourists going to beaches recovered in 2020 and boomed in 2021 despite the pandemic. Beach tourist spending in 2021 often greatly exceeded pre-pandemic 2019 levels and caused hotel and rental properties to hit capacity limits. The collapse of beach tourism in the first half of 2020, largely due to beach closures, highlighted its value to the economy. The recovery of beach tourism in the second half of 2020 and boom in 2021, despite continued problems in non-beach tourism, demonstrated its resilience. The boom continued in 2022 and 2023.

KEYWORDS: Pandemic, economic value, parks, beach nourishment

Manuscript submitted 20 February 2023, revised and accepted 12 June 2023.

The economic value of beaches at national, state, and local levels is huge and has been described (Houston 2018a, 2018b, 2021,2022a). However, there are circumstances where something's value and resilience is further revealed by adversity. Indeed, the economic value and resilience of beach tourism in the U.S. has been revealed by the impact of the coronavirus disease (COVID) on T&T during the more than three years that COVID has persisted (Figure 1). The year 2019 is the base year for comparisons because it is "pre-pandemic," with the first laboratory-confirmed case by the Centers for Disease Control and Prevention (CDC) on 19 January 2020 in the state of Washington (Centers for Disease Control and Prevention 2020).

IMPACT OF COVID ON WORLDWIDE TOURISM

The impact of COVID on worldwide tourism was dramatic. According to the United Nations World Travel Organization (UNWTO), COVID caused a worldwide collapse in international travel compared to 2019 pre-pandemic levels with 1.1 billion fewer travelers in 2020, a decline of 72% (UNWTO 2022). This fall in traveler numbers reduced international T&T direct spending by $1 trillion in 2020 with a drop in the contribution of T&T to the world Gross Domestic Product (GDP) of $1.8 trillion. There was little recovery in 2021, with tourist arrivals still down 71% from 2019 and T&T's contribution to GDP still down $1.3 trillion from 2019 (UNWTO 2022). A slow recovery started in 2022 with the number of international tourists down 43% from 2019, but most experts do not foresee the number of international tourists returning to 2019 levels until 2024 or later (UNWTO 2022).

A comparison with previous impacts on international travel show the unprecedented impact of COVID. The financial crises of 2007-2009 is known as the "Great Recession" and was the greatest worldwide economic downturn since the Great Depression of the 1930s (Britannica.com 2018). It caused a 4% decline in the number of international tourists in 2000 that was minor compared to the 72% decline caused by COVID (UNWTO 2021). The 11 September 2001 terrorist attack caused a drop of only 0.5% in the number of international tourists in 2001, and there was a 2.7% gain in 2002 (UNWTO 2013).

IMPACT OF COVID ON U.S. TOURISM

The impact of COVID on the U.S. tourism was dramatic and unprecedented with tourism being hit harder than any other industry sector. Visits by international tourists were especially hit hard, with their spending in the U.S. dropping from $239 billion in 2019 to $84 billion in 2020 and $83 billion in 2021 as international travel had almost no rebound (U.S. International Trade Administration, 2022). The contribution of T&T to the U.S. balance of trade decreased from a surplus of $54.0 billion in 2019 to $36.8 in 2020 and only $9.5 billion in 2021 (U.S. International Trade Administration, 2022). T&T is one of the rare areas where the U.S. persistently runs a balance-of-trade surplus with foreign tourists spending more in the U.S. than U.S. tourists spend abroad.

T&T contributed $1.98 trillion in 2019 to the U.S. GDP (World T&T Council 2022). This is comparable to the $2.49 trillion contribution of the entire U.S. manufacturing sector to the U.S. GDP in 2021 (Statista 2022a). It is greater than the $1.7 trillion GDP of Russia (Statisticstimes.com 2022). This contribution to the U.S. GDP sank by $937 billion from 2019 to 2020 and was still lower in 2021 by $708 billion compared to 2019. The U.S. GDP loss in 2020 was greater than the $793 billion GDP of Saudi Arabia, the largest petroleum producer in the world (Statisticstimes.com 2022).

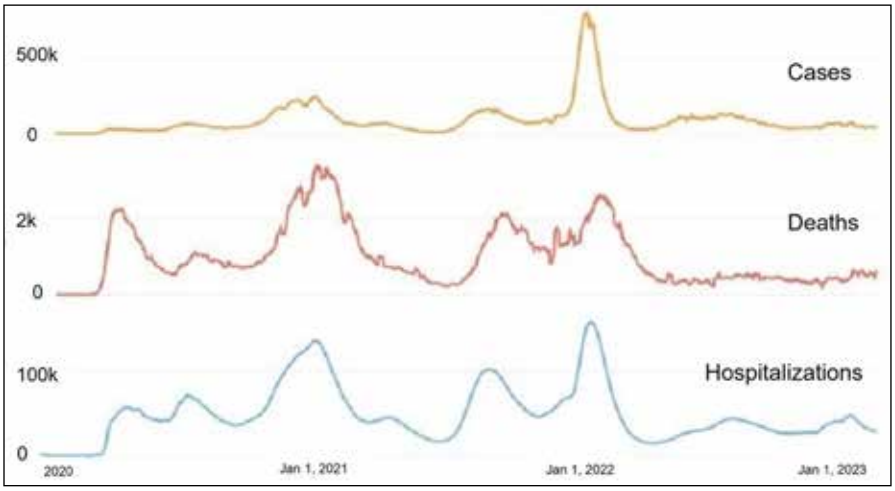


Figure 1. COVID cases, deaths, and hospitalizations in the U.S. from January 2020 through February 2023 (Johns Hopkins 2023).

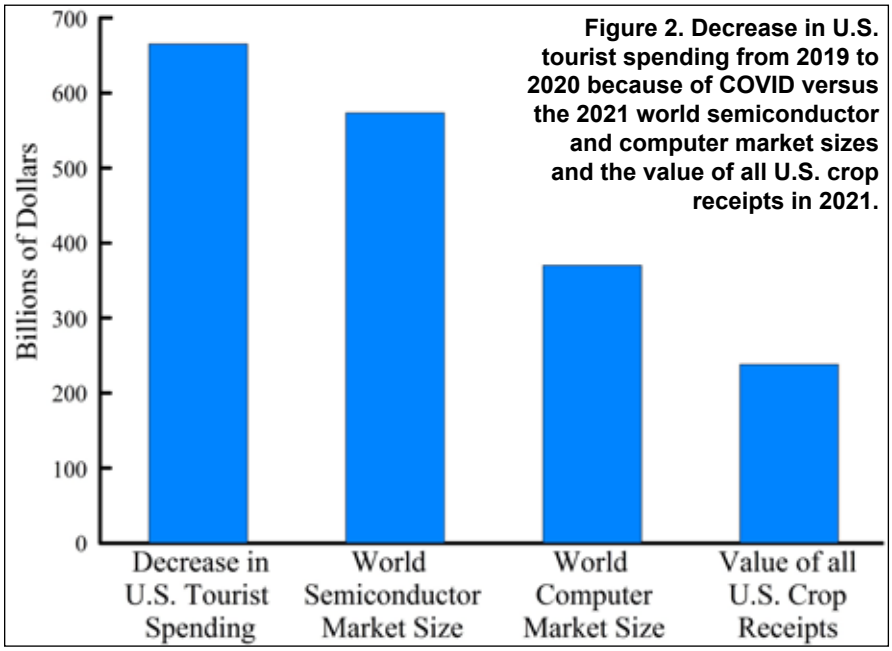


Figure 2. Decrease in U.S. tourist spending from 2019 to 2020 because of COVID versus the 2021 world semiconductor and computer market sizes and the value of all U.S. crop receipts in 2021.

Direct T&T spending in the U.S. declined by $665 billion from 2019 to 2020 and was still down by $505 billion by 2021 (World T&T Council 2022). The $665 billion drop can be appreciated through comparisons with other industry sectors. For example, the total value of U.S. farm receipts for all crops produced in the U.S. in 2021 was $238 billion (Figure 2; U.S. Department of Agriculture 2022). Therefore, the reduction of tourism spending in 2020 was comparable to the complete failure of every single U.S. crop (e.g. corn, wheat, soybeans, fruits, vegetables) for 2.8 years. It was greater than the total world computer market (PCs, laptops, tablets, and other computers) of $370 billion in 2021 and the $573 billion world semi-conductor market (Figure 2; Fortunebusinessinsights.com 2022; Thebusinessresearchcompany.com 2022).

The U.S. job loss in 2020 because of COVID was the greatest since labor statistics began to be collected in 1915, exceeding the worst year in the Great Depression (U.S. Bureau of Labor Statistics 2021a). Over 39% of the lost jobs were in the T&T sector with 7.1 million jobs lost in 2020 (U.S. Bureau of Labor Statistics 2021a). This was more than twice as many jobs as any other sector (U.S. Bureau of Labor Statistics 2021b). The loss continued in 2021 with 6.3 million jobs lost relative to 2019. The 7.1 million loss is greater than the combined number teachers (3.6 million) and federal employees (2.9 million) in the U.S. (Figure 3; Bureau of Labor Statistics 2021b). The impact of the job loss was significantly mitigated by trillion-dollar federal programs, but it was still huge.

IMPACT OF COVID ON TOURISM IN COASTAL STATES

Before considering the impact of COVID on beach tourism, it is illuminating to determine the impact of COVID on overall tourism in the 20 states bordering the ocean with beach tourism an important part of their overall tourism. Alaska and Louisiana are not included in the analysis because beach tourism is a relatively small part of their overall tourism. Great Lakes states are not included. In addition, Hawaii tourism is not considered because, although it has a strong dependance on beach tourism, most visitors arrive by airplane. COVID caused a collapse in travel to Hawaii with 74% fewer arrivals in 2020 than 2019 (U.S. Department of Transportation 2021). The shunning of air transportation caused Hawaii to have the greatest drop in tourism spending of any state (62%) despite the attraction of its beaches.

Figure 4 shows 2019 tourist spending in the 20 states before COVID. There is a correlation between tourist spending and state population because, in general, state residents are the greatest number of tourists in a state. There are some minor differences, but the only significant correlation difference is that Texas has about a 35% and 50% greater population than Florida or New York, respectively, but has lower tourist spending (World Population Review 2022).

Tourist spending in the 20 states dropped 44% or $335 billion between 2020 and 2019 and was still down 24% or $182 billion in 2021 relative to 2019 (U.S. Travel Organization 2022). Figure 5 shows the percentage decline in tourist spending in 2020 and 2021 versus 2019 for each of the 20 states. Percentage declines depend on several factors including the length of pandemic lockdowns and how many travelers including foreign travelers arrive by airplane, because air travel was down significantly in 2020 and 2021. For example, California and New York had significant lockdowns and California is the gateway for foreign tourists into the U.S. on the Pacific Coast and New York on the Atlantic Coast. Notably, Florida tourism sprung back in 2021 despite having significant international tourism from Canada and South America and attractions such as Disney World and cruise ships that normally attract tourists from the U.S. and abroad.

There was a $48.9 billion drop in state and local tax revenues generated by tourism from 2019 to 2020 in the 20 states (U.S. Travel Organization 2022). This almost double the $23.8 billion in salaries for the 5.2 million full-time and part-time state employees in all 50 states combined (U.S. Census Bureau 2022). Local and state tax revenues were still down $28.0 billion in 2021 relative to 2019. The impact on local and state governments was cushioned considerably by federal programs that provided funding to states.

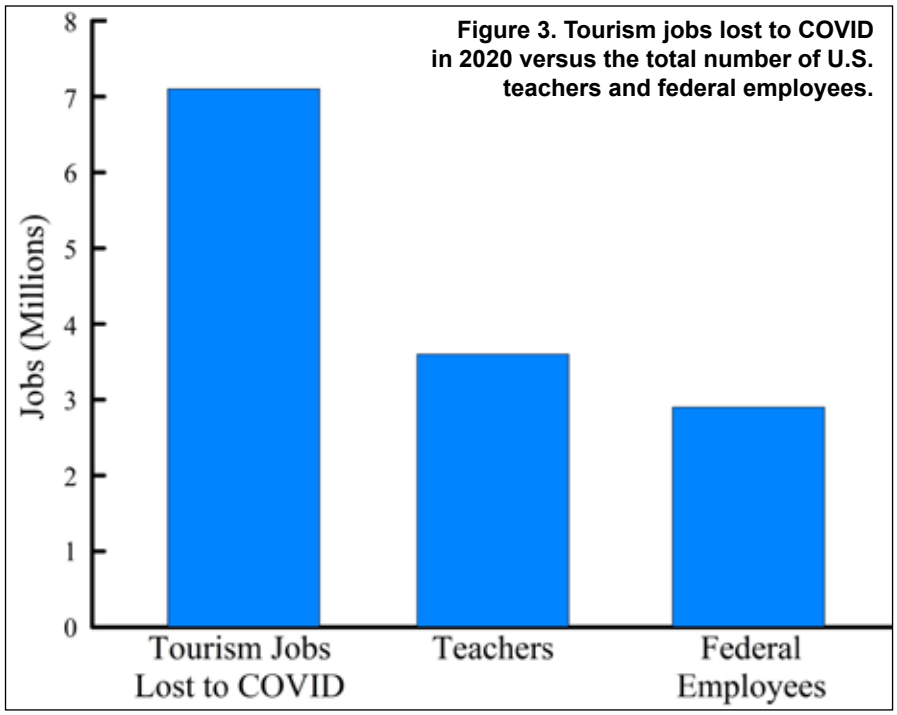


Figure 3. Tourism jobs lost to COVID in 2020 versus the total number of U.S. teachers and federal employees.

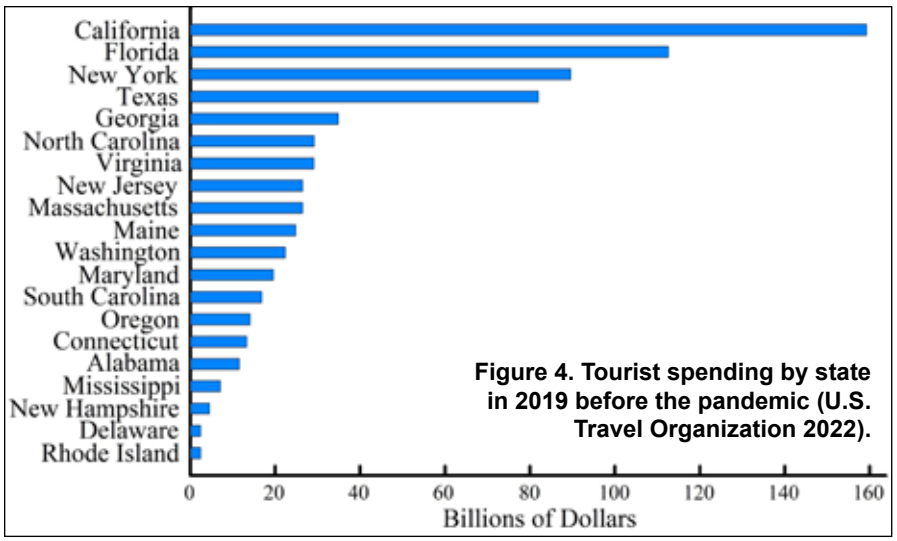


Figure 4. Tourist spending by state in 2019 before the pandemic (U.S. Travel Organization 2022).

IMPACT OF COVID ON BEACH TOURISM

There is national evidence that after the initial shock and fears of COVID and the closures of many tourist attractions, people began looking for outdoor recreation that they considered relatively safe. In May 2020, "Crowds packed beaches in Florida, California, Maryland, Georgia, Virginia, and Indiana over the Memorial Day weekend" (Wdel.com 2020). Attendance of 262 million in 2019 at the 402 recreational lakes managed by the Corps of Engineers declined only 2% from 2019 to 2020 but was up about 2% in 2021 versus 2019 (Corps of Engineers 2022a,b). Although attendance at all National Park Service properties dropped 27.6% from 2019 to 2020 and 9.3% from 2019 to 2021 (National Park Service 2022a), the drops were not uniform. There were steep drops in 2021 attendance versus 2019 at National Battlefields, National Historic Sites, and National Monuments (Figure 6). In contrast, visits to National Seashores (NS) in the National Park system increased 7.4% from 2019 to 2021 to record levels. Similarly, visits to outdoor National Parks increased 2.7% (Statista 2022b). National Seashores near urban areas had increasing visits even in 2020 despite restrictions and closures. For example, attendance at Assateague Island NS, Maryland, was up 5.8% and 13.6% in 2020 and 2021, respectively, compared to 2019 (National Park Service 2022b). Similarly, at Cape Hatteras NS, North Carolina, attendance was up 2% in 2020 and 23.0% in 2021 versus 2019 and attendance at Point Reyes NS, California, was down 0.6% in 2020 but up 20.9% in 2021 relative to 2019 (National Park Service 2022b).

Crowded beaches at the beginning of COVID in 2020 caused an outcry, and beaches were typically closed for a few months (Forbes 2020). However, once the initial shock of COVID began to wane, people began streaming back to beaches, seemingly recognizing that beaches were one of the safest places to be because they were outside where there were strong breezes and sunshine.

It has become apparent that people's perceptions of the safety of open-air environments were correct. "According to many scientists and public health experts, outdoor spaces now warming under spring sun should be viewed as havens in the battle against a stubborn virus and restriction-induced fatigue. Near-absent are examples of transmission at beaches and other open spaces where breezes disperse airborne particles, distancing is easier, and humidity and sunlight render the coronavirus less viable" (Washington Post 2021). Professor Linsey Marr, an expert on airborne virus transmission at Virginia Tech, said: "Beaches and parks are some of the safest places you can gather" (Washington Post 2021). Dr. Paul Dabisch, a senior research scientist at the Department of Homeland Security's biodefense research laboratory, said: "What we have found so far is that sunlight seems to be very detrimental to the virus. And so within minutes, the majority of the virus is inactivated on surfaces and in the air in direct sunlight" (Spencer 2020). Professor Mark Woolhouse, professor of infectious disease epidemiology at the University of Edinburgh and an adviser to the government's Scientific Advisory Group for Emergencies, told the Science and Technology Committee of the House of Commons of the United Kingdom:

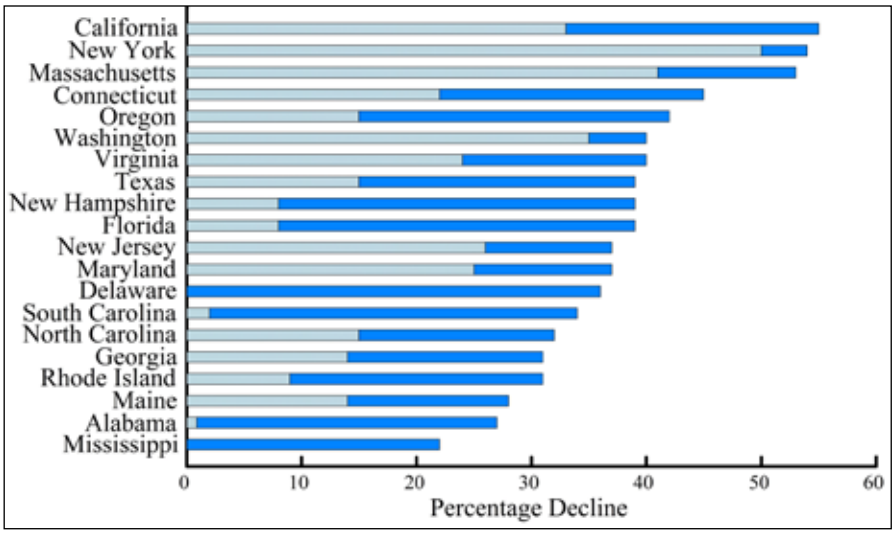
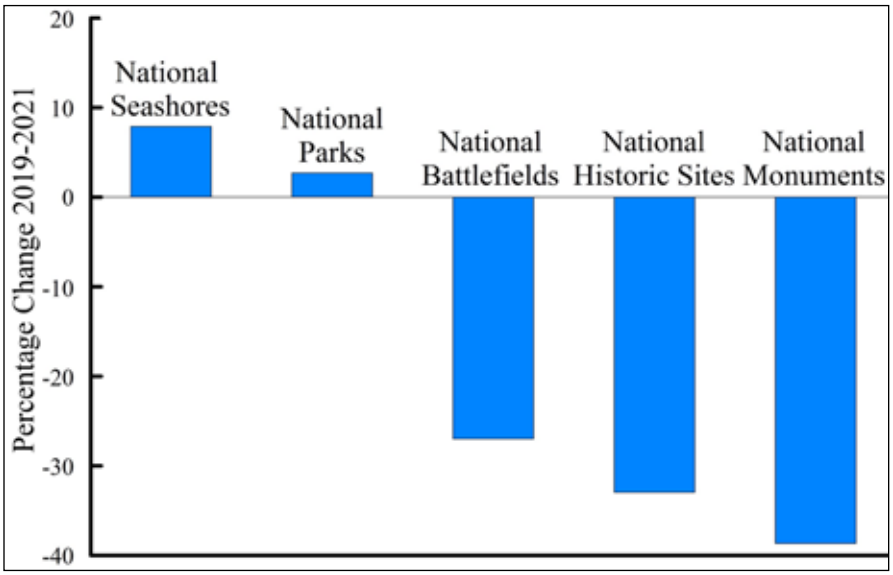


Figure 5. Percentage decline in tourist spending in 2020 versus 2019 (total bar length — light and dark) and in 2021 versus 2019 (light bars). Delaware and Mississippi had small increases of 0.7% and 0.9%, respectively, in 2021 relative to 2019 (based on U.S. Travel Organization 2022).



"There were no outbreaks linked to crowded beaches. There has never been a COVID-19 outbreak linked to a beach ever anywhere in the world" (Yahoo News United Kingdom 2021). Based on this evidence, it is unlikely that beaches will be closed if there are future pandemic outbreaks.

There are indications that increased beach tourism due to the COVID pandemic may be long-lasting. The best evidence of this is the excellent tourist surveys at Daytona Beach, FL. Before the pandemic in 2017-2019, about 60% of tourists at Daytona Beach listed beaches as their reason for vacationing at Daytona Beach (Figure 7). There were no surveys in 2020 due to the pandemic. In 2021 and 2022, conventions, races at the International Speedway, and special events such as Biketoberfest were being held, but the percentage of those listing beaches as their primary reason for vacationing in Daytona Beach rose significantly to over 80% (Figure 7). In 2017-2019 pre-pandemic, about 80% of Daytona Beach tourists said they had activities at beaches regardless of their reasons for vacationing there. But in 2021-2022 over 90% of all tourists said they had activities at beaches. In 2022 very little appeared in news media about COVID and leisure activities returned to near normal. But the percentage of tourists in 2022 that said they were vacationing at Daytona Beach increased to record levels (Figure 7). Apparently, tourists who typically might not have taken vacations at beaches pre-pandemic found a new liking for beaches after vacationing there during the pandemic.

It is challenging to separate the impacts of COVID on beach tourism from general tourism, but one way to do this is to concentrate on local communities where beach tourism is a significant percentage of the communities' tourism. The pattern that emerges is that in the first half of 2020 beach tourism experienced the same rapid decline as all tourism, in particular because of mandated beach closures. However, there was a recovery in the second half of 2020 and a boom in beach tourism in 2021, whereas non-beach tourism still struggled.

The analysis will start with Florida on the east coast (but including Florida's Gulf coast beaches) and continue north to Maine, then the Gulf coast starting with Texas and moving east, and finally the west coast starting with California and moving north. Because Florida, New Jersey, North Carolina, and South Carolina have had the greatest spending on beach nourishment as a result of the importance of beach tourism (American Shore and Beach Preservation Association 2022), these states will have an expanded discussion of the effect COVID had on beach tourism. Louisiana is listed in databases as having high spending for "beach nourishment." However, there are few recreational beaches in Louisiana with the spending largely used to restore wetlands using non-sand dredged material or to build up unpopulated barrier islands using sand to protect wetlands tens of miles away. This is not beach nourishment.

EAST COAST

Florida

Florida had 131 million tourist visitors in 2019 that spent more than any state other than California (Figure 4). The number of tourists dropped almost 40% in 2020 (VisitFlorida.com 2022). About half of Florida tourists are beach tourists because their primary reason for visiting Florida is to go to beaches (Houston 2018b). Florida tourist direct spending dropped 39% or $43.9 billion, from $112.6 billion in 2019 to $68.7 billion in 2020 (U.S. Travel Organization. com 2022). With half of tourists being beach tourists, beach tourist spending likely dropped about $22.0 billion in 2020. The magnitude of this drop can be appreciated by realizing that the total receipts of all Florida crops (in addition to citrus fruits, Florida is the No. 1 U.S. flower producer) and livestock in 2021 was $5.9

billion (U.S. Department of Agriculture 2020; 2022). The decline of just Florida beach tourist spending in one year is the equivalent of losing all Florida crop and livestock production for 3.7 years. Without federal assistance, Florida's economy would have been devastated.

Assuming local, state, and federal tax receipts generated by tourists dropped the same 39% as direct tourist spending and the ratio of federal to local/state tax collection remains constant, tax receipts declined $13.1 billion from $33.7 to $20.6 billion from 2019 to 2020 (Rockport Analytics 2019; U.S. Travel Organization 2022). With half of tourists being beach tourists, taxes generated by beach tourists were down about $6.6 billion in 2020. This loss of tax revenue generated by beach tourists in a single year is almost 3.5 times the estimated $1.9 billion ever spent on beach nourishment in Florida from 1935-2022 (American Shore and Beach Preservation Association 2022). Moreover, the $1.9 billion is overstated because it includes the cost of significant sand bypassed around 41 Florida inlets to offset modification of the inlets for navigation (Houston 2022b). Sand bypassing is not really beach nourishment because it adds no new sand to the littoral system but just restores the natural longshore sand movement that was interrupted by humankind.

Florida tourism partially snapped back in 2021 despite COVID continuing (Figure 1) with the number of tourists down only 8% in 2021 compared to 2019. Moreover, there were actually slightly more domestic tourists visiting Florida in 2021 than in 2019. As noted in the section on the "Impact of COVID on U.S Tourism," the number of international tourists did not recover in 2021. In Florida, the number of international tourists, including those from Canada, dropped from 13.9 million in 2019 to 3.8 million in 2020 and recovered only weakly to 4.7 million in 2021. Domestic tourists more than offset the decline in international tourists in 2021. In 2022 the number of international tourists is still only about 60% of those in 2019. However, the total number of tourists in 2022 hit a record, exceeding the 2019 number (VisitFlorida.com 2022).

The effect of COVID on beach tourism in Florida is seen clearly by considering Panama City beaches, which are completely dependent on beach tourism.

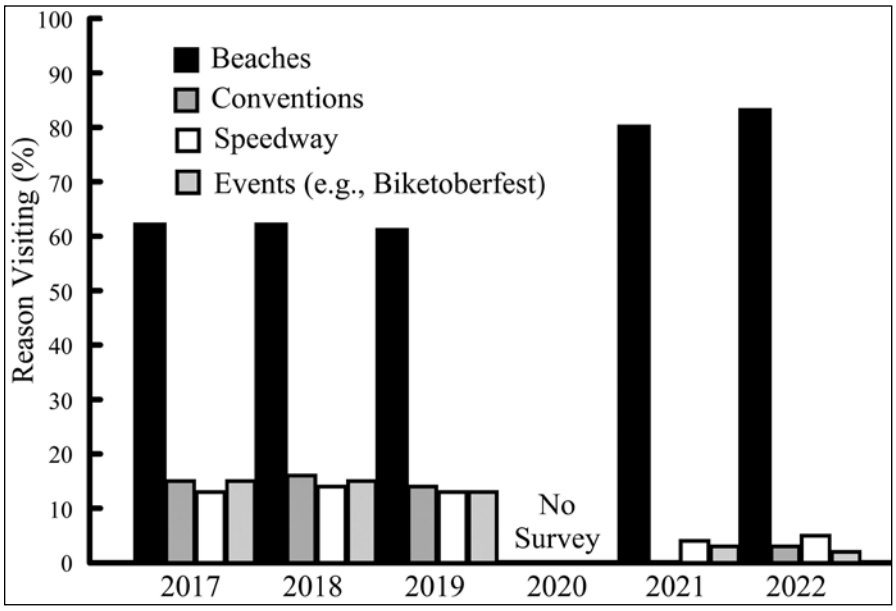


Figure 7. Reasons that tourists give for vacationing at Daytona Beach. The speedway is the Daytona International Speedway and events are widely attended special events such as Biketoberfest (held yearly in October). Based on data in Daytonabeach.com (2023).

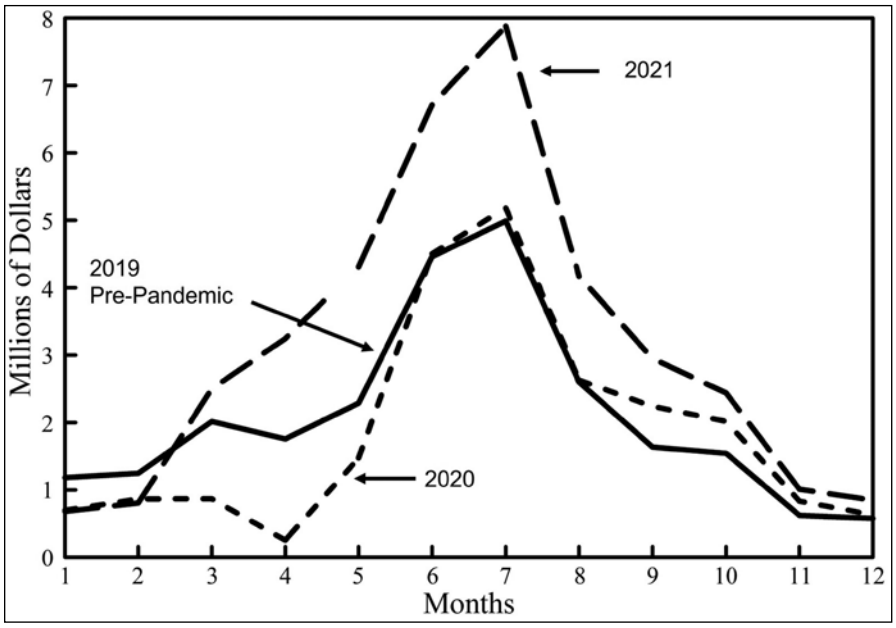


Figure 8. Proceeds from the Panama City tourist development tax by month. Solid line is 2019, small-dashed line is 2020, and large dash line is 2021 (based on data from Bay County Clerk of Court and Comptroller 2022).

These beaches are in Bay County where the No. 1 industry is tourism, generating over $3 billion in annual revenue and supporting over 20,000 local jobs (PanamaCity.org 2022; Wjhg.com 2022). Panama City Beach has a population of 15,000, which increases to 100,000 during peak summer months (PanamaCityBeach.com 2022). In 2021, *Newsweek* reported that Panama City Beach tied Huntington Beach, CA, as the most popular beach in America in terms of number of visitors (Newsweek 2021).

The impact of COVID on tourism is measured by considering the Bay County tourist development tax, a 5% tax on hotels and rental property. When COVID first struck, beaches were closed and tax receipts dropped 85% in April 2020 compared to 2019 (Figure 8, Bay County Clerk of Court and Comptroller 2022). However, beaches were reopened in May 2020 and despite rising cases, hospitalizations, and deaths in 2020 because of COVID (Figure 1), starting in June 2020 tax revenues exceeded corresponding 2019 revenues for the remainder of 2020. As

people increasingly considered beaches a relatively safe activity, tourism soared and shattered records with tourism tax receipts up a remarkable 51% in 2021 compared to 2019 as hotel and rental property reached capacity limits (Figure 8). Tax collections have increased further in 2022, up about 2% over 2021 as hotel and rental property capacity could be only slowly increased (Bay County Clerk of Court and Comptroller 2022).

Miami-Dade County is a major U.S. tourist destination. It has a population of 2.7 million and Miami Beach, a subset of the county, has a population of about 80,000, or less than 3% of the county population (U.S. Census Bureau 2021a). However, about 38% of U.S. tourists in Miami-Dade County in 2019 stayed at Miami Beach because of its beach. The number of tourists dropped 37% in Miami-Dade County and 28% in Miami Beach in 2020 compared to 2019 as pandemic restrictions took hold (Miami and Beaches.com 2022). However, in 2021, visitors flocked to beaches with the number of U.S. tourists at Miami Beach increasing a remarkable 63% to record levels in 2021 compared to 2019, whereas it went up only about 4% in the rest of Miami-Dade County (Miami and Beaches.com 2022).

The rapid recovery of Florida beach tourism contrasts with the slow recovery of other Florida tourist attractions. For example, the number of visitors at Disney World in Orlando fell 68% from 58.7 million visitors in 2019 to only 18.8 million in 2020 (Themed Entertainment Association 2022). Visitor numbers were still down 40% in 2021 relative to 2019 even though overall Florida numbers were down only 8% and the number of visitors to beaches was up sharply. In 2022, Florida was setting records in the number of tourists, but Disney World attendance was still below 2019 levels (Travelweekly.com 2022). Florida dominates the U.S. cruise industry, but cruise revenues dropped from $13.3 billion in 2019 to $1.7 billion in 2020 and were still down 47% to 7 billion in 2021 relative to 2019 (Statista 2022c). Revenues for 2022 are projected to still be down 23% from 2019 (Statista 2022d).

Georgia

Georgia had declines in tourist spending of 31% and 14% in 2020 and 2021, respectively, compared to 2019 (U.S Travel Organization 2022). However, at the beaches on Tybee Island, "The popularity spiked suddenly in 2020" as the "COVID-19 pandemic made the island a socially distanced getaway for vacationers across the Eastern United States" (Savannah Morning News 2022). The Golden Isles that comprise St Simons, Sea, Little St Simons, and Jekyll Islands reported that tourist spending was down 90% in April 2020, but, by the next month, Scott McQuade, president of the Golden Isles Convention and Visitors Bureau, said: "Record books are once again getting shattered." He also noted: "The resorts are reporting that the bookings are at an all-time record high. Unlike anything hoteliers have ever seen" (Elevenalivenews.com 2020). The surge of Georgia beach tourists continued in 2021 with attendance at the Cumberland NS blowing past records with an increase of 34% in the number of visitors compared to 2019 (National Park Service 2022b).

South Carolina

Former Congressional Majority Whip Jim Clyburn of South Carolina said that South Carolina "used to thrive on supplying textile and tobacco (but) now leans on two very different 't's': tourism and transportation" (ExploreBeaufortSC.comb2019). Beach tourism accounts for two-thirds of South Carolina tourist spending (South Carolina Legislature 2020).

The pandemic caused tourism spending to drop 34% from $25.6 billion in 2019 to $16.2 billion in 2020 (U.S. Travel Organization 2022). However, tourism largely recovered by 2021, down only 2% from 2020. Although total tourism spending was down in 2020 because of a reduction of out-of-state tourists, tourist spending by South Carolina residents was up 12% in 2020 to record levels compared to 2019 (South Carolina Parks, Recreation, and Tourism 2022). Revenues from occupancy fees at state parks dropped 85% in April 2020 compared to April 2019 but were up about 40% the next month compared to 2019 and continued exceeding 2019 revenues in each month of 2020 (Hammockcoast 2021). After Huntington Beach State Park re-opened in May 2020, its occupancy revenues were up over 30%, a new record compared to 2019 (Hammockcoast 2021). "The recovery of the South Carolina tourism industry from the impact of the coronavirus is the result, in large part, of the popularity of its beaches. South Carolina's beaches are world-famous, so it is not surprising beaches are South Carolina's most-discussed vacation activity." (University of South Carolina 2021).

The beaches along the 60-mile-long Myrtle Beach/Grand Strand in Horry County and on Hilton Head Island are by far the greatest tourist attractions in South Carolina. Tourists spend about $117,000 annually for every household in Horry County (Myrtlebeachareacvb 2022; U.S. Census Bureau 2021d). Collections of the tourist development fee in Horry County were down 12.5% in 2020 relative to 2019 but went up sharply by 27% in 2021 compared to 2019 to a record level as tourists flocked to the beach (Myrtlebeachareacvb 2021; 2022). The U.S. had little recovery of hotel revenues in 2021 with the revenue per available hotel room in the top 40 U.S. urban markets down 20% from 2019 to 2021 (Costar.com 2021; Figure 9). However, Myrtle Beach easily led the top 40 urban markets with about a 20% increase in revenue per available hotel room in 2021 versus 2019 (Figure 9). Hilton Head Island had a 5% decline in the number of tourists in 2020 due to beach closings but had record tourist numbers in 2021 that were up 16.5% from 2019 (College of Charleston 2022).

North Carolina

North Carolina tourist spending dropped 32% in 2020 and 15% in 2021 relative to 2019. However, the resilience of beach tourism was apparent throughout coastal areas. In New Hanover County, the location of Wilmington, beaches saw an increase in beach attendance in 2020 despite the pandemic and beach closures (WECT6News 2020). Beaches were not closed at Carolina Beach, and attendance in 2020 skyrocketed 78% above 2019 (StarNewsOnline.com 2021). Kure Beach had an almost 20% increase and Wrightsville Beach a 7% increase in June 2020 over June 2019 (WECT6News 2020). Currituck County depends on beach tourism, and from 2019 to 2020 tourist spending increased 2.9%, further increasing 30% from 2019 to 2021 (Partnersvisitnc.com 2021, 2022).

Dare County includes much of the Outer Banks of North Carolina, and beaches are the attraction. A newspaper article ("Outer Banks tourism numbers reflect Dare County's resilience during the pandemic"), noted that tourist

spending in 2020 dropped 32% in North Carolina from 2019, but only 2% in Dare County despite beaches being closed two months in the spring of 2020 because of pandemic fears (Islandfreepress.org 2021). Employment in Dare County actually increased 0.6% in 2020 (U.S. Census Bureau 2021c). Dare County tourist spending roared back in 2021 with tourist spending up a record 27% above 2019, hitting hotel and rental property capacity levels (Partnersvisitnc.com 2021, 2022). This contrasts with tourist spending in North Carolina that was still down 15% in 2021.

The Cape Hatteras National Seashore has 67 miles of shoreline along the North Carolina Outer Banks. Despite the fact that Dare and Hyde counties had blocked access to the beaches from March to May because of the pandemic, the number of visitors was the still highest in 2020 in 17 years (WXII12.com 2021). Cape Hatteras visitor numbers surged a record 23% in 2021 versus 2019. (National Park Service 2022b).

Virginia

Overall tourism in Virginia was hit hard by COVID, with tourist spending dropping 40% in 2020 and 24% in 2021 compared with 2019 (Virginia Tourism Corporation 2022). The beach is the main tourist attraction at Virginia Beach, and it was closed until late May 2020 with COVID restrictions in place until June/July, causing tourist spending at Virginia Beach to decrease 22% in 2020. However, in 2021, people streamed to beaches, and tourist spending was up a record 17% at Virginia Beach versus 2019 despite the 24% fall in tourism in Virginia as a whole (U.S. Travel Organization 2022; Virginia Tourism Corporation 2022). Norfolk/Virginia Beach was only the second urban hotel market of the 40 largest in the U.S. that had an increase in hotel revenues per available hotel room from 2019 to 2021 (Figure 9).

People also streamed to state parks with park attendance up record levels to 13.4% in 2020 and 15.0% in 2021 versus 2019 (Virginia Department of Conservation and Recreation 2022). Attendance at beach parks went up much more. For example, attendance in 2020 at First Landing State Park beach, the most visited Virginia state park, was up 25% and attendance at Kiptopeke State Park that has beaches near the mouth of Chesapeake Bay was up 240% (The Virginian-Pilot 2020).

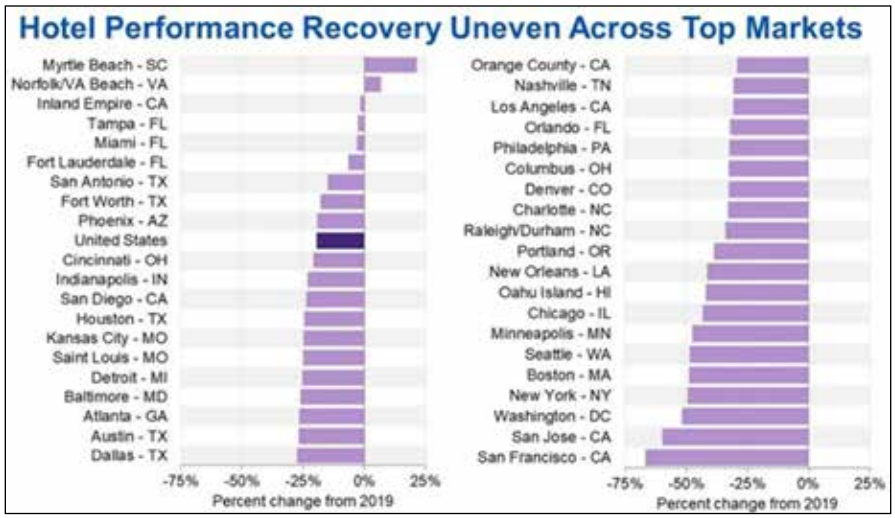


Figure 9. Percent change in revenue per available hotel room from 2019 to 2021 in the 40 largest urban hotel markets (Costar.com 2021).

Maryland

Maryland tourism was significantly impacted by the pandemic, sinking 37% in 2020 and still down 25% in 2021 compared to 2019 (U.S. Travel Organization 2022). However, beach areas boomed after closures ended. For example, Ocean City tourism tax collections by June 2020 exceeded June 2019 tax collections and were up 50% to record levels in June 2021 versus June 2019 (Ococean.com 2021). As a result, by October 2021 Ocean City's general fund had the greatest growth in the town's history (The Dispatch 2021). State parks had almost a 15% increase in visitors in 2020, shattering attendance records. According to Governor Larry Hogan: "Maryland set a new attendance record at its state parks this year due in large part to the COVID-19 pandemic" (Delmarvanow.com 2020). Maryland state officials encouraged Marylanders to use state parks and Assateague Island NS as a way to go outside and stay safe during the COVID pandemic (Delmarvanow.com 2020). According to Superintendent Hugh Hawthorne, in 2020 "Assateague Island National Seashore also crushed both its June and July attendance records this year" (Delmarvanow.com 2020).

Delaware

Tourism in Delaware sank 36% in 2020 relative to 2019 but increased 0.7% in 2021 versus 2019 2019 (U.S. Travel Organization 2022). The recovery in 2021 was led by beach communities that had record-shattering numbers of visitors. For example, at Rehoboth-Dewey Beaches the number of visitors increased 29% from 7.76 million in 2019 to over 10 million in 2021. The boom at Rehoboth-Dewey Beach has continued in 2022 with "…visitation and occupancy continuing very, very strong" (Whyy.org 2022). State parks also broke attendance records with M. Shawn Garvin, Secretary, Delaware Department of Natural Resources and Environmental Control noting: "The incredible interest our Delaware State Parks have experienced since the start of the pandemic is here to stay" (Delaware.gov 2022). The Delaware Seashore and Cape Henlopen State Parks are the two top parks in Delaware in attendance and visitor spending with their beaches being the draw, and they reached capacity in 2021, resulting in a record 69 parking lot closures (Cape Gazette 2018; Delawarelive.com 2022).

New Jersey

Tourists in New Jersey spent $26.5 billion in 2019 (U.S. Travel Organization 2022). This tourism spending is greater than the 2019 combined state budgets of Maine, New Hampshire, and Rhode Island (USgovernmentspending.com 2022). Tourist spending fell 37% ($9.8 billion) to $16.7 billion and was still down 26% in 2021 to $19.6 billion (U.S. Travel Organization 2022). New Jersey is known as the "Garden State," but the $9.8 billion fall in tourist spending in 2020 is huge compared with the total annual crop production in New Jersey of only $1.3 billion (U.S. Department of Agriculture, 2022). New Jersey lost 106,000 tourism jobs in 2020 because of the pandemic; this compares with the 63,000 jobs in the pharmaceutical industry in New Jersey that is one of the largest in the U.S., with major

medical companies such as Johnson and Johnson, Merck, and Becton Dickinson headquartered in New Jersey (Biospace 2022; Tourism Economics 2022).

Tourism in New Jersey generated $11.2 billion in local, state, and federal taxes in 2019, $8.8 billion in 2020, and $9.7 billion in 2021 (Tourism Economics 2022). The $2.4 billion fall in 2020 was enough to pay the salaries of all 49,000 law enforcement officers in New Jersey (Federal Bureau of Investigation 2019; ZipRecruiter 2022).

There are 21 counties in New Jersey, but about 55% of tourist spending is in the four coastal counties of Cape May, Atlantic, Ocean, and Monmouth (Tourism Economics 2022). As was the case for Florida, these counties were initially hit hard by the pandemic, but tourism recovered faster than non-coastal counties. The 17 non-coastal counties had a drop of tourist spending from 2019 to 2021 that was three times the drop in the four coastal counties (Tourism Economics 2022).

Cape May County has the most tourist spending of any New Jersey county, with 63% of jobs associated with the tourism industry and 90% of tourists listing "beaches" as the No. 1 attraction (Capemaycountynj.com 2022). Tourists spend about $163,000 annually for every household in Cape May County (Tourism Economics 2022; U.S. Census Bureau 2021b). As was the case for Panama City beaches, tourism collapsed at the beginning of 2020 because of COVID fears and beach closures. Its tourism occupancy tax collection was 99% lower in April 2020 than April 2019. However, after a statewide stay-at-home order was lifted in June 2020, people began heading to Cape May County beaches and in September 2020 tax collections were up 17% versus September 2019. Tourism roared back in 2021 with the tourism occupancy tax up 25% from 2019, smashing all records (Capemaycountynj.com 2022). The county was the only New Jersey county that gained tourists in 2021 versus 2019, adding 100,000 tourism visitors while the other counties lost 19.6 million visitors relative to 2019 (Tourism Economics 2022). It was also the only county that added tourism-related jobs, adding 1,323 in 2021 versus 2019 while the other counties still had 72,000 fewer tourism jobs in 2021 (Tourism Economics 2022).

Some other beach areas fared much like Cape May during 2020. New Jersey State Park attendance was down over 14% in 2020, but attendance was up 3% at the Island State Park that has almost 10 miles of beach (NJ.com 2021). In Monmouth County, Commissioner Director Tom Arnone said: "The beaches, even in the midst of the pandemic in 2020, never really saw a decrease. The only thing that may have hindered attendance were the daily capacity limits many towns had in place in 2020. Regardless, the 2020 season had record-breaking beach badge revenue and we anticipate 2021's summer totals to be on track with another successful season" (Jersey Shore Online 2021).

New York

COVID caused New York tourism to be one of the hardest hit among states, with tourist spending down 54% in 2020 and 50% in 2021, thereby having the worst percentage decline in 2021 among the 20 states (Figure 5; U.S. Travel Organization 2022). However, state parks hit record attendance in both 2020 and 2021. New York State Senator Rob Ortt touted the attendance figures, saying: "With the ongoing pandemic, our State Park attendance is at the highest it's ever been" (Politifact.com 2021). The overall increase in state park attendance in 2020 was only 1.2%, but the attendance was up sharply at most beach parks. Before the pandemic, Niagara Falls State Park had been the most visited tourist attraction in New York's state park system, but the number of tourists dropped 38% from 9.7 to 6.0 million in 2020 (Journal News 2021). Despite restrictions, Jones Beach on Long Island replaced it as the most visited New York park with number of visitors up 2% to 8.3 million in 2020 from 2019. Attendance at the beach at nearby Robert Moses State Park leapt a remarkable 39% in 2020 to a new record with nearly 6 million visitors (Journal News 2021). Similarly, beach attendance increased 35% at Sandy Island, 63% at Amsterdam, 11.5% at Orient, 12.5% at Bristol, 76% at Southwick, and 34% at Westcott Beaches in 2020 versus 2019 despite overall tourism in New York falling 54% (Lohod.com 2021).

Connecticut

Connecticut tourism spending was down a sharp 45% in 2020 and still down 22% in 2021 compared to 2019 (U.S. Travel Organization 2022). However, state parks and beaches were swamped early in the pandemic in 2020 with attendance up by nearly 50%, forcing more than 500 park and beach closures during 2020 (Connecticut Insider 2022). Local towns moved to restrict beach attendance in 2020 because of the large crowds. In Madison, Connecticut, "the town cut capacity limits at its largest beach in half and banned non-residents from using beach parking on the weekends and holidays. Along the coast, other towns took similar measures to limit out-of-towners from the beaches" (The Middleton Press 2021). Despite large declines in tourism in Connecticut in both 2020 and 2021, beach tourism boomed.

Rhode Island

Rhode Island tourist spending was down 31% in 2020 and 9% in 2021 from 2019. However, it experienced a dramatic increase in the number of people at its beaches early in the pandemic with a 79% increase in beach visitors in June 2020 compared to June 2019 (New England Cable News 2020). Governor Gina Raimondo moved to discourage beach attendance by reducing parking spots by 25% at the most popular beaches and cracking down on illegal parking. However, she reported in mid-June 2020: "Last month, even with our reduced parking, our state beaches saw 50,000 more cars than the same time last year. I believe the town beaches are similar" (Wpri.com 2020). Further she noted, "I want you to go to the beach and enjoy that, but we are struggling to keep the crowds under control. We're seeing really big crowds" (Wpri.com 2020).

Massachusetts

Tourism in Massachusetts was hit hard by the pandemic, with tourist spending down 53% in 2020 compared to 2019 and still down 41% in 2020 – making it second only to New York for having the largest percentage decline in 2021 relative to 2019 (U.S. Travel Organization 2022; Figure 5). However, it was a completely different story for parks and beaches. Massachusetts Energy and Environmental Affairs Secretary Kathleen Theoharides, said on 1 July 2020: "Our state parks and beaches are seeing record numbers, sometimes up over 200 percent above average" (The Patriot Ledger 2020). The coastal counties reported sharp increases in park and beach attendance in 2020, with Barnstable County up 323%, Essex County 207%, and Plymouth County 254% (The Patriot Ledger 2020).

Moreover, despite some beaches and all showers being closed along the 40-mile-long Cape Cod NS in Barnstable County, attendance was down only 0.3% in 2020 versus 2019 compared to a decline of 41% at National Park Service non-beach properties in Massachusetts (National Park Service 2022b).

New Hampshire

New Hampshire had a 39% drop in tourist spending in 2020 and 8% in 2021 versus 2019. It has only 18 miles of ocean shoreline, the shortest shoreline of states bordering the ocean. However, despite the pandemic and beach closures, seacoast state parks set records with 11% more visitors in 2020 than 2019 (WMUR9.com 2020). The most popular beach, Hampton Beach State Park, had a 10% increase in attendance, and Odiorne Point State Park (which has a rocky beach) had a 60% increase in attendance (WMUR9.com 2020). Increased beach attendance continued in 2021 with Village District Beach Commissioner and Pelham Hotel owner Chuck Rage noting: "We were full all summer long; we had a banner year" (SeaCoastOnline 2021).

Maine

Maine had a 41% decline in tourist spending in 2020, but only 2% in 2021 as tourists were once again attracted to parks and beaches. Despite closures in the spring, state park and beach attendance set new records in both 2020 and 2021 versus 2019 (Spectrum News 2021). The biggest increases were at coastal locations at Birch Point Beach State Park, Eagle Island State Historic Site off the coast of Harpswell, and Owls Head State Park. The attendance increases are continuing in 2022 with Popham Beach State Park becoming the most popular state park as its 2022 attendance was running 110% above its record year in 2021 (Brunswick-Topsham Landtrust 2022).

GULF COAST

Texas

Texas tourism was down 39% in 2020 and still down 15% in 2021 relative to 2019 (U.S. Travel Organization 2022). South Padre Island has a 34-mile-long beach and the City of South Padre Island has about 5,000 residents and over a million visitors annually, or 200 visitors per resident (Myspi.org 2022). Its tourism is dependent on beaches that were closed parts of 2020, including spring break and July 4th until mid-July because of COVID

Figure 10. Santa Monica Beach on Labor Day 2020 (Forbes 2020).

fears. The hotel/motel occupancy tax dropped rapidly and was down about 70% in April and May 2020. However, the tax reached record levels after mid-July 2020, resulting in tax receipts down only 14% for the year (Myspi.opengov.com 2022). Tourism increased significantly in 2021, with tax revenues up a record 34% from 2019 (Myspi.opengov.com 2022).

Galveston Island depends on tourism, with about 50% of its general fund tax revenues generated by tourists (The Daily News, 2022). Like Padre Island, beach park admissions fees on Galveston Island were down 14% in 2020 due to closures but up a record 34% in 2021 relative to 2019 (Galveston Park Board 2022). Hotel revenues were up 56% in 2021 and the tourist occupancy tax set a record (The Daily News, 2022).

Mississippi

Mississippi had the least decline among the states in tourist spending in 2020, with a 22% decline followed by a 1% increase in 2021 relative to 2019 (U.S. Travel Organization 2022). Although overall tourism declined in 2020, beach tourism held up in 2020 along South Mississippi beaches. "Despite COVID-19, however, beaches this year (2020) have some of the largest crowds seen in the last decade in South Mississippi" (Sun Herald 2020). The boom continued into 2021 with hotel revenue hitting a record, up 11% from 2019 along the Gulf Coast (Coastal Mississippi 2021).

Alabama

Tourist spending was down 22% in 2020, but only down 1% in 2021 relative to 2019 (U.S. Travel Organization 2022). The resilience of beach tourism is readily seen in Baldwin County, the only one of Alabama's 67 counties that has ocean beaches. Baldwin County is very dependent on tourism, with 64% of the jobs in the county supporting tourism (TourismAlabama.gov 2022; U.S. Census Bureau 2021e). Tourists spent $7.3 billion in 2021, or 37% of state tourist expenditures. Beaches were closed until 30 April 2020, with hotel occupancy rates plummeting to 9%. However, by the end of May, "beaches in coastal Alabama are filling up again. The roads are so choked with tourists that weekend traffic has become fully gridlocked" (Slate.com 2020). Hotel occupancy rates in the second half of 2020 were up compared to 2019 (Gulf Shores and Orange Beach Tourism 2022). Despite the long beach closures, tourist revenues for the year dropped only 6.2% in Baldwin County in 2020 compared to 26.7% in the other 66 counties. In 2021, Baldwin's tourist revenues went up a record-setting 40.7% over 2019 revenues, whereas it was down 1% statewide (TourismAlabama.gov 2022; U.S. Travel Organization 2022).

WEST COAST

California

California has the greatest tourist spending of any state, and this spending was down $87.6 billion or 55% in 2020 and still down 33% in 2021 versus 2019 (Figure 4; U.S. Travel Organization 2022). About 480,000 people lost jobs in the tourism industry (U.S. Travel Organization 2022). This loss of tourism jobs is more than the total number of jobs in Delaware (Statista 2022e). Tax revenues generated by tourism dropped $7.9 billion from 2019 to 2020 (Dean Runyan and Associations 2022). This one-year drop is more than 20 times the funding ever spent on beach nourishment in California from 1927-2022 (American Shore and Beach Preservation Association 2022). It also is more than the $7.5 billion that California spent in 2020

for its 31 undergraduate and graduate universities that educate about 750,000 students annually (Legislative Analyst's Office 2022).

Once the initial COVID restrictions including beach closures began to ease, people in California started selecting trips to beaches as a safe alternative to indoor events. The state park system is responsible for 340 miles of California coastline. Gloria Sandoval, deputy director of public affairs at California State Parks, noted: "The number of park visitors has grown exponentially since the pandemic started," and there is "no question about it, beachfront campgrounds have been very, very busy" (VisitCalifornia.com 2022). California has more surfers than any other state, and the number of surfers in the U.S. increased only 48,000 annually during the five years from 2014-2019 but increased 800,000 to 3.8 million during the one year from 2019 to 2020 as people sought what they considered a safe way to recreate during COVID (Surfrider Foundation 2022; Statista 2021).

Attendance at Disneyland in Orange County was down over 80% in 2020 and 54% in 2021 compared to 2019 (Statista 2022f). This contrasts with attendance at beaches in Orange County. Newport Beach went from 7.7 million beach visitors in 2019 to a record 8.26 million in 2020, despite having days where beachgoers were not allowed on the sand, including the busy July 4th weekend (Orange County Register 2021). San Clemente had similar restrictions, but went from 2.2 million beach visitors in 2019 to 2.6 million in 2020 (Orange County Register 2021). The booming beach tourism in Orange County was repeated throughout Southern California. For example, Figure 10 shows the busy beach at Santa Monica in Los Angeles County on Labor Day 2020 that contrasts with the 55% drop in tourist spending in California in 2020.

Oregon

COVID caused tourist spending in Oregon to drop 42% in 2020 and 15% in 2021 relative to 2019 (U.S. Travel Organization 2022). However, the drop was not uniform. Local tax revenues in 2020 from tourism dropped 44.5% outside of the coastal region, but only 3% in the coastal region despite beach closures and restrictions (Dean Runyan Associates 2021). There were record numbers of people at state parks in 2021. Eight of the top 10 visited state parks were coastal parks with a record 31.4 million visitors and, "State park officials cited the COVID-19 pandemic as a driver of increasing crowds" (The Oregonian 2022). The coastal tourist town of Seaside had record numbers of visitors in both 2020 and 2021 (Opb.org, 2022). Dan Murphy, general manager of the coastal Brookings Inn Resort in Seaside said in 2021: "Business has been up since the beginning of the pandemic. It's been crazy, this has been by far the busiest summer we've had. Conservatively, we have ten times more demand than we have hotel rooms" (KOBI5.com 2021).

Washington

Tourist spending in Washington was hit hard by COVID in 2020, with a drop of 40% but recovered little in 2021 with a drop of 35% relative to 2019. The drop in 2021 was the worst among the states other than New York and Massachusetts. However, early in the pandemic, people flocked to Washington beaches. Beach towns signed emergency orders to close motels and vacation rentals after a surge of visitors to their communities (King5.com 2020). Long Beach is 28 miles long, and it had to close beach approaches when the number of tourists became overwhelming. Vickie Raines, a Grays Harbor County commissioner, said: "Our beaches have been bombarded with visitors" (King5.com 2020). On the Olympic Peninsula children created handmade signs with messages for tourists saying: "Tourist go Home" (King5.com 2020). The number of tourists dropped 4.9% at Long Beach in 2020 due to closures but increased 14.4% in 2021 despite the 35% fall in overall state tourism in 2021 relative to 2019 (Washington State Reports 2022).

CONCLUSIONS

T&T is an important component of modern economies. Its contribution to the U.S. GDP is comparable to the contribution of the entire U.S. manufacturing sector. The impact of COVID on T&T in the U.S. was immediate and large. However, open-air attractions such as beaches and parks had declining attendance only initially in 2020, primarily because of closures. By the middle of 2020 Americans were heading to beaches and attendance increased. Beaches boomed in 2021, usually hitting new records, and this was in contrast to other tourism that remained depressed relative to 2019. The hit to the U.S. economy caused by the rapid fall in beach tourism in the first half of 2020, largely due to beach closures in response to COVID, made the value of beach tourism to the U.S. economy apparent. The rapid recovery of beach tourism in the second half of 2020 and boom in 2021, despite continued problems in non-beach tourism, demonstrated its resilience. The boom continued in 2022 and 2023 and will likely continue even if there are further pandemics, because the open air and sunlight of beaches makes them safe.

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Mixed sediment for sustainable ecosystem restoration of Louisiana

By

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ABSTRACT

Globally, human activities have contributed to the degradation of the coastal landscape and the Mississippi River Delta Plain (MRDP) is no exception. It is facing an ecocatastrophe caused in part by human intervention. This degradation and extreme rates of land loss threaten a range of key national assets and locally important communities. Restoration of Louisiana's environmentally sensitive wetlands, marshes, and barrier islands is in the national interest. Human activities have disrupted natural sediment transport to the MRDP. Sediment is trapped behind locks and dams upstream, decreasing fluvial sediment loads and preventing a naturally sustainable deltaic coast. Locally, coastal communities depend on a sustainable surrounding ecosystem for their existence. The fast-degrading coastal Louisiana needs frequent emplacement of sediment where the objective is not limited to ecosystem restoration only but most importantly to mitigate the pervasive land loss. Thus, sediment is critical for survival. Implementation of the Coastal Master Plan (CMP) for restoration and protection of coastal Louisiana depends heavily on a comprehensive Louisiana Sediment Management Plan (LASMP) that integrates various restoration quality/compatible sediment emplacement mechanisms. Louisiana's sediment need is significant and can only be met with a balance of both sand and mixed sediment. There is an increasing need for mixed sediment, as sand alone is not sufficient and not always the most appropriate sediment for restoration projects. Mixed sediment has been used for marsh restoration for quite some time in Louisiana. This paper defines mixed sediment as it applies to restoration in Louisiana and emphasizes the need to identify and preserve sources of mixed sediment to be used for the construction of planned restoration projects.

KEYWORDS: Coastal master plan, coastal restoration, habitat restoration, mixed sediment, sand, sedimentological restoration, sediment needs.

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Coastal erosion is a major global problem. The retreat of shorelines is most acutely felt along developed coastal areas where coastal communities and infrastructure are threatened by storms. This risk is compounded in deltaic plains which are rapidly subsiding including the Mississippi River Deltaic Plain (MRDP) which forms the majority of coastal Louisiana.

To address more than a century of documented hurricane impacts and extreme coastal wetland loss from a variety of causes, Louisiana's Coastal Master Plan (CMP) includes protection, restoration, enhancement and creation of vegetated wetlands in its overall goals as mitigation for the ongoing land loss crisis. Since the 1930s, Louisiana has lost approximately 0.5 million hectares of coastal land (a net decrease of approximately 25% of the 1932 land area) and is estimated to currently be losing land at a rate of about 1,440 hectares per year (CPRA 2023).

The first CMP was developed in 2007 and is updated every 5-6 years (2012, 2017, and 2023). These updates include portfolios of protection and restoration projects aimed at building and maintaining coastal land, reducing storm-induced flood risk, and improving sustainability of Louisiana's coast while also balancing short-term needs against long-term goals. The 2023 CMP includes 77 restoration projects to build or maintain more than 300 mi^2 of land over the next 50 years by restoring/creating marshes and ridges as well as restoring barrier islands along with back barrier marshes on a regional scale (CPRA 2023).

Due to the predominance of projects with the goal of creating land, a strategy is required to identify and quantify sediment resources that are commensurate with the need. The restoration of Louisiana's ecosystem requires a balance of "sedimentological restoration" (to replace/restore geomorphic form/features) and "ecological restoration" (for restoration/maintenance of ecological functions).

The emplacement of sediment serves a dual purpose — it restores/creates emergent vegetated habitats and at the same time mitigates/offsets perennial land-loss by emplacing sediment to fill the accommodation space (void). Imported sediment from sources outside of the "system" is preferred over interior sediment resources, offsetting land-loss with new sediment infusions rather than redistributing sediment already within the system. Two potential external sources of sediment include nonrenewable offshore deposits (both state and federal waters) and renewable deposits from the Lower Mississippi River (CPRA 2023). In collaboration with the Bureau of Ocean Energy Management (BOEM), which regulates the use of marine minerals in federal waters (sand, gravel, and other mineral resources), the Coastal Protection and Restoration Authority (CPRA) has been dredging and emplacing federal offshore sediment (primarily sand), mainly for its barrier island restoration projects, with great success for more than a decade.

Implementation of the CMP in coastal Louisiana depends heavily on comprehensive, holistic, and system-based sediment management for an efficient and cost-effective approach to maximize

the benefit of identified sources and to minimize waste. The Louisiana Sediment Management Plan (LASMP) not only embodies that approach but integrates various sediment input mechanisms as well. This sediment management plan includes (1) harvesting restoration-compatible sand and mixed sediment deposits from the Mississippi River and offshore, (2) long-term passive management of sediment through river diversions, and (3) beneficial use of sediment dredged annually from navigational channels (Khalil *et al*. 2023; Khalil *et al*. 2010; Underwood 2012; Underwood *et al.* 2015). As discussed below, Louisiana's sediment need to offset its land loss is significant and cannot be met by sand alone. This paper demonstrates the growing importance of mixed sediment as a resource for accomplishing CPRA's mission of mitigating land loss by restoring a sustainable ecosystem.

SEDIMENT NEEDS, TYPES, AND DISTRIBUTION

The lateral and vertical variability in sediment types in a deltaic plain is expected. Thus, it will take a range of sediment types to mitigate the land loss. In coastal Louisiana, sand is very limited and is not compatible with native marsh sediment, which is a mixture of sand, silt, and clay. While sand has typically been used to restore barrier islands and headlands in Louisiana, ecosystem restoration also has a need for substantial volumes of "mixed sediment," which is "low-grade sand." Very broad-based definitions for *sand* (70%-100% sand), *mixed sediment* (30%-70% sand), and *fines* (0%-30% sand) have been adopted exclusively for the purpose of restoration in Louisiana. These definitions are modified after Folk (1980) and Shepard (1954) by adjusting the limits of sand, silt, and clay fractions and are described in detail in Khalil *et al.* (2022).

Sediment needs

Based on Morton *et al.* (2010), Blum and Roberts (2009) and the 2023 CMP, a first-order estimate of restoration-quality sediment necessary to offset present and projected land loss is described in Table 1. Of particular note is that sediment needed to refill a void is not a one-to-one ratio, meaning that it is not realistic to assume that accommodation space created by loss of 1 million cubic yards (MCY) of sediment, for example, could be filled by 1 MCY of sediment. There are various causes of sediment loss in the process of dredging and filling resulting generally in cut-to-fill ratios that are greater than 1. For the calculations in Table 1, a cut-to-fill ratio of 1.8 was used to estimate sediment needed (Khalil *et al.* 2018a). This means that in order to emplace 1 MCY as sediment as fill for the project, 1.8 MCY of sediment will need to be dredged from the borrow pit to compensate for the losses. This is a conservative approach not used for specific restoration project (i.e. either marsh creation or barrier island restoration) but for land loss mitigation in general. It may be noted here that in cut-to-fill ratio considerations the sediment quality is the biggest factor. But there are other key factors, e.g. production rate (what equipment is being used and how much time does it take to construct); use of containment vs. uncontained vs. semi-contained practices during construction; and total volume to be placed over what surface area of the fill template.

Table 1.
First-order estimates of land loss, estimated accommodation space, and restoration-compatible sediment need (modified after Khalil *et al.* 2018a).

	Land loss (mile^2)	Accommodation (mile^3)	Sediment needed (MCY)*	Time frame
		Historical		
Morton *et al.* (2010)	1956-2004 901	1956-2004 0.5	1956-2004 8,000	1956-2004
		Predicted		
Blum and Roberts (2009)	Low/High 3,861/5,212	Low/High 2.9/3.8	Low/High 38,000/51,000	By 2100
2023 CMP FWOA	Low/High 1,100/3,000	Low**/High** 0.6/1.7	Low/High 9,000/25,000	2020-2070

Notes:
*Assumed density of 1.5 g/cm^3 for mixed sediment with a 45% porosity (based on Blum and Roberts 2009), and a cut to fill ratio of 1.8
**2023 Master Plan calculations based on same assumptions as Morton *et al*. 2010.

The "Near-Term Sediment Need" given below is projected based on projects currently in various stages of planning, whereas the "Short-Term" and "Long-Term" needs are first-order estimates and subject to change with the acquisition and availability of new sedimentological/geoscientific and Relative Sea Level Rise (RSLR) scenario data. The Near-Term and Short-Term needs are based on internal CPRA calculations.

- Near-Term Sediment Need (within the next 5 years) = ~150-160 MCY
- Short-Term Sediment Need (within 10 to 15 years) = ~1,000-1,300 MCY
- Long-Term Sediment Need (within the next 50 years) = ~9,000-25,000 MCY

Sediment types

Although the rate of land loss in Louisiana has decreased from historical highs (Couvillion *et al.* 2017), the rate is still significant and is expected to continue into the future even with planned restoration efforts. Consequently, for short- and near-term solutions, restoration projects will be needed to create new land by actively dredging sediment from both identified and yet to be explored sediment resources (CPRA 2023). However, at the same time, the planned sediment diversions (CPRA 2023) are expected to divert water and sediment from the Mississippi River to passively capture sediment and create land by replicating natural land-building processes as a long-term solution. Although these sediment diversions are a significant part of the restoration portfolio in passively capturing sediment over the long term, they are not the focus of this paper and have not been included in the calculations below.

From 2007 to 2010, projects were being constructed with both sand (42% of sediment utilized, five projects) and mixed sediment (58% of sediment utilized, six projects) at an even rate (Figure 1, Table 2). In April 2010, the Deepwater Horizon oil spill impacted Louisiana's landscape in several ways (Khalil *et al.* 2020). In addition to the inherent environmental damage, barrier islands were restored using

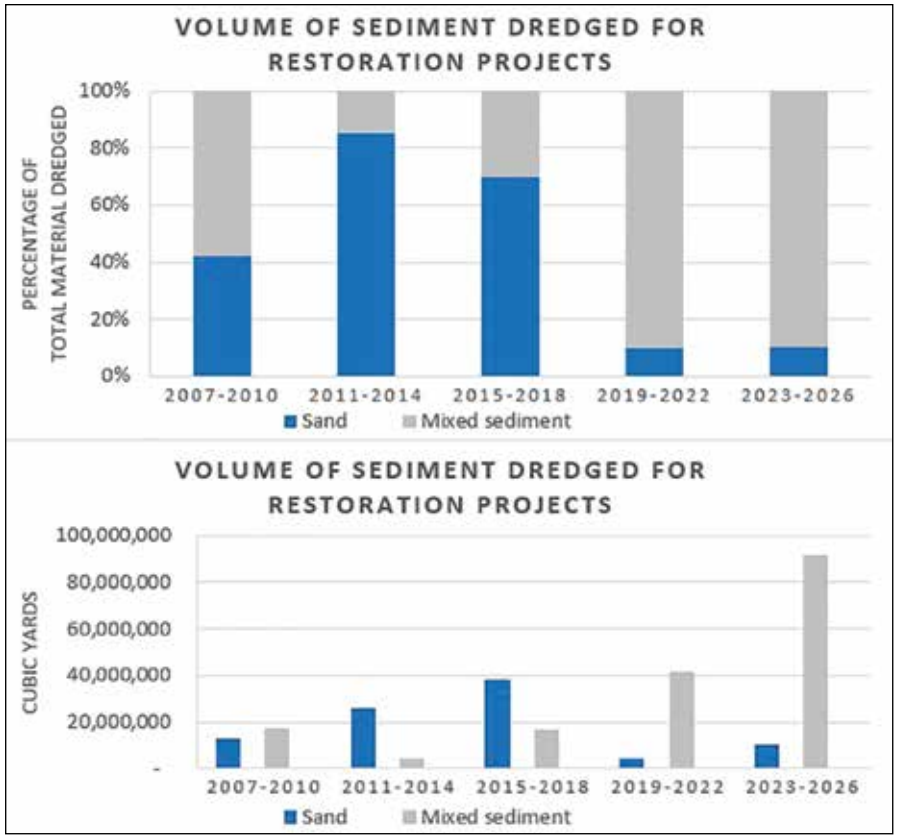
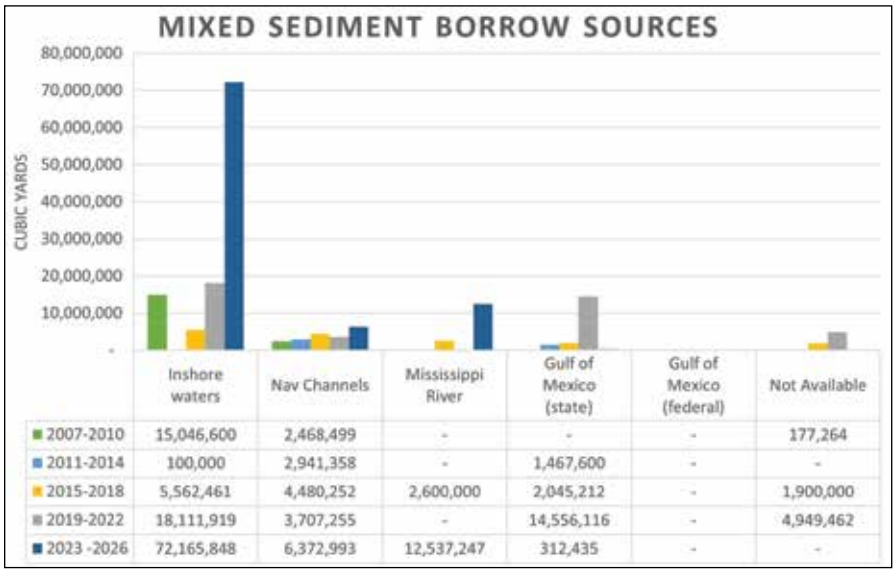


Figure 1. Volume of sand and mixed sediment utilized and/or estimated for coastal restoration projects in Louisiana between 2007 and 2026.



	Inshore waters	Nav Channels	Mississippi River	Gulf of Mexico (state)	Gulf of Mexico (federal)	Not Available
2007-2010	15,046,600	2,468,499	-	-	-	177,264
2011-2014	100,000	2,941,358	-	1,467,600	-	-
2015-2018	5,562,461	4,480,252	2,600,000	2,045,212	-	1,900,000
2019-2022	18,111,919	3,707,255	-	14,556,116	-	4,949,462
2023 -2026	72,165,848	6,372,993	12,537,247	312,435	-	-

Figure 2. Borrow sources for mixed sediment for restoration projects in Louisiana between 2007 and 2026.

sand, not only to mitigate normal erosion and shoreline retreat but also to protect the shoreline from drifting oil, as the larger pore spaces in sandy sediment are more effective at trapping oil. Between 2011 and 2014, 85% of the sediment utilized for restoration was sand (eight projects) versus 15% of mixed sediment (four projects). The period from 2015 to 2018 was similar, with 70% of the sediment volume being sand (seven projects) and 30% being mixed sediment (eight projects). The majority of borrow sources for sand were within the Gulf of Mexico (both state and federal waters) and the Mississippi River, and mixed sediment was sourced from a variety of interior lakes, bays, canals and few offshore and river locations.

As the barrier island projects were completed, the need for mixed sediment rapidly surpassed the need for sand. Only three projects (Terrebonne Basin Barrier Island and Beach Nourishment, West Grand Terre Beach Nourishment, and Louisiana Outer Coast Restoration: North Breton Island) requiring sand have been constructed since 2020. In comparison, nine projects requiring mixed sediment were constructed between 2019 and 2022 (e.g. Cameron Creole Watershed Grand Bayou Marsh Creation, South Grand Chenier Marsh Creation, Bayou DeCade Ridge and Marsh Creation, etc.) and 23 more projects (e.g. Barataria Basin Ridge and Marsh Creation-Spanish Pass, Mid Breton Landbridge Marsh Creation and Terracing, Golden Triangle Marsh Creation, etc.) are anticipated to be constructed between 2023 and 2026. Mixed sediment has dominated the sediment need (about 90%) since 2019 and into the immediate future as marsh creation and ridge restoration projects predominate over barrier islands and headlands. This represents a need of 132 MCY of mixed sediment between 2019 and 2026. Identifying useable mixed sediment resources is challenging. Current plans are to utilize a variety of locations from interior bays and lakes, to shipping channels, to Mississippi River and nearshore Gulf of Mexico sources (Figure 2). Historically, mixed sediment was harvested from inshore waters, navigation channels and from the Gulf of Mexico. However, recently the demand for mixed sediment has increased, and although dredging from Gulf of Mexico and Mississippi River sources are preferred, the dominant source of mixed sediment presently is inshore waters (lakes, bays, and inland waterways). As previously mentioned, external sources of sediment are preferred, to compensate for land-loss with new sediment infusions rather than redistributing sediment within the system. With this increased need for mixed sediment, it is imperative that cost-effective sources of mixed sediment be identified from outside the system.

Surficial Sediment Distribution (SSD) map

Maps delineating various sediment types were developed to assist in locating suitable sediment resources for restoration projects. Using the sediment classifications modified after Folk (1980) and Shepard (1954) as described above and in Khalil *et al.* (2022), SSD maps were compiled for nearshore, offshore, and the Lower Mississippi River based

on existing sedimentological, geotechnical, and geophysical data residing in the Louisiana Sand Resources Database (LASARD) (APTIM 2023; Forrest *et al.* 2019; Khalil *et al.* 2018b). Sand, mixed sediment, and fines were delineated and mapped (Figure 3, top panel) along with degree of certainty. If the data density within a deposit was relatively high, with samples spaced less than one mile apart, the deposit was designated as a *sediment deposit* with a relatively higher degree of certainty. If data were spaced more than one mile apart, the decreased level of confidence resulted in the deposit being designated as a *potential sediment deposit*. As described in Khalil *et al.* (2022), based on sediment type, the deposits were classified as *sand* or *potential sand* (predominantly sand with <30% silt and/or clay), *mixed sediment* or *potential mixed sediment* (30-70% sand with the remainder comprised of silt and/or clay) or *fines* (<30% sand). Areas where no data were available were labeled as *unknown*. Where available, interpreted sub-bottom data and poling data, including data collected during other projects (APTIM 2019; APTIM 2018; CB&I 2016), were reviewed and used to refine/supplement some of the delineated deposits. The interpretations were also used to delineate additional deposits. It is important to note that not all of the sub-bottom data have been ground-truthed (i.e. with core borings). Therefore, these additional deposits were designated as *inferred* deposits, possessing the lowest level of confidence. A large portion of offshore areas were classified as "unknown" due to a lack of adequate reliable data. The offshore limits of the SSD map (Figure 3, top panel) are based on our experience and understanding of current as well as predicted near future best-case sediment hauling and transportation distances. Additionally future installation of wind energy platform is also one of the determinants the offshore boundary of the map. Currently, the offshore limit is approximately 34 nautical miles (nm) seaward of the coastline. Based on these maps, the volumes of sand and mixed sediment were calculated as total "Available" (Table 3).

To address the need for external sources of mixed sediment, the SSD maps were developed to assist in locating both sand and mixed sediment for the construction of restoration projects. These maps are basic but important tools and were initially compiled for resource planning and played a critical role in the management of sediment resources at a regional level. They play a vital role in stakeholder engagement, conflict resolution and the enforcement of federal and state regulations related to the removal of decommissioned pipelines and coastal zone management. Removal of decommissioned pipelines helps free up valuable offshore sediment resources for restoration. These maps also help in deciding the route for laying new pipelines or offshore wind cables avoiding any conflict with sediment resources.

Table 2.
Approximate volume (MCY) and percentage of total sediment for sand and mixed sediment used between 2007 and 2022 and estimated for 2023 to 2026 restoration projects.

Sediment type	Project years 2007-2010	2011-2014	2015-2018	2019-2022	2023-2026	Total
Sand	12.8	26.03	38.02	4.42	10.31	91.55
	42%	85%	70%	10%	10%	35%
Mixed sediment	17.7	4.51	16.59	41.32	91.39	171.5
	58%	15%	30%	90%	90%	65%
Total	30.5	30.54	54.61	45.74	101.7	263.05

Table 3.
Volume of available and accessible sand and mixed sediment. Please see text for further explanation of sediment types.

Sediment type	Total volume available MCY	Volume inaccessible (active pipeline safety buffers) MCY	%	Volume inaccessible (decommissioned pipeline safety buffers) MCY	%	Accessible volume (available minus inaccessible) MCY
Sand	1,780	-390	22%	-40	2%	1,390
Potential sand	4,545	-1,030	23%	-620	14%	3,520
Mixed sediment	905	-310	35%	-55	6%	590
Potential mixed sediment	8,625	-1,455	17%	-740	9%	7,170

Note 1: Volumes are based on the 2023 SSD Map update and represent offshore deposits only.
Note 2: Final numbers rounded to nearest 5 or 10.

Impact of oil and gas pipeline infrastructure on available sediment volume

Louisiana's coast supports infrastructure that supplies 90% of the nation's outer continental shelf oil and gas (http://coastal.la.gov/wp-content/uploads/2018/03/2019-CPRA-One-Pager.pdf). Decades ago, when the oil and gas pipelines and related infrastructure were permitted and installed in coastal Louisiana and the northern Gulf of Mexico, the impact of this infrastructure on the accessibility of restoration-quality sand and mixed sediment was not taken into consideration. The result is an overabundance of infrastructure which renders a large portion of the available sediment inaccessible for restoration use (Table 3).

The required safety buffer of 500 to 1,000 ft. (Nairn *et al.* 2005) along pipelines and around infrastructure considerably reduces (by 35% in some cases) the volume of sediment accessible for restoration. Table 3 shows that it is not only the active pipelines which restrict access to the dredging of sediment, but decommissioned pipelines which are abandoned-in-place, also interfere with access to a substantial amount (up to 14% or ~620 MCY of potential sand) of sediment. These abandoned pipelines were supposed to be removed once it had been determined that they would no longer be utilized and they were proposed for permanent decommissioning. The presence of an extensive network of oil and gas infrastructure (Figure 3, bottom panel) has obstructed the accessibility to those deposits trapped within the safety buffers. Hence the category of total "Accessible" volume was estimated by excluding sediment made inaccessible by oil and gas infrastructure.

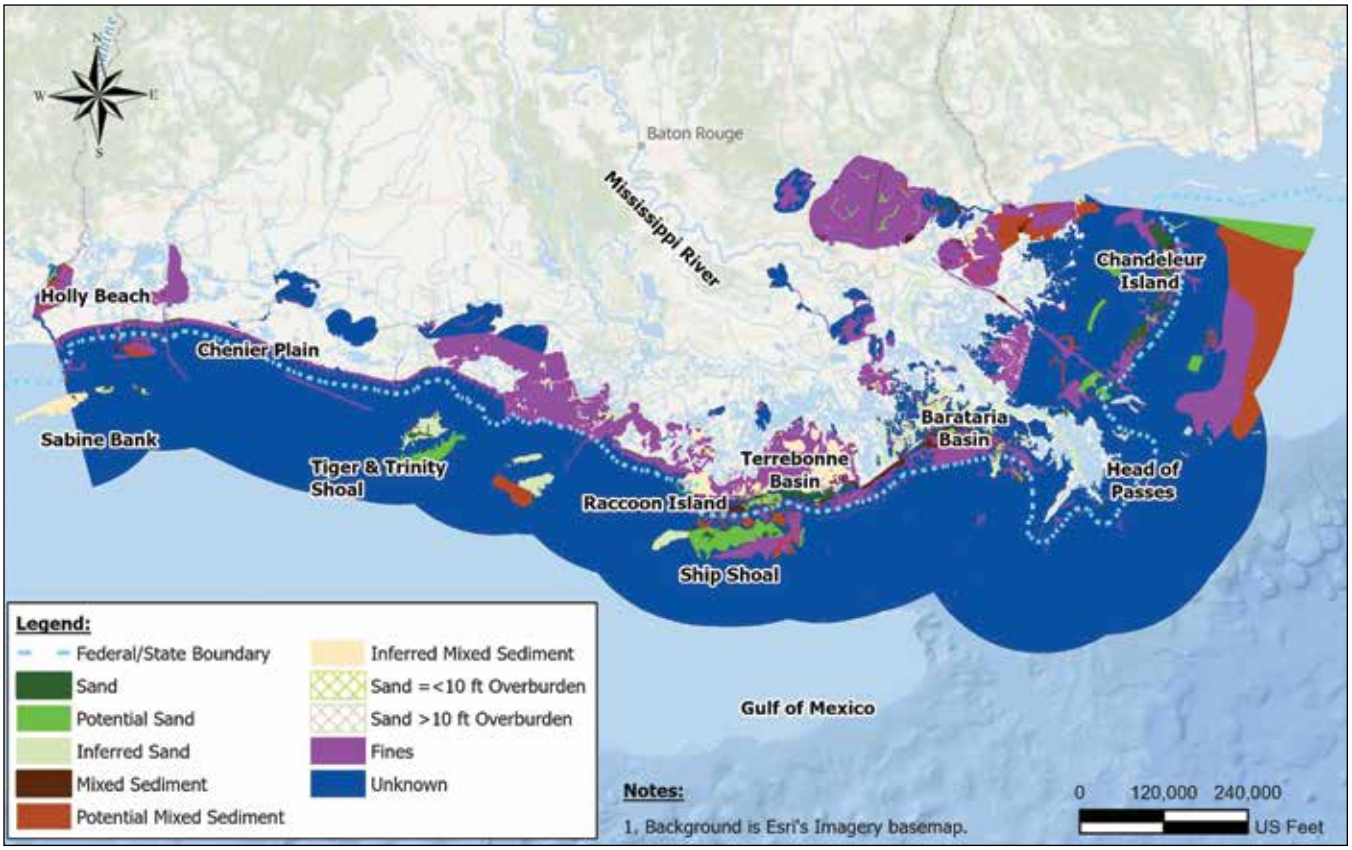
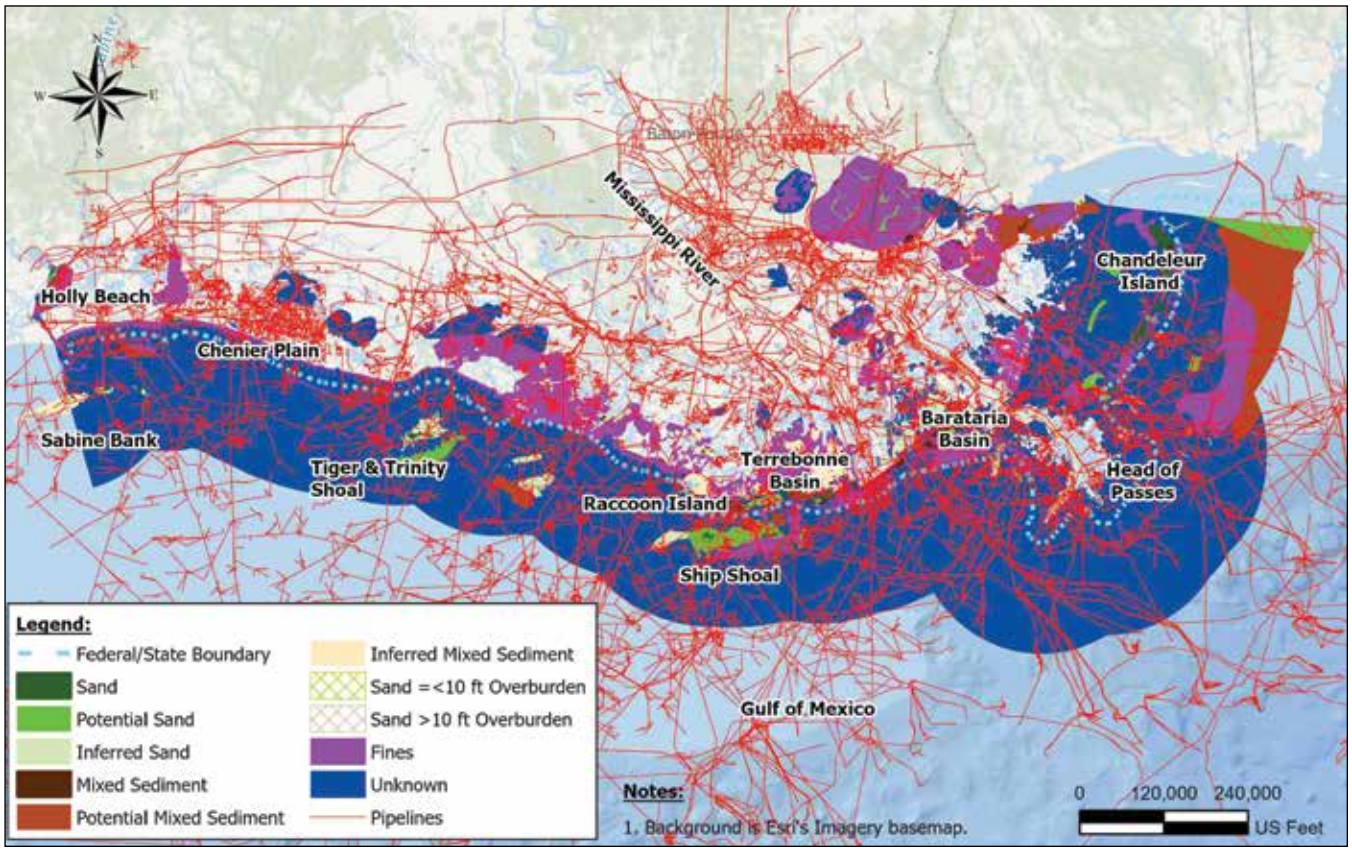


Figure 3. Surficial Sediment Distribution (SSD) map showing surficial distribution of various sediment types in coastal Louisiana (top panel) and with the overlay of pipelines which render valuable sediment resources inaccessible (bottom panel).



Mixed sediment availability

Louisiana has an ongoing as well as future need (CPRA 2023) to minimize the continued loss of sediment from its coastal environment and to identify cost-effective and reliable sources of mixed sediment that can be used for restoration projects. Many other considerations, such as distance from projects, presence of existing infrastructure in the area, available funding and improvements in dredging and transport technologies impact the linkage between borrow source and project. Including both the planned need for 91 MCY of mixed sediment for 2023-2026, and the desire to identify and delineate external sources of mixed sediment, the SSD maps have identified approximately 590 MCY of accessible mixed sediment that, barring other constraints, could be available for restoration projects. However, when the short- and long-term needs are considered, substantially more mixed sediment will be needed to sustain coastal Louisiana (see Table 1).

Steps are needed to avoid additional infrastructure construction in the locales that make identified valuable sediment resources inaccessible. Likewise, steps should be taken for removal of abandoned infrastructure that makes known sediment resources inaccessible. Based on estimates of mixed sediment availability (590 MCY) and the estimates of near-term mixed sediment need (91 MCY) over the next four years, it becomes evident that known mixed sediment resources will not last indefinitely. Consequently, discovery of new sources, and efficient use of the existing known sediment resources are both important for the continued success of restoration.

DISCUSSION

It is well documented that, over the past century, Louisiana has lost approximately 0.5 million hectares of coastal land and, based on the latest CMP estimate, continues to lose land at a rate of about 1,440 hectares per year (CPRA 2023). Despite being home to the terminus of the Mississippi River, Louisiana's coastal areas are sediment-deficient due to the artificial isolation of the river from the coastal wetlands. Infusion of adequate quantities of compatible sediment will contribute to the restoration of a sustainable coastal ecosystem. It has been emphasized that sedimentological restoration is critical for a sustainable ecosystem restoration in coastal Louisiana (Khalil *et al.* 2022). Key challenges for sedimentological restoration include understanding sources and sinks of sediment and predicting the rate of land growth under restoration strategies that include river/sediment diversions, marsh platform creation, and barrier island restoration. Critical to implementation of these restoration strategies is the understanding that sediment dynamics, deposits, and availability are not haphazard, but related to the inherent geomorphic processes of a major river system. Thus, the solution to the sediment deficit problem in coastal Louisiana is a holistic system-based approach that develops a robust regional sediment management plan to integrate various sediment input mechanisms including harvesting restoration-quality sediment (sand/mixed sediment) deposits from the Mississippi River and from offshore, long term passive management of sediment through river diversions, and beneficial use of sediment dredged from navigational channels (Khalil *et al.* 2023).

As previously discussed, in coastal Louisiana, sand is very limited and is not an effective replacement for native marsh sediment, which is a mixture of sand, silt, and fines (Khalil *et al.* 2022). Thus, ecosystem restoration in coastal Louisiana needs substantial quantities of "mixed sediment" in addition to sand. Mixed sediment has been used for decades for ecosystem restoration, especially for marsh platform creation/restoration projects. Fines in the mixed sediment are conducive to vegetation growth whereas the sand content of mixed sediment helps not only in constructability (by reducing dispersion), but with the ease of predictability of final as-built marsh-surface elevation. The need for mixed sediment is expected to increase in the future as the need to restore marsh platforms and ridges surpasses restoration of sand-dominated barrier islands. Concurrent with the need for larger quantities of mixed sediment is the need to identify sources from "outside" of the system. Adding sediment from outside the system to offset land-loss is one of the vital aspects of ecosystem restoration. If, for example, 300 mi^2 of habitat (as proposed by the 2023 CMP) are built/restored by dredging the sediment from within the system (e.g. bays), we are not adding, but rather redistributing sediment.

Sediment from offshore deposits or from the adjacent Mississippi River will add sediment back into the system in a meaningful way to offset the recurring land loss in Louisiana. Though most of the mixed sediment planned to be dredged during 2023-2026 is from inshore sources, the 2023 CMP has allocated $19 billion for marsh and land bridge creation projects which will use mixed sediment from river and offshore (CPRA 2023). This demonstrates the importance of mixed sediment in land-building. It is imperative that the same weightage and consideration be given to mixed sediment as is given to sand (e.g. to be designated as BOEM's Significant Sediment Resource Area [SSRA] blocks, policies and regulation considerations, etc.) in order to secure and preserve mixed-sediment resources for use in present and future restoration projects. It may be noted here that SSRA blocks are Outer Continental Shelf (OCS) lease blocks designated by the BOEM to be used in future coastal restoration, beach nourishment, and levee reconstruction projects. While sand has been the preferred sediment type for beach nourishment and restoration, Louisiana's coast cannot be restored and land loss cannot be mitigated by sand only.

CONCLUSIONS AND RECOMMENDATIONS

Comprehensive sediment management has been continually evolving in Louisiana for decades. CPRA has worked with federal, state, and private partners to develop and utilize SSD maps to identify, delineate and evaluate sand and mixed sediment resources and help update and classify them as SSRAs depending on sediment quality/compatibility, volume requirements, accessibility, transport distance, cost, permit restrictions, etc..

Finally, the complexity of managing and restoring ecosystems cannot be overstated. The interaction of geomorphic processes with ecosystem services is incredibly multi-dimensional. One critically significant component to ecosystem restoration in Louisiana revolves around sediment. Often considerations for sediment have focused on sand, but we have shown in this paper that mixed sediment is equally important for restoration and should be given equal consideration as a viable and critical resource for ecosystem restoration. In Louisiana, mixed sediment has been used for almost two decades for marsh creation without deliberate management. Conscious efforts have

been made here to define mixed sediment with reference to standard sediment classifications. This paper recognizes and elevates the need and importance of mixed sediment for the restoration of Louisiana's coast as mixed-sediment is imperative to the future of restoration and sand is not enough.

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The During Nearshore Event Experiment (DUNEX): A collaborative coastal community experiment to address coastal resilience

By

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ABSTRACT

The **Du**ring **N**earshore **E**vent **Ex**periment (DUNEX) was a large-scale coastal field effort focused on improving understanding of during-storm nearshore processes to ultimately develop predictive technologies, engineering solutions, and actions to enhance coastal resilience. The experiments were conducted on the North Carolina coast by a multidisciplinary group of over 30 research scientists from 18 academic and federal institutions supporting over 30 graduate students and deploying over 300 instruments from 2019 to 2021. The overarching goal of DUNEX was to gather information collaboratively to improve understanding of the interactions of coastal water levels, waves, currents, beach and dune evolution, soil behavior, vegetation, and groundwater during major coastal storms that affect infrastructure, habitats, and communities. In the short term, these high-quality field measurements will lead to better understanding of during-storm processes and impacts and will enhance U.S. academic coastal research programs by providing opportunities for students to learn about field data collection and to potentially analyze data as part of their studies. Longer-term, DUNEX data and outcomes will improve the ability to predict extreme event physical processes and impacts, validate coastal processes numerical models, and improve coastal resilience strategies and communication methods for coastal communities impacted by storms. The purpose of this paper is to describe the motivation for and science goals of the experiment, how stakeholder needs led to these goals, collaborations amongst researchers, and the knowledge gained that will lead to tools to improve coastal resilience. Herein, we first describe how researchers worked with stakeholders to structure their community-driven needs into science-based requirements. Next, we summarize how federal, academic, and stakeholder researchers worked together to design and execute a multi-organizational experiment aligned with those requirements. Finally, we articulate early findings and lessons learned from the experiment. This paper does not summarize all the research findings from DUNEX, as analyses are still ongoing. An American Geophysical Union (AGU) Special Collection on Coastal Storm Research will be published in 2025 including outcomes from DUNEX research.

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The planning, organization, and coordination of the During Nearshore Event Experiment (DUNEX) operated under the general convening of the U.S. Coastal Research Program (USCRP). The USCRP is a multi-agency, academic, and nongovernmental community of practice, with goals to focus investments in nearshore research and transition outcomes into application. The USCRP guided and facilitated the execution of DUNEX through a variety of activities:

- Provided forums for sharing information, project planning, and collaborative discussions as well as a community website with details about ongoing experiments, access to data, and a data repository.
- Organized agency-support data collection efforts (e.g. bathymetry, airborne and terrestrial Lidar, unmanned aircraft system flights, etc.).
- Coordinated logistical support and facilitated the development of a logistics team that included lead DUNEX researchers in collaboration with a National Science Foundation-funded grant (OCE-1848650).
- Assisted in coordination with local stakeholders.
- Promoted DUNEX to a multi-disciplinary audience to ensure diverse data collection.
- Coordinated training opportunities and student volunteers to further the career development of U.S. coastal researchers.

The DUNEX pilot study, conducted in 2019, focused on providing researchers the ability to test field methods, equipment, and logistics and served as an opportunity for the planning and organization teams to look for gaps in meeting the DUNEX goals and objectives, and make adjustments for the DUNEX main experiment. The DUNEX main experiment, conducted in 2021, focused on capturing a comprehensive, high-quality set of field measurements before, during, and after storm events to improve the knowledge and understanding of during-storm processes and impacts at various sites along the Outer Banks of North Carolina (Figure 1). These data will be used as inputs to numerical models and validation of those models in response to extreme event physical processes, allowing for better predictive ca-

Figure 1. Map of the overall DUNEX study area showing the three DUNEX sites (FRF, Pea Island Southern Site, Sound Side) as shown on the soundside and oceanside with approximate sensor locations. Source: Cialone *et al.* 2023.

pabilities of storm event impacts. Coastal managers and researchers can also collaborate and use these data and models to develop improved strategies for coastal resilience and effective communication methods for communities impacted by storms. From this set of experiments, the DUNEX participants have strengthened collaborations to better understand the mechanisms that affect the coast during storms, to ultimately provided insights that will lead to improved coastal resilience to major storms.

Though each of the DUNEX investigators had individual research goals, there were many collaborations and exchanges based on overlapping objectives and research interests, creating opportunities to share information, instrumentation, labor, and data. Research projects focused on storm processes and impacts and included studies related to:

- Dune and shoreline erosion.
- Groundwater influences.
- Sound-side dynamics.
- Geotechnical properties.
- Swash and overwash processes.
- Wind measurements and aeolian transport.
- Nearshore currents and sediment transport.
- Wave transformation with and without vegetation.
- Numerical modeling.
- New measurement techniques.

One of the primary DUNEX goals was to obtain measurements while expanding the network of scientists across multiple disciplines collaborating to understand the interactions of ocean water levels, waves and currents, beach and dune evolution, soil behavior, and groundwater during major coastal storms. Therefore, in addition to collecting measurements, DUNEX participants met virtually before, during, and after DUNEX to strengthen their collaborations, which improved scientific understanding of the mechanisms that affect the coast during storms, improved model parameterization and accuracy, and provided insights for improving coastal resilience to major storms into the future. Through conversations, virtual meetings, and in-person interactions amongst DUNEX participants, the collaborations and analyses using data collected by multiple researchers during DUNEX will provide information critical to understanding these processes and lead to improved forecasting of when and where risks are highest over the next several decades. Beginning this large-scale community experiment with the needs of coastal stakeholders in mind, conducting the experiments to research those needs, and analyzing and discovering information in the collected data to address those needs was the overarching goal of DUNEX.

MOTIVATION AND SCIENCE GOALS

For decades, large-scale coastal research experiments have proven to be extremely valuable through the collection of shared datasets, leveraging of resources, and the collaboration of researchers across coastal research disciplines. Past coastal field experiments have focused on aspects of nearshore hydrodynamic and sediment transport processes. Some examples of large-scale field experiments include hydrodynamic experiments such as Duck 82, Duck 85, and SuperDuck (Mason *et al.* 1984, Mason *et al.* 1987, Hubertz *et al.* 1978, Crowson *et al.* 1988, Goossens *et al.* 2018); and sediment transport experiments such as Duck 94 and SandyDuck (Gable 1981, Kraus *et al.* 1982, Allen 1988, Seymour 1989); (Birkemeier and Thorton 1994, Birkemeier *et al.* 1996, Birkemeier *et al.* 1999). Through these large-scale

collaborative experiments, the scientific community has gained increased knowledge and tools to predict coastal processes and response. However, with rapid climate evolution and increasing populations in vulnerable coastal communities, there are increasing stakeholder needs and requirements since these coastal field experiments were conducted, including a need for increased understanding of dune overtopping and flooding of coastal communities; sound side erosion and back-bay flooding of roadways; and sediment transport processes related to beach nourishment. DUNEX was designed to address these gaps.

Even though significant advancements were made in these prior experiments, there remains substantial knowledge gaps in the communities' understanding and ability to predict storm processes and impacts, as well as storm response. The coastal research community identified three primary research needs, as documented in "The Future of Nearshore Processes Research" (The Nearshore Processes Community 2015), including extreme event processes and impacts. The USCRP hosted a Storm Processes and Impacts Workshop in 2018 to gather the coastal research community and stakeholders to discuss and prioritize top research needs related to storm processes. One specific prioritized need identified through this process was to improve our understanding, knowledge, and ability to predict coastal processes that occur during storms (Elko *et al.* 2019). Storm processes may appear disparate, but can be highly coupled, such as the effects of:

- Rainfall and ocean-wave infiltration on groundwater levels and salinity.
- Groundwater, rain, wind, vegetation, and infrastructure on eolian sediment transport, dune erosion, overwash, and sediment deposition.
- The resulting morphological and ecological change on oceanographic, geomechanic, and hydrogeologic processes.

Nonlinear couplings may contribute to alongshore variability in natural and built areas, so that one region remains unharmed, while a neighboring area is damaged severely. Understanding these interactions is critical to properly convey the potential hazards (such as flooding, beach/dune erosion, overwash, barrier island breaching, etc.) to federal agencies, practitioners, and coastal communities so they are better informed to prepare for extreme events, potentially prevent or minimize damages, and enable rapid post-storm response. DUNEX addressed this identified need by collecting a shared data set quantifying impacts and processes during an extreme storm, including flooding, erosion, and the post-event impacts. By conducting individual research projects on various coastal topics with a shared goal in a common location during the same time period, the collective benefit to the research community was elevated. The experiment also addressed the USCRP goal of improving communication between scientists and coastal practitioners to facilitate the translation of scientific research into use by coastal engineers and managers.

Figure 2. Above: Photo of all the DUNEX VIP Day participants. Below: Dr. Chris Sherwood and Dr. Jenna Brown (USGS) discuss research focused on observations of dune overwash processes at the southern site.

The value of a large-scale experiment focused on storm processes and impacts begins with the scientific gains from the data collected, which will be available and used for decades to come. The scientific goals that guided DUNEX included:

- Improve prediction of storm processes and impacts.
- Estimate numerical model accuracy for storm processes.
- Identify and reduce sources of error for storm processes simulations.
- Inform strategies for short- and long-term coastal resilience.
- Support more effective communication for coastal communities impacted by storms.

Table 1.
Coastal management challenges and research needs identified by coastal management stakeholders and the DUNEX research activity working to address coastal management needs.

Coastal management challenge	Coastal management stakeholder	DUNEX research activity to address the challenge
Dune overtopping	Michael Flynn, NC Coastal Federation (currently with the National Parks Service's Outer Banks Group)	• Mechanisms for dune failure during wave impacts • Optical measurements of beach profile evolution and Overwash Processes • Alongshore variability of waves and wave runup: Observations and modeling • Autonomous Lidar scanning system for measuring wave/water level transformation and beach profile evolution • Evaluate below-ground structure of dune grasses and evaluate potential to prevent erosion
Soundside erosion	Beth Smyre, Dewberry	• Geotechnical measurements at Pea Island to evaluate wetland erosion • Drivers of shoreline erosion on the sound-side of Pea Island • Wave attenuation through vegetation during storms • Groundwater processes/groundwater flow impacts on coastal morphology
Beach nourishment	Ken Willson, Coastal Protection Engineering	• Sediment pathways and depositional patterns • Remote sensing approach to quantification of aeolian saltation dynamics • Modern coastal features with a long-term perspective • Variations in geotechnical parameters of beach and nearshore surface sediments

STAKEHOLDERS AND COMMUNITY

Early in the establishment of the USCRP, leadership recognized the importance of stakeholder engagement to determine 1) the most important coastal research needed from a community perspective, and 2) how to translate scientific findings into practical applications. To begin to address this essential aspect of the USCRP goals, workshops focusing on dune management and coastal storms were hosted in 2015 and 2018. The workshops convened various stakeholders and researchers to share the greatest coastal challenges faced by coastal communities and to provide stakeholders with a better understanding of the role of research in determining how to address those challenges. Stakeholders came away with a better understanding of the interactions that occur during storm processes, and researchers learned about the difficulties coastal managers face when making rapid decisions as a major storm approaches their region.

The USCRP leadership continued to foster stakeholder engagement and communication as part of DUNEX. First, coastal managers were interviewed with the intent of developing a video that showcased how DUNEX projects help to address their challenges. Ultimately, scientific advancements from the DUNEX research and data collection will facilitate the translation of these research findings into practical application for coastal stakeholders. Coastal managers can then use the researchers' findings to make decisions on preparing for storms and potentially preventing their impacts.

Secondly, USCRP held a series of stakeholder-researcher meetings, during which stakeholders shared coastal management research needs and researchers discussed potential methods to address them. These meetings served to bring the stakeholder perspective and coastal management challenges to the DUNEX experiment (Table 1). Michael Flynn, a local stakeholder with the National Parks Service's Outer Banks Group "found participating in the DUNEX Coffee Hours to be a very rewarding experience. Specifically, engaging with members of the coastal science research community that were conducting studies across the landscape that I help to manage on a regular basis provided an opportunity to share information with the researchers that could support their efforts as well as receive information from the researchers in a more timely and comprehensible manner compared to having to wait to review a robust final report or publication in a peer-reviewed journal." The interaction of stakeholders and DUNEX researchers was geared towards providing the researchers with a better understanding of stakeholders needs and the general societally relevant challenges faced by coastal decision-makers so that researchers could gear their research to address those needs and challenges. Another engagement, the DUNEX VIP day (Figure 2) hosted at the U.S. Army Corps of Engineers' (USACE) Field Research facility (FRF) on 9 September 2021, offered a unique opportunity for collaboration and interaction between DUNEX university researchers, students, non-governmental organizations, congressional staffers, and government agencies to further understand the research needs of the nation and provide updates on current research efforts in the coastal zone. VIPs visited four tour stops showcasing storm processes experiments under way with federal and academic collaborations. The VIPs were asked while at the tour stops

to consider their greatest coastal research and management challenges as related to storms. The VIP Day also allowed for graduate students to interact with stakeholders and explain the scientific process. The USACE's Deputy Commander General for Civil and Emergency Operations, Major General Butch Graham, asked the group what their future needs were in coastal data collection. Congressional representatives indicated that improved communication between researchers, practitioners, funding authorities, and the public was needed, including clear, concise communication about research findings and impacts. The DUNEX VIP day provided a unique opportunity for researchers to share information about existing resources with which coastal managers had been unfamiliar. For example, researchers discussed the U.S. Geological Survey (USGS) Total Water Level Viewer that can assist coastal managers by providing forecasts for dune erosion and overtopping during a storm. Coastal managers were also able to learn about community modeling output that can be useful for management decision-making, such as the Queens University Coastlines model simulations which is a dynamic, 36-hour forecast model of the waves, currents, and water levels in coastal North Carolina. Lastly, instrument and technique developments that arose from DUNEX research efforts that are benefiting coastal communities were discussed such as the micro-SWIFT drifters developed by the University of Washington, and optical-based estimates of surf zone currents and swash levels developed by Woods Hole Oceanographic Institution and Northeastern University researchers.

Coastal management challenges noted at the stakeholder-researcher meetings and VIP Day included dune overtopping, sound side erosion, and beach nourishment. DUNEX researchers provided potential methods for addressing the coastal management challenges with data collected as part of DUNEX, by transitioning other ongoing research, or potentially addressing these needs with future research. As part of DUNEX, researchers from George Mason University investigated and quantified the interaction of storm surge and waves with coastal vegetation in Pamlico Sound by measuring hydrodynamic conditions in coastal marshes during extreme events. The

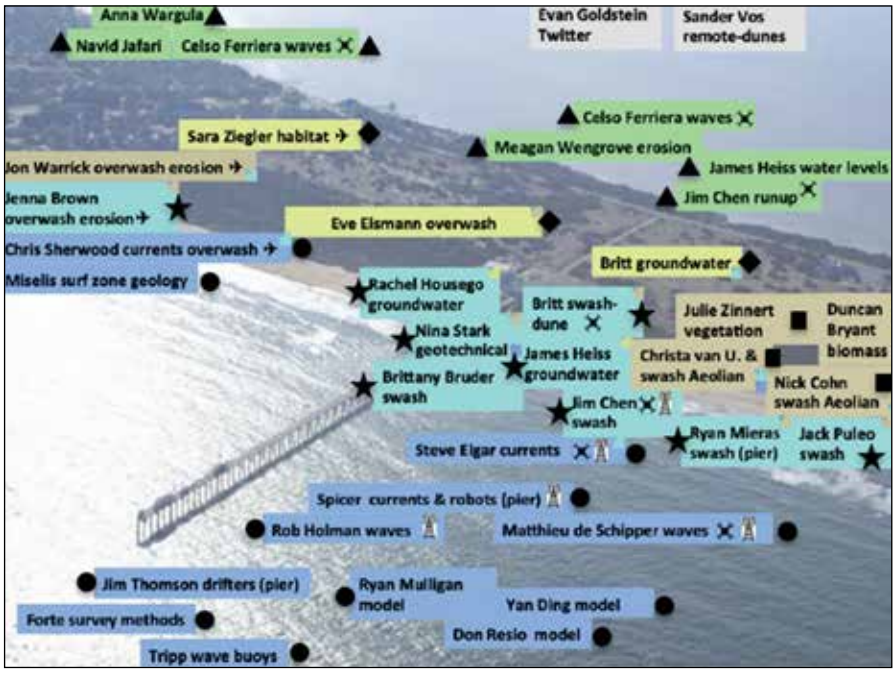

Figure 3. Early PI research location map (summer 2019). Shapes indicate the primary area of focus (triangle=sound; diamond=mid-island; square=beach/dune; star=swash; circle=nearshore ocean). Additional symbols are included to identify those using drones, aerial overflights, and the FRF ARGUS tower as explained in Cialone *et al.* (2023).

project intent was to provide field-based evidence to support vegetative features as a means of resilience from coastal flooding (Cassalho *et al.* 2021). Researchers from the U.S. Naval Academy and North Carolina State University approached the challenge of sound-side erosion by examining the drivers of this process. Their findings were used to understand sound-side dynamics near a tidal inlet and the potential consequences for inundation of the barrier island. They applied these results to quantify roadway vulnerability to flood-related closure and the severity of sound-side shoreline erosion (Wargula *et al.* 2021, Tomiczek *et al.* 2022). These field studies of the impact of vegetation on sound-side erosion and the drivers of sound-side erosion specifically address one of the stakeholder needs expressed at the stakeholder-researcher meetings.

Several other researchers focused on the mechanisms for dune failure and shoreline erosion, particularly during extreme events when more drastic changes are observed in both the condition of the shoreface and dune structure. For example, researchers from Woods Hole Oceanographic Institution investigated the effects of wave collision, wave reflection, and ocean-aquifer water exchange on morphologic evolution of coastal dunes during storms. Their goal was to improve parameterizations of ocean-sediment-groundwater interactions that affect dune slumping and failure and beach-sediment transport during storms (Florence *et al.* 2022). Researchers from USGS, North Carolina State University, and University of North Carolina-Wilmington collaborated to measure the cross-shore evolution of waves, water levels, and sediment transport at a site susceptible to overwash to better understand the timing and magnitude of such events (O'Connor and Mieras 2022). These projects specifically address the stakeholder need for research on dune overtopping expressed during one of the stakeholder-researcher meetings. Researchers from the USGS measured sediment redistribution across the shoreface during and after storms. Outcomes from this research can assist coastal communities in prioritizing post-storm shoreline erosion mitigation efforts such as beach nourishments. DUNEX provided an important contribution to address the priority to build community resilience. Future incorporation of improved representation of these processes into numerical models will improve our ability to numerically simulate and predict storm processes and impacts for coastal management. Stakeholder Michael Flynn identified what future application could look like: "The improvement of numerical models used for simulating

Figure 4. Logos from all the universities, agencies, and organizations involved in DUNEX.

landscape-scale barrier island evolution over a single storm event, as well as, annual to decadal time-frames will help to inform the viability and impacts of various coastal management activities and adaptation strategies that are being employed or considered for the maintenance of the transportation corridor throughout the Cape Hatteras National Seashore."

COLLABORATION AND PRELIMINARY SCIENTIFIC OUTCOMES

As noted in Cialone *et al.* 2023, the main DUNEX experiment included 30 research teams from 18 academic and federal institutions supporting over 30 graduate students and deploying over 300 instruments studying diverse coastal research topics. Collaboration and leveraging of resources across research teams was especially important. Traditional field measurements can be difficult and require considerable resources to collect during extreme event data due to the challenging and hazardous field conditions. For example, all field research efforts require timely measurements of the underlying topography and bathymetry conditions, which are not trivial to obtain and can be costly. By conducting complementary, multi-disciplinary research at the same field site (Figure 3), resources were leveraged to conduct topo-bathy surveys that benefited all researchers.

By leveraging the data collection efforts of all research teams, findings from DUNEX will improve basic understanding, predictive capabilities, and observational technologies for extreme coastal storm processes and impacts. To promote collaboration and communication between research teams, DUNEX researchers were invited to discuss their plans and needs for the experiment during a series of virtual meetings referred to as DUNEX "coffee hours." The coffee hours were started to exchange data collection plans, sampling strategies, and deployment timing, share logistical support and needs, and discuss data management efforts. The DUNEX coffee hours were vital to promoting the exchange of experiment plans between the research teams and collectively, research teams discovered collaboration opportunities and planned improvements among the participating teams.

The DUNEX student and coffee discussions have resulted in new interdisciplinary science collaborations. For example, discussions resulted in new efforts to:

- Explore geotechnical processes in marshes and on the beach.
- Compare estimates of surf-zone circulation obtained using various remote sensing techniques, drifters, and in situ sensors.
- Develop machine-learning-based methods for measuring swash.

In addition, DUNEX provided opportunities for students to collect and analyze data, and has already resulted in presentations at national and international conferences such as the 2022 International Conference on Coastal Engineering, the 2023 Coastal Sediments conference, and the upcoming American Geophysical Union Ocean Sciences 2024 meeting.

CONCLUSIONS AND NEXT STEPS

DUNEX provided a vital contribution to address our nation's priorities to build coastal resilience and provide data on performance of natural infrastructure (e.g. vegetated dunes and wetlands), particularly during storm events. DUNEX also provided an opportunity for student-led coastal research, collaboration among multiple universities and federal agencies, and development of long-standing collaborative opportunities (Figure 4). These collaborations can create employment opportunities for students transitioning into the work force as coastal scientists and engineers. In addition to the scientific benefits, the collaboration among 30 research groups from various institutions and agencies leveraged coastal research funding among federal and academic researchers and reduced duplication of effort.

Data compilation, analysis, and synthesis of results has occurred initially over the first few years following the completion of the field data collection effort, and these data will continue to be used by coastal scientists, engineers, and students for decades to come. Future applications of these data will improve our ability to numerically simulate and predict storm processes and impacts to coastal communities. The diversity and range of DUNEX projects spanned open-

ocean to sound-side coasts including developed and undeveloped regions with variable beach and dune characteristics.

Over the next 3-5 years, DUNEX researchers will be compiling, analyzing, and archiving the storm processes data to then be shared with the broader coastal community of researchers, practitioners, and managers. Researchers will be synthesizing results, implementing improvements into predictive tools, and outwardly sharing results in journal articles, conference presentations, and predictive tools and technologies. Specific research outcomes will be communicated by researchers and students through scientific publications and presentations across interdisciplinary avenues highlighting the importance and impact of collaboration in large-scale nearshore research experiments. As documented in Cialone *et al.* 2023, DUNEX successes, challenges, and lessons learned from the experiment were gathered from discussions with DUNEX leadership and DUNEX researchers post experiment. Planned metrics that will be used in the future to demonstrate the value and outcomes before and after DUNEX include communicating the number of projects led by students who later were hired into coastal careers, data sets that can be utilized for future research, the number of new findings documented in technical publications, publicly available storm process data, and transitional outcomes that improve community resilience. The researchers and DUNEX community look forward to communicating the results of DUNEX and demonstrating the impact of the community experiment in years to come. Researchers will continue to work with stakeholders to transition the valuable knowledge to tools for promoting resilience in coastal communities.

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U.S. coastal communities' need for water level observations

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ABSTRACT

In partnership with the Southeast Coastal Ocean Observing Regional Association (SECOORA) and the Integrated Ocean Observing System (IOOS) Association, the American Shore & Beach Preservation Association (ASBPA) conducted a survey to better understand coastal communities' water level observing needs. While the survey size was small, it was geographically dispersed along the coastal regions of the U.S. The results of this survey and the experience of the Southeast Water Level Network team should be useful to inform a national effort to expand the network.

With coastal communities facing the compound threat of storm surge, extreme rainfall, and rising sea level, the Southeast Coastal Ocean Observing Regional Association (SECOORA) began supporting the installation and long-term operation of about 200 new water level stations around the Southeast U.S. in 2021 (Figure 1). This regional water level network will enable localized flooding alerts, improve community resilience, and monitor flooding hazards.

SECOORA is one of the 11 regional associations that partner with the NOAA-led Integrated Ocean Observing System (U.S. IOOS®). U.S. IOOS is essentially the weather service for the coastal oceans and Great Lakes, providing actionable data from above and below the surface and making that information readily available for decision-making. The IOOS Association, a nonprofit organization established to advance U.S. IOOS, works with the 11 regional coastal observing systems and 17 federal partners to create a national network of ocean observations.

With funding from the NOAA Integrated Ocean Observing System, SECOORA is partnering with ASBPA, Hohonu, Coastal Carolina University, Georgia Tech, Florida International University, and Florida Atlantic University to establish the Southeast Water Level Network.

The network goals are to provide real-time local water level data to town officials, emergency managers, design engineers, and the public. This data is vital for monitoring coastal flooding, and keeping citizens informed of hazardous conditions. Ideally, communities will use the data when designing resilience and adaptation strategies to sea level rise and other climate impacts.

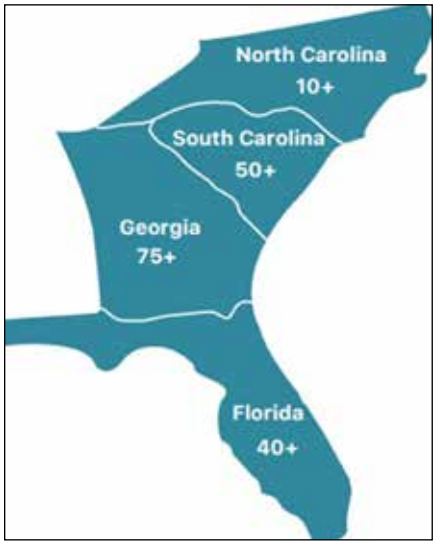

Figure 1. The proposed number of water level stations to be installed in each state in the Southeast.

Network objectives include: 1) Substantially expand real-time water level coverage; 2) partner with coastal communities' stakeholders to provide real-time water level data, with a focus on underserved communities; and 3) contribute to state and local decision-support applications and alert systems. An additional objective is to understand and document important lessons learned during this pilot project that will help to inform and operationalize a national-scale, sustainable, water level monitoring network.

The project team has prioritized collaboration with community partners to standardize sensors/stations, sampling rates, and data sharing requirements and products. For example, a test site was established with two sensors from each team co-located at the Fernandina Beach, FL, NOAA/NOS/CO-OPS 8720030 station (https://tidesandcurrents.noaa.gov/stationhome.html?id=8720030). This test site allows for analysis of the technical capabilities of each team's sensor system and comparison to the NOAA National Water Level Observing Network standard. A detailed analysis of this test site is under way and will be published soon.

Another significant challenge that the network team is considering is related to future operations and maintenance. Factors like cost, ownership, and data management are important to establish early in the development of a water level network. Roles and responsibilities should be clearly communicated to all partners.

Thus far, station location siting has been somewhat opportunistic with sensors being installed in communities with flooding challenges and interest in the project. This paper is intended to help start the process of maturing this process for an expanded or national network. Alternative location selection criteria that could be used include utilizing results of a spatial gaps analysis or responses from human surveys, like the one described here.

SURVEY RESULTS

In early 2023, ASBPA, SECOORA, and the IOOS Association conducted a survey of coastal stakeholders to help assess U.S. coastal community interest in expansion of a water level network established in the Southeast. The 11-question survey yielded 142 responses with a 75% completion rate within an average of five minutes to complete the survey. Respondents

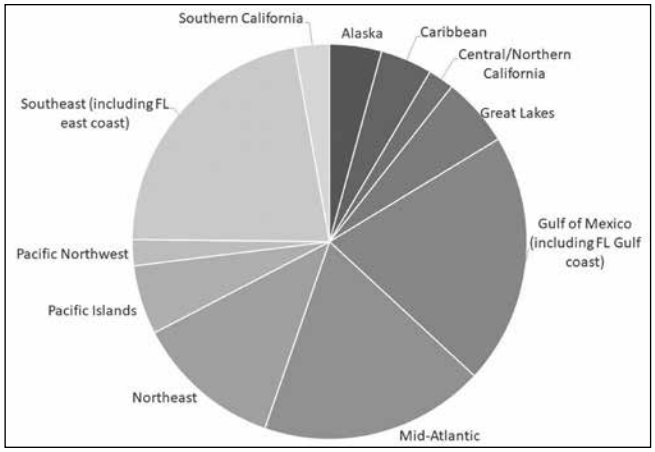

Figure 2. Regional distribution of 142 survey respondents.

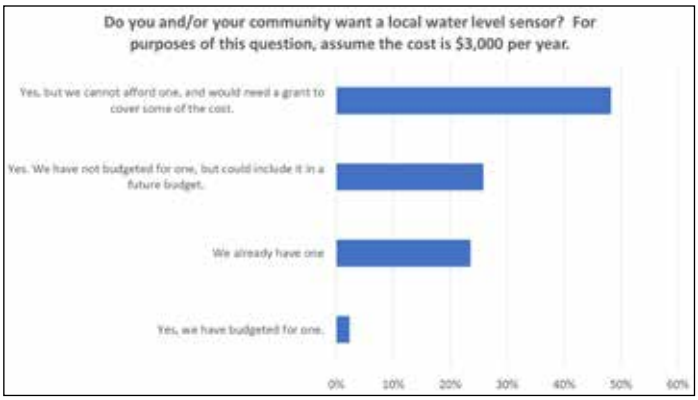

Figure 4. Survey responses to the question: "Do you and/or your community want a local water level sensor? For purposes of this question, assume the cost is $3,000 per year."

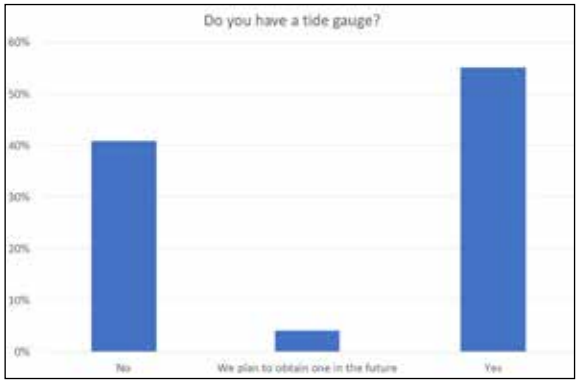

Figure 3. Survey responses to the question: "Do you have a tide gauge or water level sensor that provides real-time observations to your knowledge?"

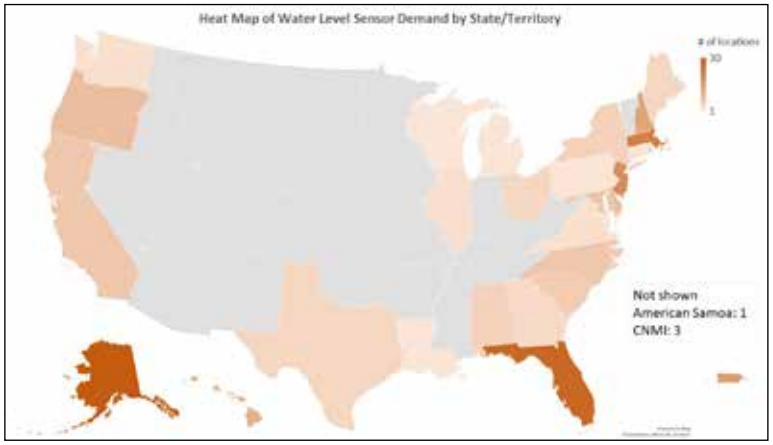

Figure 5. Map of coastal states and territories shaded by the number of locations requested in the survey.

included coastal stakeholders such as local community representatives and their industry consultants, state and federal agency representatives, and academics. Respondents collectively represented each of the 11 regional associations and all coastal states and territories (Figure 2).

Over 40% of respondents are not aware of a water level station for local, real-time observations (Figure 3). This perception reinforces anecdotes from ASBPA members noting a general lack of what coastal communities consider to be "nearby" water level stations. It also helps to verify that the spatial resolution of the existing national water level network is not sufficiently dense to meet community needs.

At an annual cost of $3,000 (which may be an underestimate), 25% of survey respondents indicated they could include funding in a future budget; whereas nearly 50% of respondents cannot afford this price-point (Figure 4). This highlights the demand for outside funding to supplement local observing budgets.

Every coastal state and territory provided specific locations where water level stations are needed. Demand from respondents is highest in Alaska, Florida, New Jersey, and Massachusetts (Figure 5). The strong and dispersed demand signal indicates an appetite for expansion of a national water level network.

As with all voluntary surveys, respondents likely reflect only direct contacts of the participating organizations and may be geographically skewed because of varied levels of communication and encouragement to participate across partners and regions. While the survey responses are not quantitative indicators of all coastal communities, key trends were highlighted by the survey results.

SUMMARY

ASBPA, SECOORA, and the IOOS Association conducted a survey of coastal stakeholders in 2023 to help assess U.S. coastal community interest in expansion of a water level network established in the Southeast. A significant portion of communities (40%) are not aware of readily available water level data for their community. Interest in water level stations and the data they provide is widespread. While there is significant interest in establishing community water level stations, funding to support such stations is not readily available even at the modest cost of $3,000. The results of this survey and the experience of the Southeast Water Level Network team should be useful in a national effort to expand the network.

Figure 1. Photo shows original beach at Coney Island prior to start of project. Photo courtesy of E.E. Rutter (1922), NYC Municipal Archives.

Figure 2. Photo shows construction of boardwalk looking west from Silver's Bath. Photo courtesy of E.E. Rutter (1922), NYC Municipal Archives.

Commemorating 100 years of beach nourishment on Coney Island, New York

By

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This year (2023) marks the 100th anniversary of the nation's first beach nourishment project, which was constructed on Coney Island, New York. The project planners and engineers showed astonishing foresight by incorporating the following elements into the original nourishment project: equity and inclusion; balancing private property rights with public access; the beneficial use of dredged material, hybrid engineering with groins and coincident beach nourishment; a scientific tracer study; and the monetization of return on investment. This article is an overview of the historical account of the actions and legislation that enabled this landmark event to take place.

The Coney Island Public Beach and Boardwalk Improvement Project of 1923 was engineered by Philip P. Farley, a consulting engineer for the Borough of Brooklyn, New York. The city established the nation's first public beach at Coney Island in 1923 under legislative authorization in 1921. Ground broke in spring of 1922 and the beach and boardwalk were opened to the public in 1923, roughly a year after construction began.

The goal of the Coney Island project was incredibly insightful: the city wanted to give the poor, underserved community affordable access to clean recreational space. In the early 1900s, Coney Island's beaches were rocky and narrow, and access was controlled by private bathhouses (Figure 1). To provide public beach access without interfering with the rights of landowners, legislators passed Chapter 610 of the Laws of 1921. This paved the way for the Coney Island improvement project, allowing for the acquisition of land and construction of a boardwalk and beach.

Table 1.
ASBPA Beach Nourishment Database records of beach nourishment events at Coney Island, New York. (No costs adjusted for Present Value.)

Year	Length (ft)	Volume (cy)	Cost
2014	3,000	100,000	
2013		569,000	$7,216,755
2004	9,504	20,000	
2001		105,000	$1,970,695
1996		35,000	
1995	15,840	2,317,513	$8.608.693
1961	7,000	750,000	$608,766
1941	12,500	500,000	$100,050
1926	2,500	850,000	$137,152
1923	8,750	1,700,000	$282,275

The first piling for the boardwalk was driven in March 1922 (Figure 2). Upon completion of the boardwalk, work began on the beach. A total of 16 groins and jetties, each 360 ft in length, were constructed (Figure 3). The purpose of these groins was not to accumulate sand, but to retain placed sand, reduce scour, and reduce wave action during storm conditions. As the groins were constructed, beach fill was pumped from four sites between 1,500-3,500 ft offshore (Figure 4). A total of 1,700,000 cy of sand was placed, advancing the high and low water lines 330 ft seaward (Farley 1923; Dornhelm 2003).

The use of dredged material for beach fill was itself a novel idea, but this project also yielded the first-known tracer study. The four offshore pumping sites were selected due to the availability of fine white sand. One site, however, produced reddish-brown sand shortly after work began. While the public was unhappy about the aesthetics of this sand, Farley used the mishap to his advantage. A monitoring study after the winter storm season revealed the reddish sand had moved 1,000 ft alongshore both east and west. Based on this finding, Farley was able to calculate the frequency and placement location for subsequent beach renourishments (Dornhelm 2004).

The benefits of the Coney Island and Beach and Boardwalk Improvement Project of 1923 are countless. The project created 10,000 ft of beach along Coney Island, increasing the health and happiness of residents living in the congested city. Additionally, property values adjacent to the boardwalk increased by $5 million in the first year after construction. Farley estimated that the increase in taxable revenue alone would pay the interest on the cost of the entire project. The engineered beach is also thought to have reduced property damage; reports from 1927, 1932, and 1935 note that landowners on Coney Island experienced less damage than nearby neighbors.

While Farley recommended renourishment every three to four years, the beach was filled fairly infrequently over the next 90 years. ASBPA's Beach Nourishment Database has a record of 10 nourishments in total at Coney Island from 1923's project completion to 2014 (Table 1; Elko *et al.* 2021). During this period, a total of nearly 7 million cy was placed on Coney Island beach.

Coney Island's beach also provided notable reductions in damage during Hurricane Sandy in 2012, continuing the trend started almost a century earlier. Anthony Ciorra, Senior Program Manager

Figure 3. Photo shows old wreck near constructed groin #17. Photo courtesy of E.E. Rutter (1922), NYC Municipal Archives.

Figure 4. Photo shows a 20-in discharge pipe near West 8th Street placing fill on beach. Photo courtesy of E.E. Rutter (1922), NYC Municipal Archives.

at the U.S. Army Corps of Engineers, New York District, was quoted saying "the beach's higher elevation avoided an estimated $494 million in damages to houses and structures" (Castagna 2016). Analysis from Coney Island and nearby beaches was compelling enough that the Army Corps began a deeper investigation into the benefits of beach nourishment (Castagna 2023).

In summary, the Coney Island beach nourishment is recognized as a precedent setting event that has led to more than 1,600,000,000 cubic yards of sediment placed in 470 communities across the nation to protect and restore beaches one hundred years later (Elko *et al.* 2021). It was the nation's first beach nourishment project, the first to make a concerted effort to provide an underserved community affordable access to clean recreational space, one of the first to implement beneficial use of dredge material, and one of the first known tracer studies. Finally, Coney Island has continued to provide public access, support the local, state, and national economy, enhance tourism, and reduce storm damage for 100 years (as of 2023).

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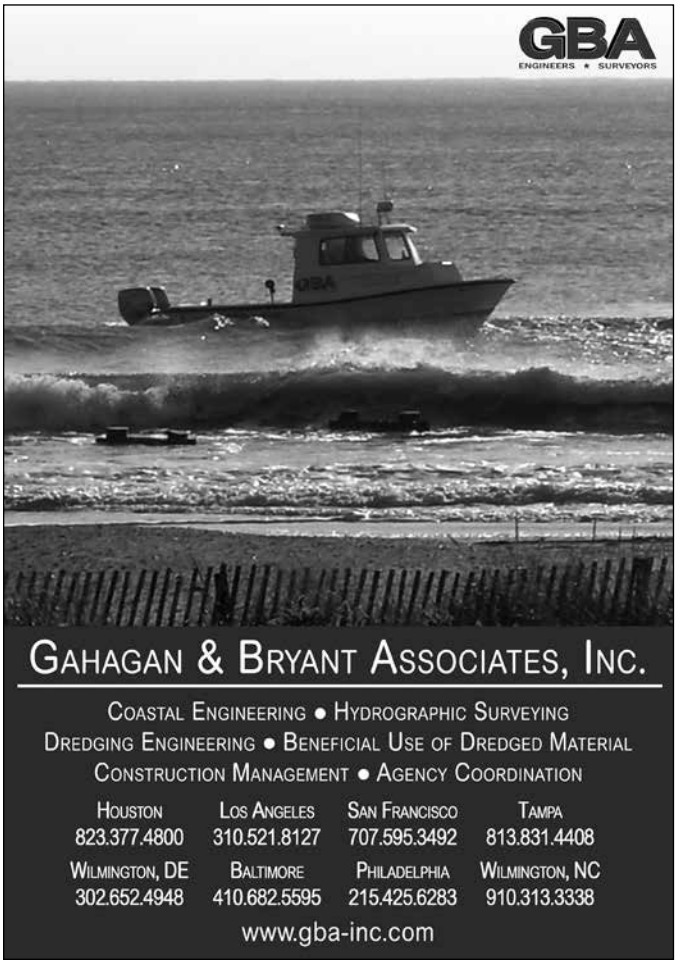

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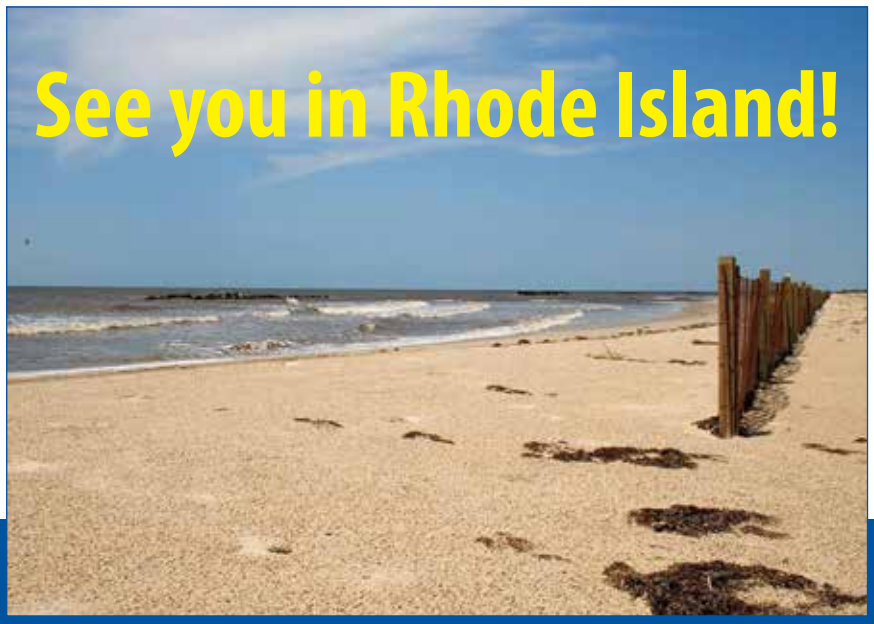

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