An Assessment of Coastal Vulnerability Due to Sea-level Rise and Increased Storminess, Sanibel and Captiva Islands, Florida

Project Funded by the Florida Resilient Coastlines Program

Michael Savarese[1], Felix Jose[1], Andrew Gross[1], Katherine Arnett[1], James Evans[2], and Joel Caouette[2]

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[1] Florida Gulf Coast University, Department of Marine & Ecological Sciences
[2] City of Sanibel, Department of Natural Resources

Abstract

The City of Sanibel (Lee County, Florida) and scientists from Florida Gulf Coast University have begun an analysis of Sanibel's and Captiva's vulnerability as a consequence of sea-level rise (SLR) and increased storminess with this funded 6-month project. A complete and successful vulnerability analysis for a coastal community requires 3 components: the engagement, support, and input from the stake holders; a categorization and description of the landscape, coastal geomorphology, and reconstruction of that geomorphology over recent history; and finally, a computer modeling approach to simulate future inundation and coastal erosion and deposition. This study undertakes the first two elements; the third will be proposed in the subsequent year.

The work specifically addresses two objectives. First, a community-based engagement strategy was used to: focus the attention of civic leaders and island residents on the pending problem, address concerns, and identify, map, and prioritize the critical natural, cultural, and urban assets under risk. This was accomplished through a series of public meetings and focused, facilitated forums. Second, the history of beach and dune habitat was documented between 1995 and the present through: the production of digital elevation models (DEMs); the extraction of beach profiles from those DEMs; the quantification of sediment budgets along the coast; and the monitoring of change in the position of the foredune over time.

The community engagement efforts were very successful. The Sanibel City Council and the public, at two separate meetings, were actively engaged in conversation about the value of a vulnerability analysis, and both groups endorsed the project and pledged their support. Eight teams of civic leaders, with each team representing a different sector of the islands' economy and social services, were created and engaged in group interviews to canvas their sector's concerns and to catalogue and map their assets. These forums generated a diverse canvas of opinions, concerns, and fears that will well inform government, commerce, and management while planning for adaptation. The teams also generated a list of over 150 assets, representing facilities and services of value. These assets have been mapped as geospatial, GIS files to permit

an assessment of their vulnerability once the effects of SLR and storminess are modeled in the next phase of Sanibel-Captiva's climate-change preparedness.

The history of coastal geomorphologic change between 1995 and 2019, through the production of DEMs, the comparison of beach profiles over time, the accounting of sediment budgets, and the monitoring of the positional shift of the foredune's seaward-most vegetation line, clearly revealed those regions of the Captiva and Sanibel coastline that are most vulnerable and most resilient to the impacts of SLR and storms. Those coastal regions founded upon strandplains (e.g., sectors 5, 9, & 10) have experienced significant foredune progradation and sand deposition, which has imposed great resilience. Coastal regions neighboring inlets (e.g., sectors 3 & 4 [Santiva area]) or adjacent to shoreline inflections, where wave energy is focused (e.g., sector 7), exhibit shoreline recession and erosion, making them more vulnerable. The majority of Captiva's length is relatively stable, exhibiting subtle geomorphologic changes over recent history. These datasets will be of great value when undertaking coastal geomorphologic or inundation modeling (e.g., XBEACH, ADCIRC-SWAN) of the island's response to future SLR and storminess.

These two accomplished objectives have predisposed the community to the next phase of a vulnerability analysis: the undertaking of a modeling effort that identifies those locations across the landscape at greatest risk to sea-level rise and storminess as we move forward through this century.

Project Description

The Southwest Florida region has only recently drawn its attention to the potential effects of climate change-induced sea-level rise (SLR) and increased storminess. Collier County, to Sanibel's south, has undertaken a risk vulnerability assessment with support from funding from NOAA (Sheng, Savarese et al., 2017) and is currently developing an RFP for adaptation planning. The City of Punta Gorda, to Sanibel's north, has conducted an analysis of risk potential and used those results to adjust their comprehensive planning efforts (Beever et al., 2009). Cape Coral just recently commissioned a vulnerability study from the South Florida Regional Planning Council (Beever et al., 2016). Lee County, however, has been remiss, though conversations have begun with civic leaders (FGCU Forum, 2018). The City of Sanibel has maintained a vigilant approach to environmental management and planning through the Sanibel Plan—a Comprehensive Land Use Plan based on natural systems. Their Mayor and City Council are desiring a more proactive, community-based assessment and planning process, and the City has welcomed this work. We expect this project to provide much-needed help to the Sanibel and Captiva Islands, but it should also serve as a role model for the rest of Lee and Charlotte Counties.

The Sanibel Plan, the City of Sanibel's Comprehensive Land Use Plan, takes a novel approach to land use planning, which puts natural resources at the top of its hierarchy of community values. As a result, the community has conserved more than two-thirds of the entire island for protection of wildlife and wildlife habitat. The Sanibel Plan establishes strict limits on impervious coverage and clearance of natural vegetation. It also prohibits or limits the use of hardened structures in the Gulf Beach and Bay Beach Zones, respectively. These elements of the Sanibel Plan have helped reduce the potential risk to private and public infrastructure and have put the City in a better position to deal with the future impacts of SLR.

The City is currently in the process of updating several planning documents to incorporate the impacts of SLR. The City recently incorporated a SLR component into the Sanibel Stormwater Management Plan (June 2017) and the Sanibel Island Wide Beach Management Plan (Draft Update September 2018). The City is working towards full compliance with the 2015 Peril of Flood legislation, and this project will provide planning tools necessary to be compliant with the statute. The City has also completed several beach dune restoration and living shoreline projects to enhance the community's coastal resilience. These projects include the restoration of several miles of beach dune and coastal scrub habitat and construction of two living shoreline projects along the bayside of the island. Another living shoreline, which extends along 1,000 linear feet of shoreline, has recently been designed and permitted and is currently out for bid. The City is also one of three pilot communities in a National Academies of Science Gulf Research Program grant obtained by The Nature Conservancy to investigate "Enhancing community resilience by linking conservation and restoration with coastal hazards risk reduction via the FEMA Community Rating System*"*. The goal of the project is to improve the capacity of Nature Conservancy staff in the coastal U.S. to work jointly with communities to use science and science- based tools to identify and develop nature-based projects that can enhance resilience to storms and SLR, and potentially earn FEMA CRS points. Despite these efforts, a comprehensive vulnerability assessment has yet to take place.

Any future planning for SLR adaptation must begin with an assessment of the community's vulnerability to future effects. The City of Sanibel comprises the entirety of a barrier island. (Though Captiva sits outside the auspices of Sanibel's city government, because the islands are so interdependent, this project will concern both islands.) The geomorphology of Sanibel Island is rather unusual for the southwestern Gulf Coast – Sanibel is an aggradational strandplain (Missimer, 1973; Stapor et al., 1991; Taylor & Stone, 1996), which affords it greater resistance to inundation and erosion because of multiple dune ridges with higher-than-typical elevations. The strandplain sits on the seaward edge of the island, and it is here where suburban development is most pronounced. The leeward side of the island is principally low-lying and composed of a back-barrier mangrove forest. Consequently, the potential effects fore and aft of the island are considerably different. Captiva Island, on the other hand, lacks well-developed, mature strandplains, and is a relatively thin barrier island. Vulnerability is also stake holder specific: the community must be both supportive and engaged. The city government and their constituents must be informed and supportive of any planning effort. It is also these same people that understand the value of their landscape and their natural, cultural, and urban resources, and therefore should be involved in the identification and prioritization of Sanibel's and Captiva's assets.

This project was designed to complete the first steps in a comprehensive vulnerability assessment for Sanibel and Captiva. Two objectives were undertaken. First, the project developed and implemented a communication plan to both inform residents about the project and the possible effects of accelerated SLR and storms, and, more importantly, engage them in small group forums to address their concerns and to solicit their opinions about critical resources requiring attention. Second, the prediction of coastal response to SLR and storms requires two steps: the landscape, its geomorphology, and its recent history of environmental response (i.e., to the effects of recent storms, extreme tides, and wave action) must be described and understood; and then its future response modeled. Because of the time limitation of this funding program, we completed the former – the description and characterization of the coastal landscape and recent history. The latter – the modeling – will occur in the subsequent year. The City and Florida Gulf Coast University (FGCU) are committed to pursuing future funding for these secondary steps.

Project Need and Benefit

Sanibel is working toward full compliance with the 2015 Peril of Flood statute, and results from this study will provide the planning tools necessary to be fully compliant with the statute. These efforts foster Sanibel's vulnerability assessment. Finally, a number of decision support tools were generated, further assisting Sanibel and Captiva in its future planning efforts.

The project period is too short for a comprehensive vulnerability assessment. For example, coastal geomorphologic response simulations to storms and SLR and inundation simulations (computer modeling using such programs as XBEACH and ADCIRC-SWAN) require that a preliminary description and historic response of the coast (our second objective) be completed first.

Objective I: Community Engagement

Introduction

The first purpose of the study was to engage the citizens of Sanibel and Captiva, the City's Council Members and management staff, and members of the natural resource management community in the importance, design, and implementation of a vulnerability study to the effects of climate change. This involved the scheduling and delivery of 3 presentations and discussions about the nature of climate-change preparedness and the help this project would bring to the community, and the development of a web page to serve as an information resource.

Additionally, the public was engaged: to obtain feedback about their understanding of climate change and its effects on a barrier island community, to hear their concerns about their community's future in the context of climate change, and to develop a catalogue of their perceived assets (i.e., facilities or social services of value now or in the future) that might be at risk to the effects of climate change. For this last piece, assets were described and their locations on the landscape mapped as ESRI ArcMap geospatial layers. Later, when a vulnerability modeling effort is conducted for Sanibel-Captiva, these assets can be overlain on vulnerability maps, allowing adaptation planning to occur. In order to well represent a cross section of the population and the islands' business and social services sectors, 8 teams of volunteers were assembled. The 8 teams comprised the following sectors: (1) Business Community, representing the business and tourism aspects of the local economy; (2) Infrastructure Team, those responsible for the islands' utilities, emergency management, and public works; (3) Development Team, those representing the insurance, real estate, and mortgage communities; (4) Social Resources Team, including religious organizations, human services, community housing, and health; (5) School and Education Team, including preschool education, and public and private elementary schools; (6) Natural and Cultural Resources Team, people representing parks, preserves, conservation agencies and NGOs, and historical and archaeological resource managers; (7) Captiva Community Team, people representing all sectors but living or working on Captiva; and (8) a Community At Large Team, a group of civic leaders with various responsibilities across the Sanibel-Captiva community. With help from staff at the Department of Natural Resources, a leader was recruited for each team. Savarese held a workshop for the team captains, briefing them on the project and training them on the interviewing process. Team leaders then assembled their teams, enlisting the participation of 6-12 members each. A 2-hour interview workshop was held with each of the 8 teams and information was collected.

Results & Discussion

A web site was created in January, 2019 and will continue to serve as a repository for Sanibel-Captiva's vulnerability analysis as this project transitions through all subsequent efforts. The site is housed at the City's Department of Natural Resources and can be visited at: https://www.mysanibel.com/Departments/Natural-Resources/Coastal-Resiliency-Planning.

A presentation was given to the Sanibel City Council on February 5, 2019, and a public forum was scheduled on February 22, 2019 at the Sanibel Community House. The project was endorsed by City Council with members pledging their support. The public forum was attended by approximately 75 individuals; all participants were very receptive to and supportive of the project, and were engaged in a lively discussion. Both presentations and meeting notes are available at the web site.

The team structures and compositions were established in late January, and the team captain workshop was facilitated on February 12, 2019. The captains were briefed, their team organization was discussed, and the interview questions for the team forums were reviewed. Notes from this meeting are also posted at the web site.

The 8 team forums were conducted over the months of March and April, 2019. Each provided a wealth of information about their respective sector's concerns. The results of those team interviews are provided below two ways: "A. Sanibel-Captiva Team Comments: Summary", a collated collection of responses to each of the questions; and "B. Sanibel-Captiva Team: Synthesis", a synthetic narrative that identifies and describes common themes.

A. Sanibel-Captiva Team Comments: Summary

Each team's comments are color coded as shown below. The names of the participating team members are included, though no comment is specifically attributed to any individual. The interview questions are presented in bold, black text.

Business Community

Evelyn Stewart, Chris Davison, Calli Johnson, Fran Peters, and Daniel Thompson

Captiva Community

David Mintz, Larry Baras, Jay Brown, Kate Fetissoff, Jim Restivo, Mike Mullins, Kelly Sloan, Linda Laird, Bill Riley

Community At Large

Millard Everhart, Herb Rubin, Gary Chelsey, Sarah Propst, Anne Golden, Anne Wallace, Malcom Martini, Jon Gustafson, Geoff Moss, David Ouchterlony

Infrastructure Group

Roy Gibson, Oisin Dolley, Tricia Dorn, Diana Wilson, David Harding, Joel Caouette

Development Group

Dustyn Corace, Chris Heidrick, David Wright, Bill Robinson, Mark Anderson

Natural & Cultural Resources Group

Joel Caouette, James Evans, Kelly Sloan, Jeremy Conrad, Alison Hussey

School & Education Group

Bruce Neill, Cindy DeCosta, Milissa Sprecher, Rachel Rainbolt, Shelley Greggs

Social Resources Group

Mike Miller, Mike Bugler, Pat Boris, Maggi Feiner, Alicia Tighe, Nitza Lopez, Rachel Tritaik, Melissa Rice, John Danner

What barriers does your business or community sector face with recognizing or discussing the effects of climate change? Are there fears, misunderstandings, denials that inhibit dialogue?

- It is important to avoid losing day visitors because they transition to long-term vacation rentals to ownership; all team members agree on this. Day visitors often become long-term vacationers, and the seasonal or permanent residents. Events (e.g., HABs, storms) discourage visitation, leading to short-term economic losses. However, if this modifies future visitation and at these higher "residential" levels, the economic loss would be much greater.
- This said, it is necessary to be honest and forthright with visitors and clients. There should be a community-wide strategy for providing the right communication.
- Storms and SLR may make rental and hotel properties unusable. Resilience of these properties, therefore, must be great. Business must be returned to normal as quickly as possible.
- A barrier is the lack of understanding, among the population, or the uncertainty of future outcomes, because of the scientific limitations with respect to climate change. This makes it difficult to plan and allows denial and skepticism to flourish.
- The lay public does not understand the uncertain, yet predictable nature of storm surge. This creates a lack of confidence among people, and this can ill-effect a person's response to a pending storm in the future ("crying wolf" phenomenon). Hurricane Charley was a good example, where 10-15 feet of storm surge was predicted, but never realized. Education is important, along with better communication in advance of a storm.

- Sanibel and Captiva rely on the draw of the natural environment (e.g., the Refuge, public lands, and beaches). SLR and storminess put these at risk. Resilience must also include natural resources, in addition to urban resources.
- Sanibel is a world-wide destination for shelling, which brings collectors to its beaches. SLR and storminess put beaches at risk.
- Cultural assets are also important and draw visitors. The Sanibel Lighthouse is a good example and a cultural resource that should be protected.
- The community must keep its infrastructure, emergency services, and life-necessary services resilience so that the islands can be re-inhabited quickly after an event. One example is the islands' grocery stores. Only some of these facilities are elevated and therefore more resilient to flooding and surge. Investments should be made to improve resilience of all these necessary assets and services.
- Many residential, rental, and hotel properties are built at ground level (i.e., are not elevated or not adequately elevated). These properties are at greater risk and of reduced resilience. There are also multi-storied properties, where the lowest units are at ground level, while the upper levels are, by design, effectively elevated. How are lower units retrofitted in these situations when condo owners exist above them?
- Developmental decisions are influenced by the position of the mean high-water line, which changes over time as a consequence of accretion, erosion, and the height of mean sea level, unlike the "coastal construction control line" (CCCL), which is less dynamic over time. Often the City's permitting decisions are based on the former, rather than the CCCL, which has caused financial hardships for property owners and development.
- Home and business owners, and potential purchasers, are often not well-informed with respect to coastal development restrictions. Communication could be better.
- The island is not on a beach renourishment schedule. Renourishment only occurs when life or property is threatened. There are exceptions for areas that are chronically eroded (e.g., Blind Pass).
- Many / most business owners lease their space, rather than owning it. In these situations, a business owner does not have the flexibility to improve their space's resilience.
- Lift stations are near inadequate. Excessive rainfall in the dry season, for example, when the islands' population is at its highest, can stress lift stations. This happened in January, 2018.
- SLR and storminess should be priority issues for Sanibel and Captiva, yet the population may not be motivated to address these concerns because of its demographics. Most people are 60+ years in age and don't necessarily have a vested interest in the more distant future.
- Captiva is a small area and very narrow along much of its length. The expectation is that this seriously worsens its vulnerability when compared to other barrier islands in Southwest Florida.

- Sanibel is a “sanctuary island”, a destination or home where the natural world is respected. It’s important that this aesthetic be sustainable and resilience to the effects of climate change.
- It’s disingenuous to not reveal what vulnerabilities exist with respect to SLR and storminess to those seeking to relocate here, buy property, or invest in business. There should be some way to disclose this information without creating panic and misunderstanding. One team member, who recently was shopping for real estate on Sanibel, felt misled by their agent, who claimed that climate change and SLR were not issues, that housing prices were not affected, and there would likely be no effect in the future.
- The island should remain attractive and healthy to ensure quality of life and to retain existing and to encourage new residents. Understanding vulnerability and maximizing resilience are therefore necessary to achieve this. Infrastructure should be improved to maximize resilience and minimize the time life on the islands is disrupted.
- Many people on this team recognize the importance of restoring business after an event quickly.
- Change is difficult to accept for the residents on Sanibel and Captiva, particularly those that have been living there for many years. And change to the life style may be necessary to accommodate the future effects of climate change.
- There is concern over the socially unjust nature of climate change’s effects. Those of lower income are least likely to afford the changes necessary for greater resilience. This sector of the population is most likely to suffer the ill effects or those most likely to become climate refugees.
- Resilience favors the wealthy and those on higher elevation!
- Residents have a reasonably good understanding of the risks involved; residents are well informed, educated, and sophisticated. They need, however, to be engaged in finding and implementing solutions.
- Others on the team, however, find that the public is not well informed about climate change and its possible effects. Public education is non-existent, with people acquiring information from the popular media. The community should facilitate a public educational effort.
- A couple of team members suggested that Sanibel adopt as its mission [paraphrased]: “To keep Sanibel Island a place where people want to come to live and visit while sustained the current style and quality of life. All of our island’s assets (e.g., beaches, wildlife preserves, tracts, bike paths, homes, condos, rentals, social services, and critical infrastructure) should remain sustainable by improving their resilience to chronic and episodic climate effects.”
- “Sea level rise is perceived as being a problem for the next generation. However, we are beginning to see a falling off of demand for housing for permanent residents. Homes are listing longer for offers and prices are declining. This is reported to be coming about due to the expectation of future storms and water damage on the island. Reduction in vacation visitors is probably more due to red tide fish kills and ocean pollution, meaning it should recover as these problems dissipate with the season.”

- Utility companies must accommodate multiple levels of jurisdiction (e.g., boards, various levels of government, private interests) and this can create administrative hurdles for change.
- There is a fear that the entire island will be lost because of climate change.
- A common barrier is an individual's lack of acceptance or understanding of the science related to climate change due to lack of education and fear of confrontation with their peers. There are fears of ridicule, reprisal, and isolation.
- To date, there has not been any difficulty in acquiring home owners' insurance on Sanibel and Captiva. Insurance has not been denied, rather the costs, related to the flood zone designation, vary.
- Currently FEMA policies are such that low cost home owners are subsidizing high cost owners and inland owners are subsidizing coastal home owners. This is changing, however.
- Real estate professionals rarely talk about the risks of SLR and storms because of the nature of their business. Some clients do bring it up independently but, in this team member's experience, this has not resulted in the loss of business.
- The effects of recent storm events increase awareness and activism. However, the increased concern quickly dissipates when the community rebounds. Perhaps a greater frequency of events will change this.
- There has not been any pressure from local government to dismiss the potential effects of SLR and storminess. That said, there hasn't been proactive engagement with government to address it.
- There seems to be greater pressure to protect urban infrastructure at the expense of natural resources, while certain well-maintained natural resources (i.e., green infrastructure) can increase resilience for the entire community. Sanibel needs to profess the value of green infrastructure (aka NNBFs: Nature and Nature-based Features). The Sanibel Plan does not explicitly address this, but the Peril of Flood language will.
- Some people are of the opinion that if the entire island is doomed, why bother with improved resilience. More people, however, recognize that planning is important and not pointless.
- Educational materials available to those on the islands are limited. SCCF is currently creating public education materials regarding climate change. The Refuge and CROW don't have materials, but should. Other Refuges are doing this. Ding Darling's visitor center should have climate change educational materials.
- There hasn't been much support or action from the State, though this appears to be changing with the new administration.
- This team noted many of same barriers voiced across the other teams: climate change denial; lack of education about the matter; fears of economic collapse, particularly of the real estate and tourism sectors; lack of governmental action and support.
- Climate change effects are perceived by many as problems of the distant future, and not a pressing matter for the current residents and visitors. The incipient impacts should be revealing and discussed.

- The economic ramifications of climate change are vague and uncertain, making it difficult to take seriously.
- It's difficult for lower income workers (i.e., minimum wage workers), which principally fulfill the islands' service needs, to cope with climate events. Storms, when resilience is poor and community rebound is slow, can lead to loss in income and unemployment. There is little to no assistance for these workers when employment is disrupted.
- SLR is a global problem. How is one tiny island going to stop it? This creates a sense of hopelessness.

What concerns does your sector have with respect to the present and future impacts of sea-level rise and increased storminess?

a. Has your sector used climate effects in its decision making?

- Businesses have learned that it is necessary to have more available capital to cover lost business over the prolonged intervals of 'down time' after a climate event.
- Business owners recognize the importance of having power restored quickly to contact and communicate with existing and pending customers. Many have invested in generators.
- Life-necessary businesses (e.g., grocers) recognize the importance of having generators. In advance of Irma, at least one grocery storm rented a large capacity generator to avoid loss of inventory.
- The City recognizes that the building code is no longer adequate for businesses given climate change's effects, and is making allowances for this. Some code changes have been implemented. For example, Sunset Beach Resort was renovated within the new code. Team members view these as positive signs.
- Captiva is potentially interested in pursuing a vulnerability modeling effort right away and on its own.
- The Building Code on Sanibel is the most stringent in the State. This is true for restrictions on building elevation, roofing, and window requirements.
- One person noted that, in their opinion, climate change effects are not used in decision making. The focus is "on water quality and loss of tourism caused by dead fish on the beaches. There has been some work on shore erosion protection, but sea level rise is so small and slow that it is not a priority."
- Beach renourishment is in place to handle existing problems but not overly foresightful to deal with future impacts.
- Lift station control panels have been elevated to handle higher inundation.
- IWA (Island Water Association) has undertaken a number of changes. They are conducting a lightning study to minimize future strike damage; and they have increased the hurricane ratings on their roofs and raised the elevation of their well electronics. Admittedly, these resiliency measures are dealing with more immediate effects, rather than more distant future problems.
- Service reliability is of critical importance to Lee County Electric Cooperative (LCEC). Consequently, continual maintenance is necessary and improved resilience desirable.

Furthering these is often compromised by the need to keep rates lows. LCEC infrastructure is a combination of above ground and underground technology; powerlines are both above and below, while transformers and power stations are above. There are advantages and disadvantages to both. One change LCEC has recently adopted concerns the materials used in utility poles. Wood poles were replaced with concrete in some places, and power lines were buried along Woodring Road to avoid utility pole deterioration.

- The city has undertaken or is planning a number of living shoreline projects to improve coastal resilience. These include projects at: Sanibel Lighthouse, Bailey Beach Park, and a pending project for Woodring Road.
- The insurance industry is developing something called "Flood Fax". Similar to Car Fax, Flood Fax would require that past flooding effects were disclosed to potential buyers. A company called Core Logic is developing this.
- Though home owners' insurance has been consistently available, the cost of premiums is rising, which is good for the industry. Insurance consumers, however, want incentives to reduce their rates. This leads to making homes more resilient through improvements that reduce wind and inundation damage. Increasing home elevation is the most effective at improving resilience to inundation, but is very expensive and impractical. It has become more viable for redevelopment efforts.
- The greatest measure of risk is the insurance premium (if not subsidized).
- Insurance premiums are rising at a lesser rate for elevated homes, when compared to homes built at ground level. This will lead to greater disparity between ground and elevated homes as we move forward.
- The National Flood Insurance Program (NFIP) gives Sanibel a CR5 score. This generates a 25% savings on Sanibel residents' premiums. Sanibel is more restrictive than the NFIP requires. For example, NFIP stipulates that if 50% of a property's value is compromised by damage, then the rebuild must meet the new requirements. Sanibel's requirements are stricter than this.
- The impacts of climate change have not ill-effected the mortgage industry in Florida, not even in Miami, at least not yet. If the insurance is available, then the mortgages will come.
- Climate events are addressed for emergency management. The Beach Management Plan reflects climate change, and the living shoreline projects directly address climate change resilience.
- Weir elevations have been adjusted at the flood gates because of climate change. The structures themselves, however, have not yet been redesigned for climate.
- SCCF sea turtle management strategies reflect climate effects; erosion and temperature-controlled sex ratios are both considered.
- SCCF shorebird monitoring has exposed climate effects. Snowy plover and least tern nesting was harmed by a king tide in June, 2018. No change, however, in shorebird management has occurred because of climate change. It's not clear if alternative effective strategies exist. Perhaps this is an opportunity.

- Ding Darling is currently looking at changes that have occurred along the bayside coastline since the 1960s. Vegetative changes are evident; no saltern formation has been documented; and no mangrove mass mortalities have occurred because of inhibited tidal flow. Surface Elevation Tables (SETs) have been deployed in the Refuge.
- CROW is conducting a feasibility study to determine their capabilities in the wake of an event. The impact of climate change is part of the dialog, but not the driving force. (Harmful algal blooms and their effects on sea turtles and birds are of greater concern.)
- CROW worries about their health care professionals' safety and availability during and after a storm. Their management plan considers this, and their Strategic Plan calls for an off-island site. CROW is also a teaching facility; of concern is the safety of dorm residents and staff.
- Enrollment is in decline at least two schools (Sanibel School and Children's Education Center of the Islands). Though the cause of these declines is uncertain, the suspicion is that fewer families are remaining or moving to Sanibel and Captiva due to financial and economic concerns. Climate change is perhaps indirectly related to the phenomenon. The Children's Education Center has altered its plans to make significant repairs and build a new structure due to decreased enrollment.

b. Have recent climate events (e.g., Hurricane Irma, nuisance flooding, fire) affected your sector?

- Gulfside and Periwinkle Parks were rebuilt in concert with the new building code. Gulfside was rebuilt after Hurricane Charley, at a cost of $14M.
- The recent harmful algal bloom resulted in the many rental cancellations and harmed business. The same impacts occurred after Hurricane Charley.
- Nuisance flooding (principally during king tides) is occurring at a number of locations: (1) Dixie Beach Road and subdivision (the northern portion in particular); (2) Woodring Road; (3) along Bailey Road; and (4) at Castaways and Santiva Inn.
- There are freshwater flooding hot spots. These may or may not be related to higher tides, extreme precipitation, and inadequate storm water management infrastructure. They include: (1) the neighborhoods of Sea Oats and The Rocks (both east and west); (2) Island Inn Road; and (3) Sanibel Shores. The latter two are exacerbated by inadequate infrastructure. The City has made improvements at Sanibel Shores.
- Salinization is a potential problem. SCCF has conducted a study of well salinization. We have not seen their findings. The ponds along Middle Gulf Drive do exhibit tidal fluctuation.
- Irma caused 18" of overwash along Woodring Road, and storm surge inundation across Bailey Beach Road from a breach along the beach.
- The living shoreline at Bailey Beach and at Lighthouse Road functioned well during Irma. These successes have motivated future living shoreline projects.
- Hurricane Charley was awful; Wilma was better; Irma outages were scattered and short lived.
- The preparations made by the Island Water Association, in advance of Irma, were inadequate. Facilities were evacuated too early, which created some problems. IWA

would like to have offsite monitoring and control of their infrastructural elements. Offsite monitoring cameras do exist, but the offsite control of features is limited.

- Hurricane Irma slowed down real estate business for a few months, but this was short lived.
- Hurricane Andrew's impact was the seminal influence on stricter building codes.
- Sanibel and Captiva were lucky to have avoided extreme damage from Irma, while it improved the community's awareness of its coastal vulnerability.
- Sanibel adopted a "build back" policy after Hurricane Charley, which allows for rebuilding on the same footprint. This was not allowed previously.
- Irma hammered the shoreline and caused coastal flooding. Some areas remained flooded for almost 2 weeks.
- CROW experienced an influx of injured animals during and after Irma.
- SCCF observed harm to sea turtle nests because of Irma.
- The Refuge documented Irma-cause windfall of trees, some mangrove defoliation, but not significant mangrove mortality.
- Irma caused some storm surge on the bay side, of up to 1-1.5 feet. A debris / sediment berm was created on the bay side.
- Fewer families are moving to Sanibel / Captiva. The group believes this is partly caused by climate events like Irma.
- Fewer tourists ultimately cause a reduction in educational offerings.
- The health sector was or can be impacted in more subtle ways by storms. Physical therapy was disrupted after Irma; the Therapy Center was closed for almost a month due to water damage to the facility. Physical therapy at home was disrupted in a number of homes that were constructed at ground level.
- The human health impacts of recent storms (e.g., Irma) were relatively minor, while the recent harmful algal bloom caused many serious health problems.
- One member of the team noted there was 100% cancellation of renters in their neighborhood in October, 2018 (presumably due the harmful algal blooms). The combined effects of HABs and storms have caused grief and home-ownership regret for many people in the area.
- Churches on the island are needing to self-insure because they can't afford the insurance policy premiums. At least one church needed to forgo flood insurance.
- Irma and HABs have made it difficult for employers to keep workers, and to recruit new employees.
- The new building codes, requiring greater building elevation, make it difficult for seniors that have limited mobility.
- FISH's resources were stretched thin after Irma and the HABs. They have increased their budget for natural disaster / crises relief. During the HAB event, FISH staff stepped up to assist with the work typically taken on by volunteers. Resources have become particularly limited in the off-season months.
- After Irma and the HABs, the preschool at one local church provided more scholarship assistance to local kids.

c. Are any of these effects being experienced now? Or are they perceived as being near or far into the future?

- There are people on Sanibel that are already experiencing chronic or nuisance flooding.
- The island experiences localized street flooding during heavy precipitation events. Periodic loss of power and cell service is not uncommon.
- "Recent climate events have affected the island. Cleanup from Irma cost the island several hundred thousand dollars. But it was done quickly and without much involvement of the public. Nuisance flooding is not generally noticed, and only so on very low-lying streets and out-of-the-way neighborhoods. Again, there is no loud public outcry and no alarm on climate change."
- How reliant is Sanibel and Captiva on septic? All household waste should be switched to sewer.

d. Could any of these effects cause your sector to diversify or change its focus?

- At what point do business or home owners decide to leave or not invest? Vulnerability would give people a sense of when this threshold is likely met. When is tourism no longer sufficient to economically support the islands?
- "[Climate change] effects could cause the island to diversity or change its focus. We should see a modest shift toward visitor housing and services. The costs to hold residential property that is subject to storm damage and flooding will increase over time, making permanent housing unaffordable for the non-rich sector. Housing for visitors should remain strong as these increased costs can be passed on in the visitor upcharges."

e. Could climate change effects provide new opportunities for you sector?

- As SLR and storminess intensify, Sanibel / Captiva could become a more isolated tourist destination, becoming more remote and potentially more exclusive.
- The City should consider revising ordinances to promote or encourage the development of higher or more resilient ground.
- Residents of Sanibel are loyal to the island and committed to the sustainability ethic. They are well intended and motivated to work the problem.
- It's difficult to envision climate change leading to new opportunities simply because Sanibel is a relatively small barrier island, minimizing the diversity of landscape types and environments that might otherwise benefit from climate change.
- "No new opportunities are envisioned as a consequence of climate change. Existing remodeling, roof and home repair, and landscaping services should thrive if storm damage accelerated. Once a program of storm protection, adaptation, and resilience is operational, then certain contractors should create new employment opportunities on the island. Unfortunately, the island is the home of very few construction workers and they will become part of the work force that commutes each day from Ft. Myers."
- There is an opportunity to invest in more offsite remote-control features of power and water.

- Weir management strategies during an event should be revisited to minimize inundation.
- New practices to minimize the infiltration of seawater into the wastewater system are needed. Seawater infiltration creates greater volumes of wastewater that need to be treated.
- The Beach Management Plan currently has no mention of SLR. It will be included in the upcoming revision.
- There is an opportunity to recraft the Comprehensive Land Use Plan in the context of SLR and storminess. The current Sanibel Plan has no mention of SLR. This will change in the 2020 revision.
- The approach to renourishment seems uninformed and wasteful. There should be greater foresight when improving beach resilience. More costly solutions should be allowable if they provide for greater longevity.
- There's an opportunity to provide climate change and resilience educational materials within SCCF, the Refuge, and CROW. Both visitors and residents need education.
- Sanibel's Beach Management Plan will have a chapter addressing climate and SLR.
- The value of NNBFs should be further emphasized. Living shorelines should be used more often, and an integrated plan for their deployment should be developed.
- A better connection between climate change and water quality, particularly HABs, should be made.
- This DEP-funded study should transition to the development of a Coastal Resilience Plan for the island and region.

B. Sanibel-Captiva Team Comments: Synthesis

The eight different teams, representing the various social and economic sectors of life on Sanibel and Captiva Islands, each gave thoughtful responses concerning sea-level rise and its effects on their island community. The main themes that seemed to recur throughout the discussions are detailed below. Inputs and opinions have been condensed for the sake of the reader; however, all responses are represented within this synthesis.

The most often voiced barrier by the community to addressing climate change's effects is the lack of knowledge surrounding climate science and its societal implications. Many team members commented that conversations are hindered by the lack of confidence, or fear of the subject. Some members advocated for educational programs, while others declared that an honest and straightforward conversation be held among the islands' residents. Additionally, the groups expressed a consensus opinion that the topic of climate-change's effects on sea-level rise and storminess must be addressed and truthfully considered without imposing a sense of hopelessness among island residents and visitors.

The Development Group described a social phenomenon of critical importance to the island's economic health that will be influenced harmfully by climate change: the transition of first-time visitors to repeat, longer-term renters, to eventual full-time or seasonal residents and home ownership. Climate change effects, particularly the impact of storms and harmful algal blooms, can quickly and permanently dissuade visitation, which then has the potential to interrupt the economic evolution to a longer-term commitment by visitors to the islands.

The Business Group recommended the development of a plan to appropriately inform residents and visitors of environmental risks, without instilling fear and hopelessness. This could serve to preserve the interest in return visits and in more permanent investment on the islands. The significance of this point became clearly evident when a participant revealed that he/she had felt misled when shopping for real estate on the islands. The Development Group, alternatively, agreed that a briefing about environmental risk is important, but rarely given unless the matter is brought up by a client. This may have immediate and short-term positive effects for the real estate market, but a less-informed community results in less opportunity to discuss resiliency planning and adaptation, which can have longer-term devastating economic consequences.

Group members expressed concern that efforts to establish resilient structures and action plans have been slow in the making or have yet to happen, thereby putting Sanibel-Captiva at a disadvantage. The efforts that have been attempted have focused on the rapid-rebound of critical societal functions after a major climatic event (i.e., a hurricane). There was general agreement that of greatest importance was getting businesses operational as soon as possible after a storm: a business that can minimize its downtime can recover from lost revenue more quickly and remain successful longer in a changing climate. Those most important services include: emergency management, utilities, major arterial roads, health care, and sanitation. Improving the resiliency of these services and facilities would improve the overall quality of life, ensure future economic health, and better maintain the tourism economy.

Many businesses are further disadvantaged when leasing or renting their facility, rather than owning it. This prevents business owners from investing in large-scale changes that would improve their economic resilience. For example, many business owners lease ground-level space in shopping plazas, which are more vulnerable to inundation and more likely to be seriously damaged during an event. Comparably, certain companies that provide public works services may be prohibited to make significant structural improvements to their facilities because boards or public ownership typically want to maximize profits, while keeping the cost to customers low. This provides little incentive for investment in resiliency improvement.

In addition to the importance of a resilient business sector, a natural environment able to withstand recurring climatic events is crucial to the sustainability of Sanibel and Captiva. Some fear that resiliency planning may come at a cost to natural resources and structures. There is some sentiment among the groups that incorporation of natural and nature-based features (i.e., green infrastructure) will help dampen impacts on urban communities during severe climate events. The emphasis of Sanibel being a world-class destination for shelling, nature watching, and island living makes the beaches and natural reserves an integral part of the attractiveness of the community. Development of long-term adaptation and resiliency plans that consider both urban and natural resources are paramount to the success of the Sanibel-Captiva community and consistent with their progressive policies with respect to environmental sustainability.

An all-encompassing plan to combat sea-level rise and climate change must include and benefit the entire community. This includes residents that may not have the means to relocate or renovate infrastructure to meet future resiliency codes. Certain groups pointed out that low-income workers, fulfilling service needs on the islands, may not be able to afford the likely changes necessary to withstand future storms or king tides. In addition, the less resilient infrastructure can lead to a longer redevelopment period, meaning greater losses in business and income. With the onset of king tides and nuisance flooding, homeowners have already experienced an increase in insurance rates. Some non-profit organizations have even had to give up insurance altogether because of its unaffordability. Even if they have the money to address resilience concerns, how will ground-floor residents in multi-floor buildings such as condominiums and apartment complexes fare? Others may be immobile, unable to climb stairs or ramps up to elevated homes. In one instance, residents were not able to meet with physical therapists and doctors because of flooding and the closing of businesses before Irma. In these examples, one can see how resiliency might favor those with higher incomes, more mobility, or structures that are already built higher than ground-level. These points should all be addressed in future dialogues.

Some of the resistance to planning for future increases in sea level and other climate events stems from the time horizons of island-goers. Many of the residents retire on Sanibel to live out their remaining years in paradise. For those of retirement age, this mindset is not conducive to the planning for climate change's effects. Those effects are often perceived as being too distant in time to have an impact on their lives or property. Recent events (e.g., Hurricane Irma, freshwater flooding) have demonstrated, however, that effects may be more immediate. Consequently, adaptation and mitigation planning demands that all residents, the older included, change their mindset and lifestyle to accommodate.

The 8 teams identified and located approximately 150 assets throughout Sanibel and Captiva Islands. These included a variety of asset categories including, but not limited to: emergency service facilities, government buildings, arterial roadways and bridges, storm water infrastructural elements and weirs, waste water treatment facilities, Island Water Association wells, cell towers, businesses providing critical services, hotels and tourism businesses, neighborhoods and housing subdivisions, natural resources, historical structures and buildings, churches, schools, and recreational areas. A complete catalogue and the corresponding GIS shape files have been provided to the City and will eventually be displayed at the project web site.

In addition, the City of Sanibel provided GIS shape files for: public infrastructure, neighborhoods, conservation lands, and roads. These shape files will also be displayed at the project web site.

Objective II: Characterization of the Coastal Geomorphology and its Recent History of Change

Introduction

The second purpose of the study was to characterize Sanibel's and Captiva's gulf-ward coastal geomorphology and its recent history of geomorphologic change (Figs. 1-3). Any subsequent modeling effort to analyze the two islands' vulnerability to future sea-level rise and storminess will undoubtedly explore the resilience of its beaches, dunes, and strandplain system to inundation and erosion. This aspect of the study provides the necessary foundational data to support such a future modeling effort. The principal investigators and Sanibel's Natural Resources staff have already discussed the value of employing XBEACH modeling, which requires these baseline data, as the next logical step in a vulnerability analysis.

In pursuit of this objective, the following datasets were acquired:

(1) *Digital Elevation Models (DEMs) for the islands.* LiDAR data exist for Sanibel and Captiva for 5 years: 1998, 2004 (post Hurricane Charley), 2004 (post Hurricane Ivan), 2006 (which exists for just Captiva), 2010, and 2015. For each of these datasets, a DEM was constructed for the islands. The DEMs cover the entire subaerial area of the islands and extend offshore some distance to show nearshore bathymetry. These DEMs document changes in coastal geomorphology, ground elevation and bathymetry, and shifts or alterations seen among landforms. The DEMs are presented both as static maps (TIF images) and as GIS shapefiles. Each year's DEM is subdivided into 3 regions for easy interpretation: Captiva, North Sanibel, and South Sanibel. Additionally, maps showing elevation differences between 2010 and 2015 are provided. These document the location and magnitude of elevation changes across the region.

(2) *Beach profiles extracted from the DEMs.* The quality of the DEMs was high enough to allow the extraction of beach profiles from each of the DEM years. Florida Department of Natural Resources (FNDR), and its successor, the Department of Environmental Protection (FDEP), established 100 R-monuments running the length of the Captiva and Sanibel coast, each separated from its neighbor by 1000 feet. Monuments are numbered from R-084 (in northern-most Captiva), southward and eastward to R-174 on the eastern tip of Sanibel. Each monument's position and elevation were surveyed in, and FDNR/FDEP prescribed azimuthal orientations for beach profile monitoring. (The location of each monument is shown in Figures 4-6.) Elevation data were extracted at each monument, for each DEM year, following the prescribed profile orientations. This has yielded a time series dataset from which beach erosion and deposition can be reconstructed since 1998. Figures are provided for each R-monument's profile evolution over the 6 DEM years.

(3) *Maps showing positional change of the seaward-most vegetation line and the position of the shoreline*. Historic satellite imagery within Google Earth exists for 13 dates: April 1994 (Captiva only), January 1995 (Sanibel only), January 1999, October 2002, December 2004 (post Charley and Ivan), January 2006 (Captiva only), August 2006 (Sanibel only), June 2008, April 2010, April 2012, March 2014, February 2016, and January 2019. Most critical for coastal resilience is the integrity of the foredune. Sands on beaches in front of the foredune are dynamic and experience short-term patterns of erosion and deposition. Damage to the foredune, however, affects the barrier island's vulnerability more seriously and more permanently. Damage can manifest itself as: dune scarping, whereby erosion occurs along the dune's stoss surface but the dune is not permeated; breaching, where an erosion-caused gap or reduction in amplitude allows for overwash; or obliteration, where the entire foredune is eroded, allowing for over-topping. A clear indication of a positional change in the foredune, caused by erosion, is the position of the seaward-most vegetation along the coast. Vegetation will take root and effectively stabilize a dune, while vegetation will not persist on the backshore in front of the dune. Consequently, mapping the spatial shift in the seaward-most vegetation provides a measure of geomorphologic change to the foredune. Maps showing the shift in vegetation position between 1994 and 2019 are provided and are interpreted.

Similarly, maps have been created showing the spatial shift in the shoreline's position over the same time interval. These provide a sense of beach aggradation and recession over time, though these data are less reliable. Each set of satellite imagery was taken potentially at a different time in the diurnal tidal cycle and during different seasons, reflecting tidal variability associated with neap/spring tidal cycles. This variability partially masks the width of the beach relative to NAVD88, the established vertical datum, making patterns difficult to interpret. These data are presented as a set of maps (Figs. 39-74), but they have not been interpreted for this report.

(4) *Sediment budgets for the foredune and beach between 2004 and 2015*. The beach profiles extracted from 5 of the DEMs (post Charley 2004, post Ivan 2004, 2006 [Captiva only], 2010, and 2015) were used to quantify sedimentary erosion and deposition for the following intervals of time: post-Charley 2004 to post-Ivan 2004, post-Ivan 2004 to 2006 (Captiva only), post-Ivan 2004 to 2010 (Sanibel only), 2006 to 2010 (Captiva only), and 2010 to 2015. The software package SANDS was used calculate sediment budgets (i.e., a quantification of sediment erosion or deposition over time) across these time frames. In order to identify spatiotemporal patterns, the length of the Captiva-Sanibel coast was divided into 10 sectors, with each sector combining 10 neighboring R-monuments, comprising 10,000 linear feet of beach. Sector 1 is located on the northern tip of Captiva, and sector 10 is located at the eastern end of Sanibel (Figs. 5-6). This dataset, coupled with the maps produced for item 3, reveals which portions of the Captiva-Sanibel coastline are most vulnerable to the effects of sea-level rise and storm-related erosion.

(5) *Vulnerability maps*. The information acquired for the 2 previous datasets are synthesized through the production of vulnerability maps. Each vulnerability map color codes the magnitude of erosion or deposition for a given interval of time experienced between each neighboring pair of R-monuments. Regions color coded a deep red have experienced extensive erosion; those coded a deep green, extensive deposition; and yellow represents minimal net change. Shades of red represent various degrees of erosion; shades of green represent variation in deposition. This imagery identifies the critical erosion hotspots and their spatial and temporal variability, allowing for the anticipation of needed future management strategies to improve resilience.

Results & Discussion

*<u>Digital Elevation Models.</u>—*DEMs are displayed for 6 time frames (1998, post Charley 2004, post Ivan 2004, post Wilma 2006, 2010, and 2015) in Figures 7 - 22. The quality of these DEMs is high for all but 1998. The LiDAR technology that existed in 1998 was considerably less sophisticated. Consequently, the beach profiles extracted from the 1998 DEM should be viewed with greater suspicion.

Most informative is the elevation changes when DEMs are compared. Figures 23 - 25 show those elevation differences for 2010 to 2015. The LiDAR flown in 2010 did not extend far enough offshore of South Sanibel to provide extensive bathymetry for this portion of the island. Consequently, the map of elevation difference between 2010 and 2015 for South Sanibel (Fig. 25) is limited principally to the subaerial portions of the island. Captiva Island (Fig. 23) shows a significant increase in water depth just offshore (the regions noted in orange and red), with bathymetry dropping as much as 3 meters. The loss of sediment and increased water depth gets progressively more extensive moving south along the island's length. These losses may reflect a loss in sediment available for future natural renourishment. This pattern continues as you move to North Sanibel (Fig. 24), with substantial drops in bathymetry between monuments R-109 and R-115. Unlike Captiva, this northernmost portion of Sanibel has a nearshore shoal (shown in green) storing a significant volume of sediment. South and east of R-115 nearshore shoaling is absent, while lesser increases in offshore depth persist. Not much can be inferred for South Sanibel between R-129 and R-150 because of the limited LiDAR data (Fig.25). Beyond this eastward, between R-151 and R-167, shoaling occurs offshore, while beach erosion (shown as a strip of orange just seaward of the monuments) occurred on shore.

Beach Profiles.—Beach profiles, and the associated sediment budget data from our SANDS analysis (see next subsection), provide insights as to the location of erosional hotspots and depositional cold spots. The former should inform management strategies designed to improve resilience; the latter represent areas that are naturally more resilient. Rather than exhibiting beach profiles for every R-monument, exemplars have been selected to showcase those areas that are either at greatest risk, of greatest stability, or exhibit some unusual storm effect. At least one profile representing each of the 10 sectors is featured in this analysis. Each figure (Figs. 26 - 38) contains superimposed profiles extracted from each of the DEM years, beginning in 1998 and ending in 2015. This allows for easy visualization of change over time.

Sector 1: The profiles for R-088 (Fig. 26), located near the northern terminus of Captiva Island, show great fluctuation between erosion and deposition over the 20-year study interval. This northern region of Captiva experienced extensive erosion from 1998 to post-Ivan 2004. This change is presumably credited to the impact of Hurricanes Charley and Ivan in 2004. Much of this erosion, fortunately, occurred seaward of the foredune; the position and height of the foredune show little change over this time interval. Since post-Ivan 2004 and up through 2015, the beach has rebuilt itself to and beyond the geomorphology exhibited in 1998. The foredune crest exhibits a slight rise in amplitude since Hurricane Ivan. These two observations indicate this region of Captiva has been dynamic and unduly influenced by major storms, but naturally resilient for the conditions it has recently experienced.

Sector 2: R-098, located at the mid-point of Captiva Island's length (Fig. 27), reflects similar behavior to R-088. The profiles for post-Charley and post-Ivan in 2004 exhibit erosion out in front of the foredune since 1998. Similarly, the beach has regained its elevation through deposition by 2006, and remained relatively stable since then. The position of the foredune crest appears to have receded landward between 2006 and 2015. This, however, contradicts results from the change in position of seaward-most vegetation through this same time period, which shows a continual progradation of the vegetation line (see below). We have greater faith in the vegetation line data and suspect the position of the foredune crest is inaccurately placed through the DEM extraction. This middle region of Captiva has also exhibited natural resilience through the 20-year study period.

Sector 3: R-108 sits near the southern terminus of Captiva Island, just north of Blind Pass (Fig. 28). Hurricanes Charley and Ivan appear to have had little influence on the beach profile; the shape and elevation differences among the 1998, post-Charley 2004, and post-Ivan 2004 are insignificant. Between post-Ivan 2004 and 2006, this region accreted to a morphology well beyond what existed in 1998. The region has exhibited minor erosion from 2006 through 2015, but, nonetheless, is reasonably resilient.

The "Santiva" area, located just south of Blind Pass on the northern end of Sanibel, is a region of chronic erosion, and perhaps the most serious erosional hotspot for the two islands. The profiles for R-110 and R-111 (Figs. 29-30) exhibit extensive erosion due to Hurricane Charley, shown be the comparison of the 1998 and post-Charley 2004 profiles, and, after some renewed deposition up through 2006, additional erosion between 2006 and 2015. The 2015 profiles show the region mostly below NAVD88 and intertidal.

Sector 4: The pattern at Santiva persists spatially to the south and east to monument R-114 (Fig. 31). This entire area has received much management attention over recent years by the City, and will presumably become even more highly vulnerable as sea-level rises and storminess increases.

Sector 5: The region south and east of Santiva, exemplified by the profiles at R-126 (Fig. 32), is considerably different than the region to its northwest. This is an area where a dune-ridge strandplain has been prograding seaward since 1998. The profile for R-126 for 2015 shows 5 dune ridges, with the active foredune of incipient height located at the 150 m position on the transect. The 2010 profile has 4 dune ridges with the active foredune at 125 m. Finally, the post-Ivan 2004 profile has only 3 dune ridges with the active foredune located at 100 m. Since post-Ivan 2004, this portion of Sanibel has added 2 dune ridges, extending the strandplain 50 m seaward. This pattern of strandplain development can be traced back, though with less clarity, to 1998. While the Santiva region is most vulnerable, this region of Sanibel is the most resilient.

Sector 6: The strandplain thins moving southeast nearing R-130 and the profiles show a pattern change. It's difficult to assess the effects of Hurricane Charley on the profile at R-130 (Fig. 33), because the length of the 1998 profile, against which the comparison could be made, is terribly short. Nonetheless, the post-Charley 2004 and post-Ivan 2004 profiles are similar and are geomorphologically consistent with a storm-eroded topography. Significant deposition occurs between 2004 and 2010, with slight erosion up to 2015. The profiles at R-134 (Fig. 34), in the same general region, are comparable. Here, however, the 1998 to post-Charley 2004 erosion is obvious. The profile then accretes with deposition to 2010 and again to 2015. This region is reasonably resilient.

Sector 7: R-144 is located just west of the southernmost coastal location on Sanibel, near to the island's inflection point (Fig. 35). The profiles here exhibit an interplay of erosion and deposition over time, defining the region as another vulnerable hotspot. Erosion occurred between 1998 and the two 2004 hurricanes. Renourishment occurred between post-Ivan 2004 and 2010, but significant erosion occurred up through 2015.

Sector 8: R-154's profiles (Fig. 36) typify this as a region of deposition and resilience. The effects of 2004 hurricanes are not evident, in part because the profile from 1998 is short. However, net deposition has occurred between 2004 and 2010 and again between 2010 and 2015.

Sector 9: The profiles at R-162 (Fig. 37) denote relative stability over the 20-year study period. Some 2004 hurricane erosion is evident, but deposition occurred up to 2010 and this has been maintained through 2015. This location typifies the sector as being relatively resilient.

Sector 10: Beach stability continues eastward into sector 10. R-171's profiles exhibit great consistency over the 5 time frames (Fig. 38). Not much impact is seen from the 2004 hurricanes, and the profile shape from 2015 is comparable to both the 2010 and post-Ivan 2004 profiles. A well-developed strandplain exists along this stretch of coast, creating an appreciable width to the dune field and beach, presumably imposing greater resilience to this sector. The profiles show the addition of new foredune ridges, with one added between 1998 and 2010 and at least one other between 2010 and 2015. Overall, this stretch exhibits accretion and strandplain development, decreasing its vulnerability to future effects. The strandplain thins and disappears by monument R-173, as the east terminus of the island is approached.

Seaward Vegetation Line.—The position of the seaward-most vegetation serves as a proxy for the position of the foredune at that point in time. Monitoring the movement of this line tracks the erosion and progradation of the foredune. Consequently, these data are critical to understanding coastal resilience – a stable or prograding dune field decreases vulnerability. Google Earth historic imagery begins in April, 1994 and ends in January, 2019.

Sector 1: For most of the sector, the most recessed vegetation line existed in 1994 (Figs. 75-79). The foredune field has prograded considerably since then with the most seaward position in either 2016 or 2019. This corresponds to a dune field widening of as much as 20 m. There was, however, a setback in the vegetation line of ~ 10 m because of the 2004 hurricanes (comparing 2002 and post-Ivan, 2004). The strandplain appears to be healthy and resilient along this region of Captiva.

Sector 2: The pattern of vegetative line movement is similar in this sector to that seen in sector 1 (Figs. 79-83). The foredune recessed the furthest in 1994, and has exhibited net progradation through the subsequent 25 years. Here, however, the seaward-most position occurred in 2002, before the 2004 hurricanes, representing a ~ 35 m progradation since 1994. The current position is slightly landward, having been setback ~ 8 m to 2019. A significant setback of up to 30 m occurred due to the 2004 hurricanes. Overall, the strandplain here, though relatively narrow, is healthy and progradational.

Sector 3: The 1994 Google Earth image is not available for this sector; January, 1999 is the oldest image available. Between 1999 and 2002, the foredune prograded ~ 22 m to what is the seaward-most position for the 20-year history (Figs. 84-88). The vegetation line was then eroded back by ~ 25 m by the effects of the 2004 hurricanes. Since post-Ivan, 2004, the vegetation line has been either stable in its position or prograded slightly by up to 10 m to its present 2019 position. The accretion of the strandplain is occurring, but not of comparable magnitude as seen in the two previous sectors.

Southern Sector 3 and Northern Sector 4: The southern 400 m of sector 3 and the northern portion of sector 4 encompass Blind Pass and Santiva on the northern tip of Sanibel Island (Figs. 87-88). This region has exhibited the greatest erosion and coastal setback for both islands. It has also been highly dynamic over the 25-year history. The recession of the vegetation line has been considerable, moving eastward by as much as 75 m from its most seaward position in 2002 to its current and most landward position in 2019. At least half this lost width in currently subtidal. Between 1995 and 2002, the vegetation line did prograde westward considerably by almost the same 75 m distance, and was then eroded back by the 2004 hurricanes. Clearly, this is the most critical region of concern for both islands, and one requiring careful management.

Sector 4: The central and southern portions of sector 4 are also highly dynamic and net erosional, but not as extreme as in Santiva (Figs. 88-92). Here the seaward-most position of the vegetation line occurred in 1995, and there has been ~ 85 m of net recession to 2019. The bulk of that setback occurred between 2002 and post-Ivan 2004. These results are consistent with those from the beach profiling and confirm the highly vulnerable state of this stretch of coast.

Sector 5: This sector circumscribes the progradational strandplain described in the beach profile section. The evolution of the vegetation line well documents that progradational nature (Figs. 93-96), with the landward-most position occurring in 1995 and the seaward-most position occurring in 2019, a distance of ~ 80 m. There is some setback and recovery during and after the 2004 hurricanes. This is the most highly resilient and least vulnerable stretch of coastline for the two islands.

Sector 6: The strandplain thins eastward into sector 6. The behavior of the vegetation line differs from what is seen in sector 5 (Figs. 97-99). The landward-most position occurs in 2006, and the seaward-most position is in 2002, defining a recession of ~ 30 m. Since 2006, the vegetation line has prograded gradually to its 2019 position, moving seaward ~ 15 m. Consistent with the beach profile data, this sector's foredune evolution suggests it is reasonably resilient.

Sector 7: This sector shows sign of vulnerability, as seen in the profile data, with regard to the behavior of the vegetation line (Figs. 100-103). The seaward-most position of that line occurred in 2010, and the landward-most position occurs currently in 2019, representing a net setback of ~ 40 m. The 2010 position is currently subtidal. The bulk of that setback occurred between 2002 and the 2004 hurricanes. Nonetheless, in relatively storm-free conditions (2004-2016), recession of the vegetation line continued. This is considered a highly vulnerable, erosional hotspot for Sanibel.

Sector 8: As the southern-most point on Sanibel's beaches is rounded toward the east, the beach and strandplain widens (Figs. 103-107). Consequently, sector 8 undergoes a transition in coastal resilience. In the vicinity of R-154, a number of dune ridges are observed. Here the landward-most vegetation line occurs in 1995, with the seaward-most line occurring today in 2019. This represents a net progradation of ~ 30 m. As elsewhere, the 2004 hurricanes resulted in a setback of ~ 15 m. The widening of the strandplain, as exemplified by the progradation of the vegetation line, indicates this is a resilient stretch of coastline.

Sector 9: The 1995 Google Earth image does not cover this portion of Sanibel. Consequently, the oldest glimpse of sector 9 is from 1999. The landward-most position of the vegetation line in this sector occurs in 1999, and the seaward-most position is in 2019. This defines a net progradation distance of ~ 35 m (Figs. 107-110). Between post-Ivan 2004 and 2010, the position is dynamic, moving slightly seaward and landward. Since 2010, the position progrades to its current position. The growth of the strandplain, as indicated by the shift in the vegetation line, indicates this is also a resilient portion of the coastline.

Sector 10: The pattern of vegetation line change is similar here to sector 9. 1999 is the time of the landward-most position (the 1995 image is absent from here as well); the seaward-most position occurs today, in 2019, representing a net progradation of ~ 25 m (Figs. 111-113). The strandplain has added ridges over time. This, in conjunction with the seaward net movement of the vegetation line, suggests this sector is also resilient.

Sediment Budgets & Vulnerability Maps.—Sediment budget data are presented herein just for the interval of time between 2010 and 2015. (2015 is the last date for which a LiDAR-based DEM can be acquired.) Sediment budget data were also obtained for 4 other time intervals (post-Charley, 2004 – post-Ivan, 2004 [Sanibel & Captiva]; post-Ivan, 2004 – 2006 [Captiva only]; post-Ivan, 2004 – 2010 [Sanibel only]; and 2006 – 2010 [Captiva only]), but will not be considered in this analysis. Values displayed in the bar graph (Fig. 114) reflect total sediment loss or gain for the entire sector between 2010 and 2015, while the color coding seen on the vulnerability maps (Figs. 115-117) reflects sediment loss or gain for each monument location within a sector.

These results provide a somewhat different perspective on vulnerability and resilience when compared with the vegetation line analysis. A foredune or a dune ridge strandplain may remain stable or prograde over time, while erosion on the beach, in front of the foredune, may result is the net loss of sediment for the entire profile.

Captiva, in sectors 1 and 2 (R-084 – R-102), exhibits slight net erosion or slight deposition for this time interval (Fig. 115). The vulnerability map shows a range of values for individual monuments from -3500 m^3, at the northern tip, to +3250 m^3 near R-093. Sector 3 (R-102 – R-111), which crosses Blind Pass to the northern tip of Sanibel, experienced a net loss of -36,000 m^3 of sediment. Much of that loss was located just south of the pass at Santiva. Discounting the extensive erosion adjacent to Blind Pass, the length of Captiva has had a relatively stable sediment budget. There is limited strandplain development along Captiva, but considerably less than what is seen on portions of Sanibel. This may be explained by the paucity of available sediment.

Western-most Sanibel, at sector 4 (R-111 – R-120; Santiva area), experienced net erosion with a total sediment loss of -17,000 m^3. The loss is concentrated north of R-115, with the southern portion of the sector showing net deposition. All metrics indicate that the Santiva area (sectors 3 and 4) is highly vulnerable to coastal erosion.

Just south of Santiva, in sector 5 (R-120 – R-129), the opposite is true. This region experienced the largest volume of deposition for the entire study area, with a gain of +58,000 m^3 of sediment. This, when coupled with the other metrics, defines sector 5 as the most resilient and least vulnerable stretch of coastline. The strandplain continues, though thins, into sector 6 (R-129 – R-138). Here net deposition also occurred between 2010 and 2015, but at a much smaller magnitude: +16,500 m^3 of sediment. The sediment budget values for this sector are consistent with an interpretation of relative resilience from the other data.

Sectors 7 and 8 on Sanibel (R-138 – R-147 and R-147 – R-156, respectively) are located around the southern elbow of the island. Sector 7 experienced considerable erosion, with a net loss of -20,000 m^3 of sediment, the second largest loss among the 10 sectors. Sector 8 experienced inconsequential erosion of -2,200 m^3 of sediment. Sector 7, after sector 3, is the second most vulnerable region for all data metrics, while sector 8 is relatively resilient.

The eastern end of Sanibel, at sectors 9 and 10 (R-156 – R-165, and R-165 – R-174), has experienced net sediment loss: -18,600 m^3 and -8,800 m^3, respectively. Despite this sediment loss and its indication of vulnerability, the progradational shift in position of the vegetative line through time suggests better resilience. This may be a situation where erosion has occurred seaward of the foredune, while the foredune and strandplain have remained unaffected.

Conclusions

This project has provided the greater Sanibel-Captiva community 2 foundational pieces on its journey to the completion of a vulnerability analysis of the future effects of climate change, most influentially by the impact of sea-level rise (SLR) and increased storminess. The community (government and the public) are now informed about the potential effects of future SLR and storminess, and appreciate the importance of assessing the islands' vulnerability and eventual adaptation and mitigation planning. The effort to compose sector-focused teams and then engage team members in the processes of defining the problem (i.e., the opportunity to express their sector's concerns) and identifying assets engages residents, provides a sense of stewardship, values their contributions, and, most significantly, provides genuine guidance to government for planning.

Despite these successes in community involvement, we recommend that community education and engagement in analysis and planning continue. Though our efforts were effective, the population of the islands and its ephemeral character make it difficult to inform and engage everyone, and a six-month duration project does not provide sufficient opportunity to reach every individual.

Of greatest influence on Sanibel-Captiva's vulnerability and resilience to climate change's effects is the character of the outer coast. Sanibel-Captiva's beaches, foredunes, and strandplains serve as sentinels by attenuating tidal surge and wave energy, thereby protecting the landscape behind them. This project has provided an assessment of the outer coast's geomorphology and history of recent change, essential foundational data for any future effort to model the landscape's vulnerability to inundation and erosion.

We recommend that a concerted effort be made to further Sanibel-Captiva's vulnerability analysis and relatively quickly. An inundation and geomorphological computer modeling effort is the next logical step. Modeling can be conducted in very sophisticated, and consequently more expensive, ways. It can also be accomplished more modestly and still yield valuable heuristic results. Avoiding a long hiatus between this and the next step will better ensure community focus and engagement.

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