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

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Executive Summary

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, social services and resources, 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 were analyzed. 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, revealed those regions of the Captiva and Sanibel coastline which are most vulnerable and most resilient to the impacts of SLR and storms. Those coastal regions founded upon strandplains (e.g., sectors 5 & 6, 8-10) 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 shoreline 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.

Table of Contents

Executive Summary *2*

Glossary of Terms *5*

Project Description *7*

Project Need and Benefit *8*

Objective I: Community Engagement *9*

Introduction & Methods **9**

Results & Discussion **10**

Objective II: Characterization of the Coastal Geomorphology and its Recent History of Change *27*

Introduction & Methods **27**

Results & Discussion **29**

Conclusions & Recommendations from Objective I *36*

Conclusions & Recommendations from Objective II *37*

Overall Summary *39*

Acknowledgments *40*

References Cited *40*

Figures *41*

Appendix I *155*

Appendix II *201*

Appendix III *247*

Glossary of Terms

Accretion: The process of coastal sediment returning to the visible portion of a beach or foreshore following a submersion event.

Aggradational: The deposition process in which depositional area fills with vertical stacking of sediment from the thick layer of water.

ArcMap: The main component of Esri's ArcGIS suite of geospatial processing programs, and is used primarily to view, edit, create, and analyze geospatial data.

ARCGIS: A geographic information system (GIS) for working with maps and geographic information. It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database.

Digital Elevation Models (DEMs): Digital elevation models (DEMs) are arrays of regularly spaced elevation values referenced horizontally either to a Universal Transverse Mercator (UTM) projection or to a geographic coordinate system.

ESRI: Environmental Systems Research Institute-is an international supplier of geographic information system (GIS) software, web GIS and geodatabase management applications.

Foredune: A part of a system of sand dunes on the side nearest to the sea.

Geomorphologic: Relating to the form of the landscape and other natural features of the earth's surface.

Geospatial layers: The mechanism used to display geographic datasets in ArcMap; each layer references a dataset and specifies how that dataset is portrayed using symbols and text labels.

Green infrastructure: A patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water.

Hardened shoreline: The installation of engineered-shore structures to stabilize sediment and prevent erosion and/or as well as provide flood protection.

King tides: The highest predicted high tide of the year at a coastal location.

Leeward: The side protected by the elevation of the island from the prevailing wind.

LiDAR: LIDAR, which stands for *Light Detection and Ranging,* is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth.

Living shoreline: A protected, stabilized coastal edge made of natural materials such as plants, sand, or rock

Progradation: Seaward growth of a beach, delta, fan, etc., by progressive deposition of sediment by rivers or shoreline processes.

Resilient: The ability of a community to "bounce back" after hazardous events such as hurricanes, coastal storms, and flooding – rather than simply reacting to impacts.

Renourishment: Beach nourishment (also referred to as beach renourishment, beach replenishment, or sand replenishment) describes a process by which sediment, usually sand, lost through longshore drift or erosion is replaced from other sources

Strandplain: A broad belt of sand along a shoreline with a surface exhibiting well-defined parallel or semi-parallel sand ridges separated by shallow swales.

Vulnerability: Refers to the share of the historical and current barrier island population located in areas at risk from forecasted sea level rise over the coming decades

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 Sanibel and Captiva Islands, but could also serve as stimulus to pursue similar activity across the entire region.

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 shoreline 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 2019). 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 local governments 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 & Methods

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 began with the development of an outreach strategy, which included: (1) presenting and discussing the project with Sanibel's City Council; (2) identifying teams and leaders of community stakeholders; (3) scheduling a public forum about the nature of climate-change preparedness and the purpose of this project; (4) creating a web page to serve as an information resource; and (5) actively engaging members of Sanibel-Captiva's community in the preparation process. This last element created a sense of stewardship for the project. 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 and middle 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 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; 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, Peter Corcoran
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?

- 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 resilient 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 at 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 resilient 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 style of life 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 of permanent residents. Homes listings are going 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. Reductions 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 homeowners' 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 homeowners 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 members' 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.
- Concerns that development and infrastructure utilized to adapt to sea level rise will impact existing wildlife habit on Sanibel. 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 it is anticipated that 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.
- There is little effort or curriculum dedicated to climate and climate-change education in K-12 public school. Similarly, coverage in higher education is very limited. This need should be filled. Additionally, science education rarely makes connections to societal practices (e.g., adaptation and mitigation). Climate education, when considered in schools, should make this connection.
- It's difficult for lower income workers (i.e., minimum wage workers), which principally fulfill the islands' service economy, 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.
- In many instances, parishioners that are well-informed about climate change express fear, even despair and grief. Those not expressing concern typically carry misunderstandings about the effects of climate change and the seriousness of the crisis.

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 store 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.
- One team member, as a small consulting business owner, has made a conscious decision to not purchase property on the barrier islands because of predicted climate-change effects.
- 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 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 be disclosed to potential buyers. A company called Core Logic is developing this.
- Though homeowners' 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 in 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 considered in emergency management planning efforts. The Sanibel Island Wide Beach Management Plan includes language on potential impacts of sea level rise and living shoreline projects may help mitigate the impacts of sea level rise.
- A project has been completed in the Dunes Community to adjust the control elevation of the weir, which controls water leaving the stormwater system. The weir control elevations have been adjusted by installing a one-way flow gate because of higher tide overtopping the weir, which have been exacerbated by sea level rise. The Tarpon Bay and Beach Road weirs have not yet been redesigned for sea level rise but may need to be modified or redesigned in the future.
- 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 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 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 / Captiva was 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 impacted 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-caused 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.
- "Surely, the dramatic effects of recent climate events affect the education sector, albeit slowly. I believe they affect awareness, consciousness, and concern more than they influence effective action-taking."
- 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 because of 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 already experience chronic or nuisance flooding.
- The island experiences localized street flooding during heavy precipitation events. Periodic loss of power and cell service are 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.
- "The education sector is affected to some extent by the current effects of climate change, but there is a lack of a sense of urgency—as if the effects will be in the distant future."

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

- At what point do business or homeowners 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."
- "I hope so! A problem is that formal education is fundamentally conservative. Changes in curriculum tend to be slow in coming. I used to think that as the situation became more difficult, changes in content would be made, but this does not seem to be the case."

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.
- "Yes, indeed. Educational processes will be critical to any cultural, social, political, or economic change. There are important new opportunities related to school and higher education learning, including in-service professional development for teachers and professors. There are also educational opportunities for specific audiences such as policymakers, businesspeople, and religious leaders."

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.

Barriers and Concerns

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 island's 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 educational gap is made more pronounced because of the very limited climate and climate-change curriculum in K-12 public schools. Students get little exposure to climate science, let alone a foundational understanding of climate change. Similarly, coverage in higher education is limited. Only those students typically enrolled in earth science-related courses are informed. Additionally, if the science is covered, rarely is the science connected to societal practices (e.g., for adaptation and mitigation).

At least one member of the Social Resources team, someone affiliated with a house of worship, noted that parishioners that are well informed about climate change effects often express fear, even despair and grief. Those not expressing concern typically carry misunderstandings about the effects of climate change and the seriousness of the crisis.

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, less resilient infrastructure can lead to a longer recovery 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 other 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.

Decision Making Already Influenced by Climate Change

Many of the participants involved expressed their opinions on the city's building codes and coastal development restrictions. While some claimed that government recognizes the need for improvement and should better reflect climate change's effects, potentially making them more stringent, others thought codes should be more accommodating for business and home ownership. Businesses have also taken an initiative to change the way they operate to minimize future damage. For instance, the Island Water Association has undertaken a "lightning study" in order to determine how the corporation might better avoid costly future repairs on stricken utility poles. Roof ratings, window requirements, and elevation minima have all been changed as a result of the changing climate. The effects addressed by these changes, however, concern immediate, short-term impacts and have yet to focus on the resiliency to longer-term effects.

Most groups voiced the same argument: adaptation planning must consider long-term goals, in addition to incorporating short-term fixes. Some team members view beach renourishment efforts as short-sited quick fixes. Alternatively, the 'living shoreline' projects are more forethoughtful efforts that address the immediate needs of coastal erosion, while also sustaining long-term effects by providing habitat and green infrastructure. These projects are great first steps in assessing future problems. Recent efforts to combat harmful algal blooms exemplify the problem. Efforts have focused upon the immediate impacts, rather than on longer-term mitigation. Team members recognize, however, that harmful algal blooms are complex, geographically widespread problems whose solution requires efforts far beyond the Sanibel-Captiva community.

There was much conversation about the longer-term resilience of Sanibel-Captiva's storm water system. The weir system will require a major redesign to adjust to sea-level rise and increased precipitation. Forethoughtful planning and financial investment will be needed here.

The risk of businesses shutting down for extended periods (after Hurricane Irma, for example) has changed behaviors among business owners. Many businesses have adjusted their budgets to maintain greater capital to serve as "crises funds", money needed to withstand the

loss of revenue during a recovery period. A number of team members noted they purchased generators to withstand power outages to preserve merchandise or to maintain communication with their customers.

Difficult decisions are being made about maintaining insurance after a severe climatic event. After Irma, the insurance rate increases forced some businesses and social services to become self-insured. Many others are struggling with the increased costs. Customers expressed their interests in insurance companies providing new incentives to lower rates, making resilient structures more obtainable. Nonetheless, rebuilding homes to garner insurance savings is still too expensive for most homeowners to pursue. It was noted, again in this context, that resiliency management favors the wealthy. Improving design resilience is perhaps more likely for large-scale, redevelopment efforts. One member of the Business Community team, as a small consulting business owner, has made a conscious decision to not purchase property on the barrier islands because of the burden of insurance costs.

All groups had opinions about their sector's climate change-effected decision-making process. Some are reserving more money in their 'crises funds', such as members of the Social Resources and Business Communities. Others, such as the Infrastructure Community, are trying to secure structures. The Natural Resource Community's members explained that some strategies in monitoring and managing marine and coastal wildlife have been considered. One participant from the group noted their dependency on workers and volunteers, noting that greater consideration is needed for worker safety when commuting to the island in the wake of a storm[1]. Finally, the Education Community detailed their plans to forego repairs and improvements on schools due to lower enrollment, suspecting climate change has caused demographic shifts in the island population.

Recent and Current Impacts from Climate Events

The main themes expressed in the answers to this survey question concerned the loss of income or increased costs associating with storm-related inundation or harmful algal blooms[2]. In their own unique ways, most community groups lost some form of business. Some examples include: the premature evacuation of the Island Water Association facilities, cancellation of rentals, loss in real-estate sales, and the costly rebuilding of Periwinkle Park. Harmful algal blooms resulted in some renters experiencing 100% cancellation rates. Other service-industry workers on the island experienced major losses in income and could not pay their bills. Some churches committed more dollars to charitable needs to help those more seriously impacted. Excess expenditures for some non-profits are still being felt in off-season months, where resources are particularly limited.

[1] After hurricane evacuation, the City of Sanibel regulates access to the island for safety and security purposes. Sanibel has established the Reentry Pass Program which issues reentry passes to residents, businesses, and workers before a disaster. This allows the City to screen residents and workers prior to a disaster rather than during it. This process helps streamline the reentry process.

[2] While harmful algal blooms cannot be solely attributed to climate change, there is emerging evidence that factors such as water temperature and stormwater runoff from urban and agricultural landscapes may exacerbate algal blooms such as cyanobacteria, red tide, and drift algae stranding events.

A second reoccurring response to this question was the experience of flooding, as both nuisance flooding from king tides, flooding from storm surge, and flooding from heavy rains. After Irma, many businesses and non-profits experienced flooding. In some parts, sites remained flooded for almost two weeks. This flooding prevented some disabled residents from seeking medical assistance and physical therapy. Flooding and winds from Irma also caused extensive harm to wildlife. The Center for the Rehabilitation of Wildlife saw an influx of injured animals after the storm. As for king tides, many remarked on their abilities to inundate low-lying neighborhoods, making streets impassable for cars or other forms of transportation. Some neighborhoods still experience chronic flooding with precipitation events. With the onslaught of nuisance flooding, the Development Community brought up an in-the-works concept of a "Flood Fax," requiring the disclosure of a home's flooding history to prospective buyers. Other instances of flooding were noted by the Infrastructure Community where saltwater intruded the storm water system, necessitating a greater volume of water requiring treatment.

Recent climate events improve climate-change awareness by exemplifying the impact of extreme storms, tides, and precipitation. The aftermath of Charley and Irma, for example, clearly focused residents' attention on the problem. One member of the School and Education group stated: "Surely, the dramatic effects of recent climate events affect the education sector, albeit slowly. I believe they affect awareness, consciousness, and concern more than they influence effective action-taking." Events should do more than just improve awareness; they should also spur conversation and action with regards to future resilience.

Future Opportunities and Diversification

As group members look forward, there is a sense that plans should be made to include and inform the public on future climate impacts. It was mentioned that new ordinances would benefit the community's preparedness. In addition, it was suggested during one team meeting that the island's mission statement should be altered to include the future resiliency efforts for the island. Additionally, information on SLR and resiliency could be incorporated into the City's "New Residents Packet" program where all new citizens to the island receive a welcome packet containing information about island life, programs and resources. The residents on Sanibel are very loyal to the community and to a sustainability ethic. This commitment and mindset predispose Sanibel-Captiva to successful adaptation and mitigation planning for resilience.

New monitoring techniques within the public works and natural resource sectors will benefit the community and its sustainability. The Sanibel Plan's modification to include the topics of sea-level rise and climate change would also assist the community in its resiliency planning. Finally, the value and use of nature and nature-based features to improve resilience is a worthy and logical method for the islands. The Natural Resources Group noted that living shorelines had worked to prevent erosion during Irma. Future preparations must incorporate the natural landscape, and not just urban settings.

The education sector has an opportunity, or perhaps an obligation, to develop practices that better inform the public. A member of the School and Education team stated: ". . . formal education is fundamentally conservative. Changes in curriculum tend to be slow in coming. I used to think that as the situation became more difficult, changes in content would be made, but this does not seem to be the case." The sector needs to be more proactive in delivering the

necessary curriculum both in formal and informal educational realms. That same team member further stated: "Educational processes will be critical to any cultural, social, political, or economic change. There are important new opportunities related to school and higher education learning, including in-service professional development for teachers and professors. There are also educational opportunities for specific audiences such as policymakers, businesspeople, and religious leaders."

Lastly, one opportunity noted from a number of teams is the need for each afflicted community to develop a sense of urgency. Climate-change effects, though seemingly a matter for the distant future, are here now. Without a greater sense of import and immediacy, the costs of resilience and mitigation will continue to rise.

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, drinking water 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 & Methods

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 a 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. LiDAR data were obtained from the NOAA data access viewer (https://coast.noaa.gov/dataviewer/). A terrain was created with a horizontal resolution of 2

meters and 5-levels of pyramid structure for optimal zooming using the 3D Analyst processing tool in ArcGIS. The terrain model was then transformed to a raster DEM. 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 Appendix I). Beach profiles were also generated from FL DEP data collected in 1974, 1982, and 1989, years prior to the advent of LiDAR and DEM technology. These profiles were surveyed manual while working in the field. Unfortunately, the data are not reliable enough to compare profiles between pre- and post-LiDAR years. The data, nonetheless, are included in Appendix II.

(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 (Figs. 75-110).

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. The maps were constructed by comparing data from the 2010 and 2015 DEMs.

Results & Discussion

*Digital Elevation Models. —*DEMs are displayed for six timeframes (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 1998 DEMs and the beach profiles extracted from them should be viewed with 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. A complete collection of profiles for each R-monument for the post-LiDAR years is in Appendix I and for the pre-LiDAR years in Appendix II.

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 and immature foredune 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 is 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. Accretion 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 five timeframes (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 is 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 2006. 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. 92-94), 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. 95-98). 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. 98-101). The seaward-most position of that line occurred in 2002, and the landward-most position occurs currently in 2006, representing a net setback of ~ 40 m. The 2002 position is currently subtidal. The bulk of that setback occurred between 2002 and the 2004 hurricanes. Nonetheless, in relatively storm-free conditions (2006-2016), the receded vegetation line persisted in the same general vicinity. 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. 101-104). 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. 104-107). 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. 107-110). 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. (All data are provided in Appendix III.) Values displayed in the bar graph (Fig. 111) reflect total sediment loss or gain for the entire sector between 2010 and 2015, while the color coding seen on the vulnerability maps (Figs. 112-114) reflects sediment loss or gain for each monument location within a sector. Appendix III contains the tables with the sediment budget details for each 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. 112). The vulnerability map shows a range of values for individual monuments from -2500 m^3, at the northern tip (Table 1, Appendix III), to +3250 m^3 near R-094 (Table 2, Appendix III). 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 (Table 3, Appendix III). 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 (Table 4, Appendix III). 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 (Table 5, Appendix III). 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 (Table 6, Appendix III). 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 (Table 7, Appendix III), the second largest loss among the 10 sectors. Sector 8 experienced inconsequential erosion of -2,200 m^3 of sediment (Table 8, Appendix III). 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 (Tables 9 & 10, Appendix III). 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 & Recommendations from Objective I

The following 8 recommendations are distilled from the engagement with the 8 teams:

(1) The need to improve the awareness of the islands' citizenry and engaging residents in meaningful discussion is the most commonly voiced concern from the citizen team members. We suggest that a forum / discussion series be designed and implemented for the public. The series would contain a collection of public presentations and discussions, implemented across one or more tourism seasons, whose purpose is to engage, inform, and enlist opinion in climate-change science, the current and anticipated future effects on the islands, and how to best plan for adaptation and mitigation. We envision a cooperative effort that would be organized and sponsored by City government, local civic groups, and Florida Gulf Coast University.

(2) Awareness could also be improved by affecting children's education. The teaching of climate science and climate change happens sporadically, at best, in Florida public schools. However, the Florida State STEM curricular standards do prescribe entry points to engage climate in standard science courses. Perhaps STEM educators at the middle school levels at the Sanibel School and teachers at the Sanibel Sea School would be willing and interested in the development and implementation of course modules. FGCU currently has two faculty members (in the Departments of Marine & Earth Science and Ecology & Environmental Studies) with experience in the development of climate-based STEM teaching lessons and would be willing to assist.

(3) Resources should be developed to inform residents and visitors of the environmental risks associated with barrier island life in the context of sea-level rise and increased storminess; this information could be included in the City's "New Resident Packets" which are distributed to all new residents of the City of Sanibel. These resources, however, should be forthcoming, but not designed to instill a sense of fear and hopelessness for Sanibel and Captiva's future. Though a complete vulnerability study has yet to be undertaken, the preliminary assessment conducted in this project reveals that Sanibel-Captiva's resilience is reasonably high, and the islands, barring the impact of a number of severe hurricanes, should remain environmentally and economically sustainable for 2 or 3 decades. Consequently, proactive conversations about risk and preparedness should not ill-influence business and real estate.

(4) The entire community living or working on Sanibel-Captiva should be engaged and considered when any activity concerning climate-change preparedness is undertaken. There is considerable concern for the lower income, service employees that commute to Sanibel-Captiva and cannot afford the expense of living on the islands. Their needs and concerns must also be addressed. There is only a single ingress/egress point to the islands owned and maintained by Lee County, therefore the county should also be engaged in this process. Sanibel and Captiva are considered large economic drivers for Lee County both as tourist destinations and employers of county residents making this roadway a vital link both physically and economically to the barrier islands.

(5) A dedicated effort should be made to assist business owners, public works managers, and property managers in the development of measures and practices to minimize down time after a major environmental event (e.g., hurricane, extreme tide, harmful algal bloom). In effect, a "post-event resiliency plan", even in advance of a complete vulnerability study, is needed and would be advantageous.
(6) The City has been proactive in the use of green infrastructure to improve resilience. The use of natural features for resilience is also consistent with the community's environmental ethic. This effort should continue to be fostered on both private and public lands.
(7) The 8 teams of citizens generated a list of approximately 100 assets, features, structures, and services on the Sanibel-Captiva landscape of value to the community, and elements whose vulnerability should be investigated. This process was very informative and engaging. We recommend that the asset identification and mapping effort, started here, be furthered and continue to engage the public. Additional assets such as flood prone and/or vulnerable developments/neighborhoods should be added to these asset lists
(8) Most importantly, Sanibel-Captiva should move forward on a complete vulnerability assessment, one that, at the very least, employs computer modeling to predict tidal nuisance flooding, marine water inundation associated with sea-level rise and storm surge, and explores the geomorphologic response of the Gulf-side beaches, dunes, and strandplains. It would also be prudent for the City to engage the surrounding communities regarding this modeling effort. Identifying other communities at risk and incorporating them in modeling would provide a more complete picture of storm, storm surge, sunny day flooding, etc. behavior. Additionally, the City should begin to budget money or at least seek alternative funding sources for these modeling efforts, hence another reason to bring neighboring communities into the fold on this effort.

Conclusions & Recommendations from Objective II

The geomorphologic analysis of the Gulf coast has yielded the following generalizations:

(1) The Gulf-side beaches running the length of Sanibel and Captiva Islands are highly dynamic, yet, with the exception of two erosional hotspots (sectors 3 & 4 [Santiva], 7), they are highly stable over the long term. Excluding the hotspots, the foredunes, outside of the above-mentioned areas, have been resilient and have remained largely undamaged by storm or tidal erosion, or they have naturally repaired themselves. (Damage to the foredune predisposes the landscape behind it to inundation and further erosion.)
(2) Portions of Sanibel and Captiva (within sectors 2 & northern portion of 3, 5 & 6, 8-10) are fortified by the development of strandplains (i.e., former dune ridges that prograde seaward over time and increase the width of the island). The time series analysis (from the seaward-most vegetation data) documents this progradation over the islands' recent history. The sectors of the islands that lack strandplains are less resilient and show greater disposition to net erosion in the future.

(3) The strandplain in sector 6 (particularly between R-monuments 134-138) has some of the highest elevations on Sanibel, with an interior dune ridge sitting 3+ meters above sea level. The combined effect of a wide strandplain and high elevation provides greater resilience.
(4) The greater vulnerability to sea-level rise and storm inundation will likely be located on the backside of the islands, where elevations are lower and fortifying dunes are absent. Here, fortunately for most of the islands' length, expansive green infrastructure exists with the distribution of intertidal mangrove wetlands. Mangrove forest serves to attenuate tidal surge and wave and wind energy, reducing the lateral extent and depth of inundation.
(5) The modeling of inundation caused by sea-level rise, tides, and storms will provide insights for vulnerability, particularly coming from the landward side of the islands. Computer modeling of the geomorphologic response of the beaches, dunes, and strandplains will help assess the future vulnerability and resilience of the Gulf-ward exposed coast.

Overall Summary

This project has provided the greater Sanibel-Captiva community two foundational pieces on its journey to the completion of a vulnerability analysis of the future effects of sea-level rise (SLR) and increased storminess. The community (government and the public) are now better informed about the potential effects of climate change and appreciate the importance of assessing the islands' vulnerability and eventual adaptation and mitigation planning. The effort to compose sector-focused teams and then involve team members in the process 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.

The behavior and vulnerability of the islands' backsides to SLR, and to tidal and storm surge must be considered, something that inundation modeling can explore.

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.

Acknowledgments

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Figures

Figure 1. Google Earth map showing Captiva and Sanibel Islands, the study area for this project.

Figure 2. Google Earth map for Captiva Island.

Figure 3. Google Earth map for Sanibel Island.

Figure 4. Google Earth map showing the location of Coastal Range Monuments (R-Monuments) on Captiva and Sanibel Islands. Monuments are numbered R-084, in the north, to R-174, in the southeast.

Figure 5. Google Earth map of Captiva Island showing the location of its Coastal Range Monuments (R-Monuments) and its 3 sectors.

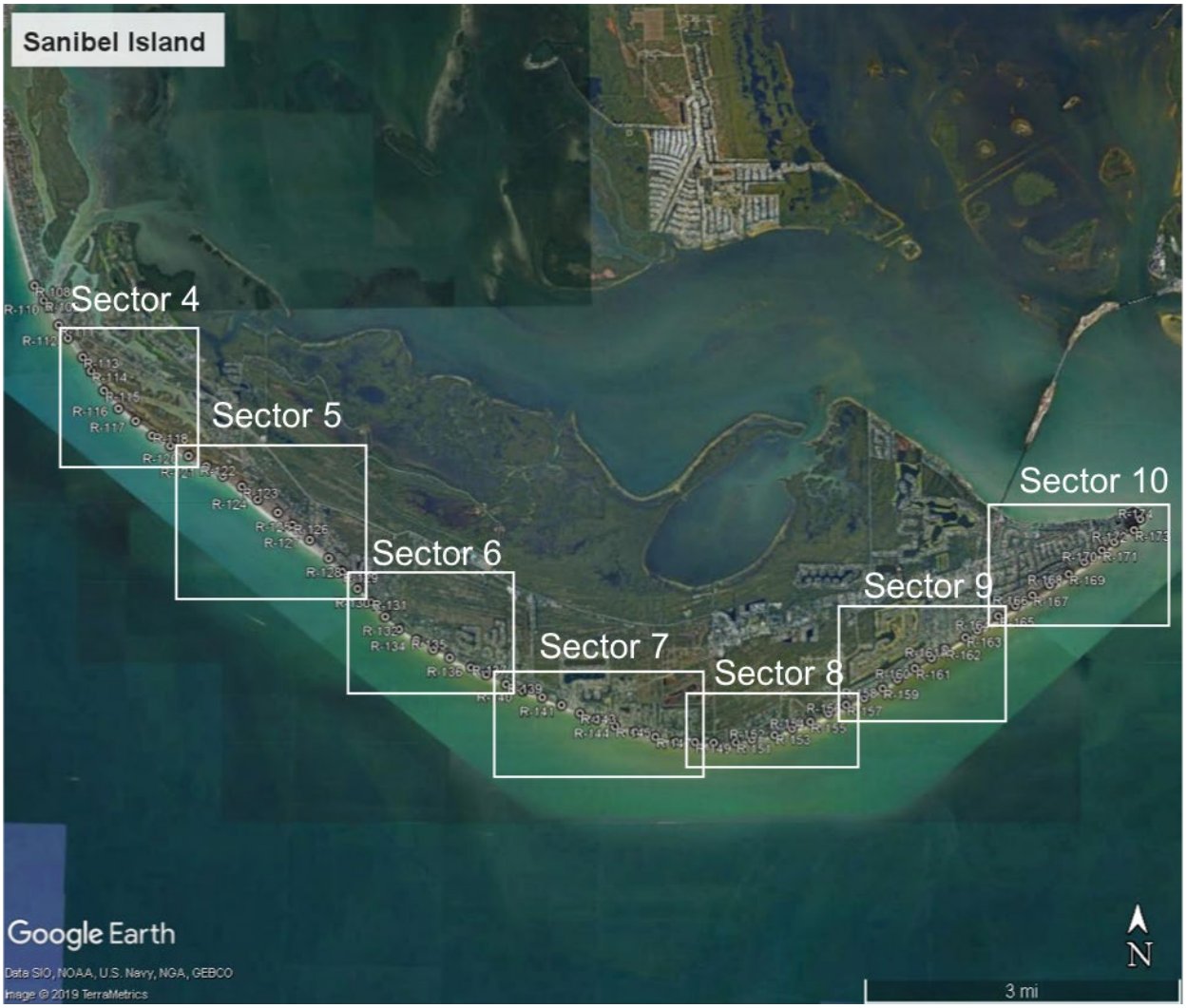


Figure 6. Google Earth map showing Sanibel Island's Coastal Range Monuments (R-Monuments) and its 7 sectors.

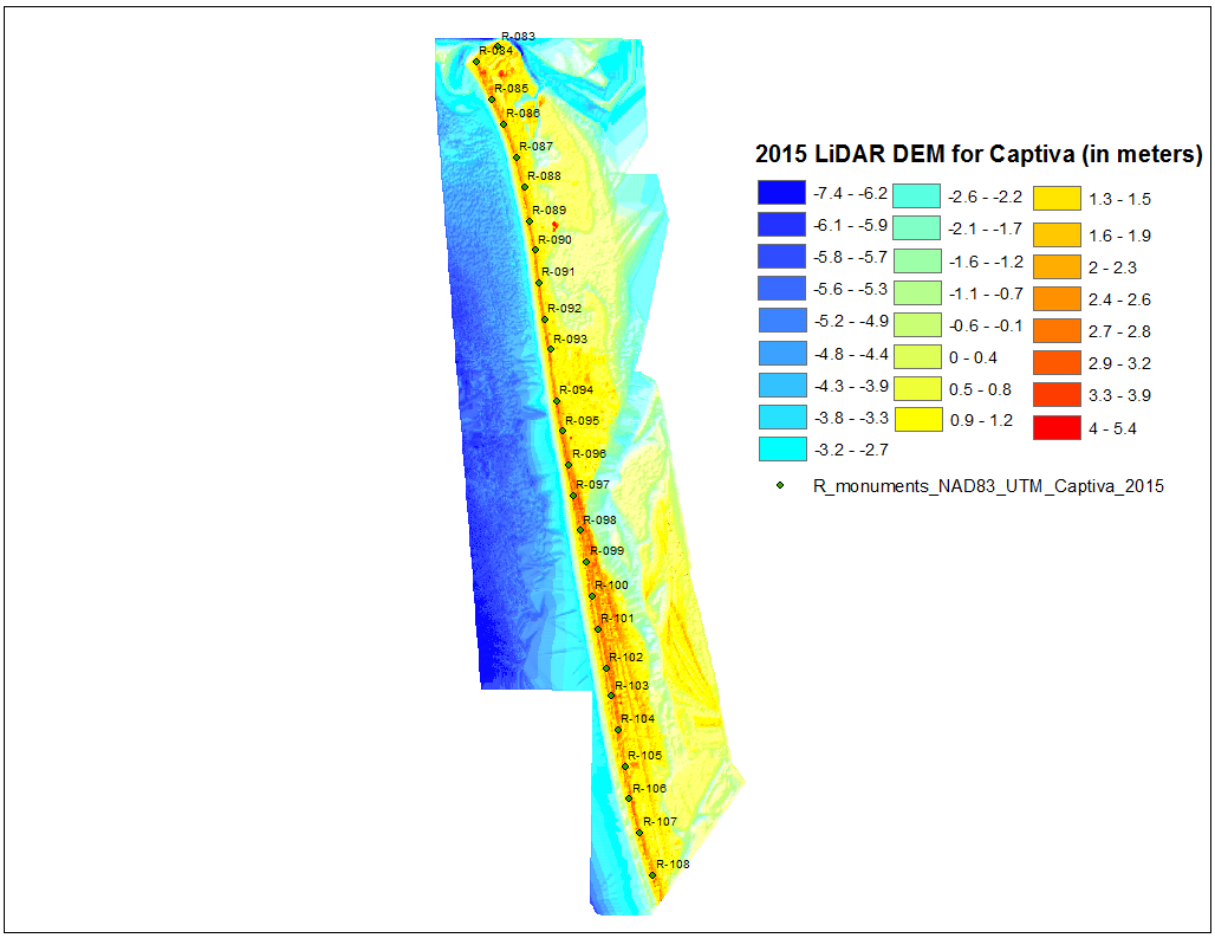


Figure 7. 2015 LiDAR Digital Elevation Model (DEM) for Captiva Island. Elevations in meters and relative to NAVD88.

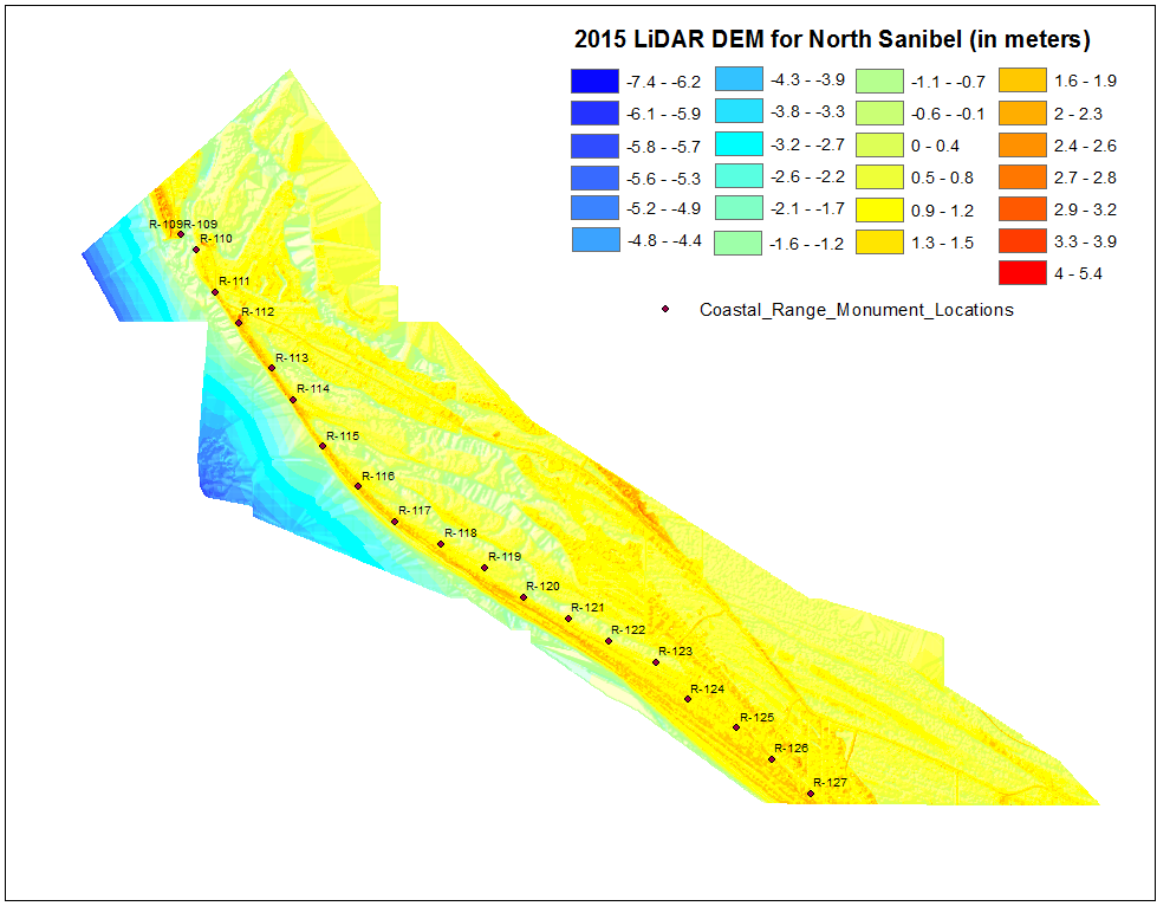


Figure 8. 2015 LiDAR Digital Elevation Model (DEM) for North Sanibel Island. Elevations in meters and relative to NAVD88.

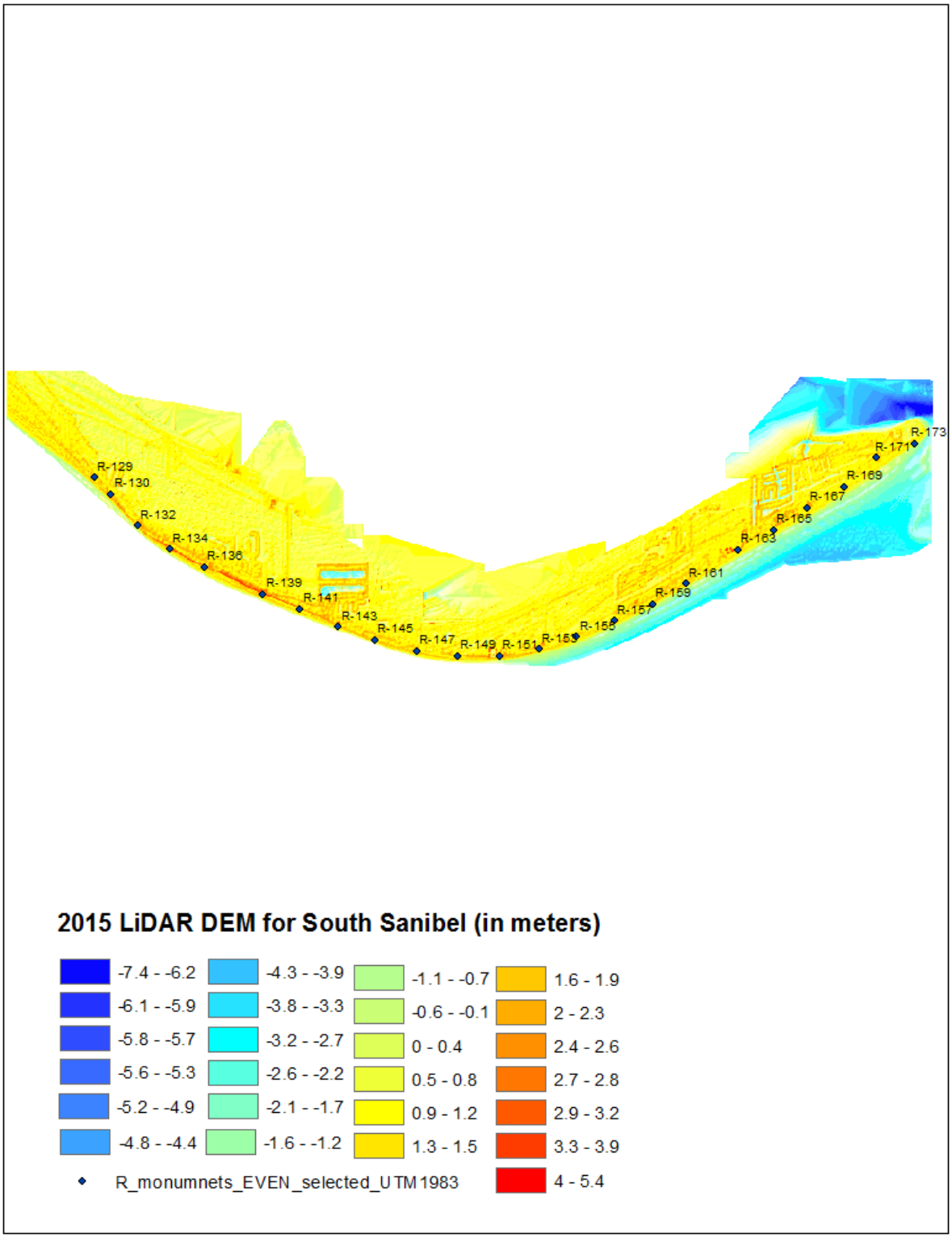


Figure 9. 2015 LiDAR Digital Elevation Model (DEM) for South Sanibel Island. Elevations in meters and relative to NAVD88.

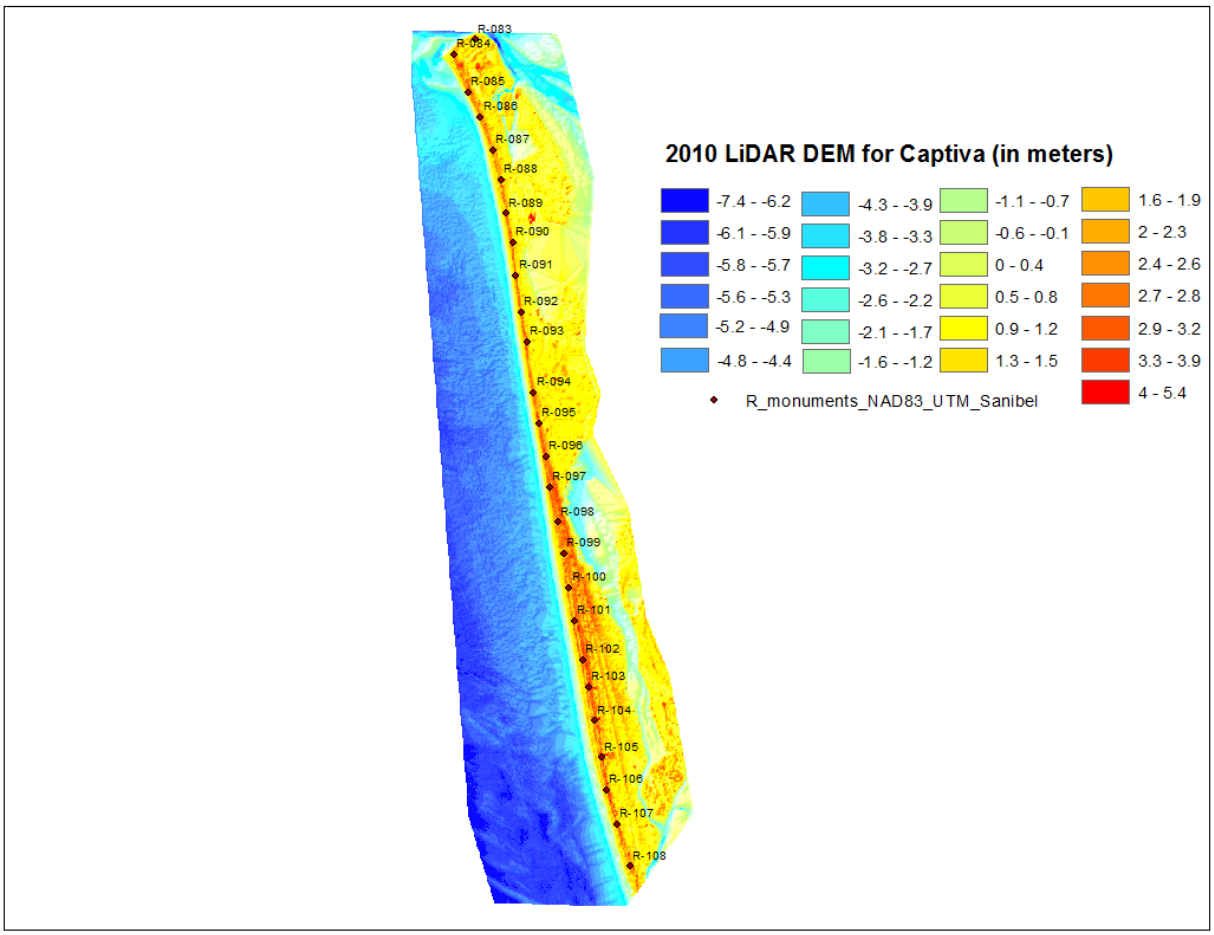


Figure 10. 2010 LiDAR Digital Elevation Model (DEM) for Captiva. Elevations in meters and relative to NAVD88.

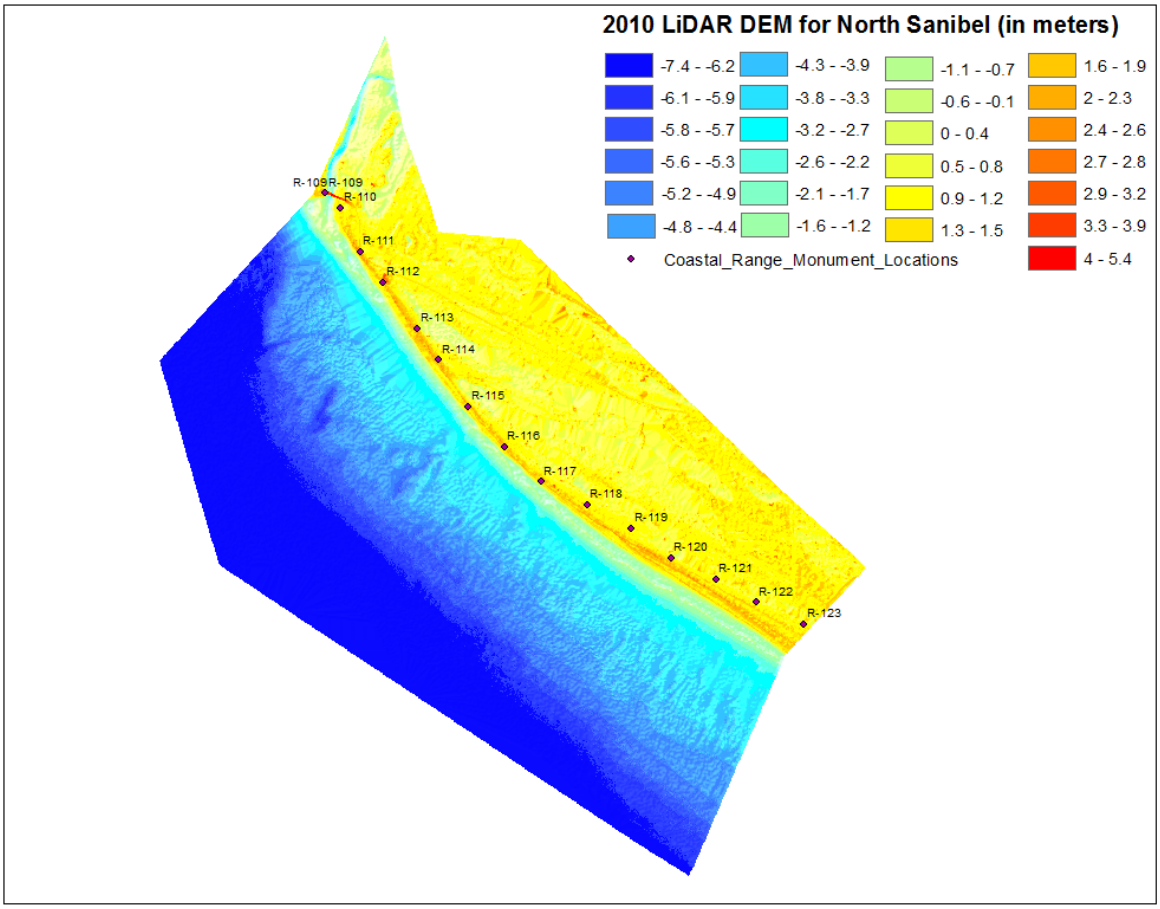


Figure 11. 2010 LiDAR Digital Elevation Model (DEM) for North Sanibel. Elevations in meters and relative to NAVD88.

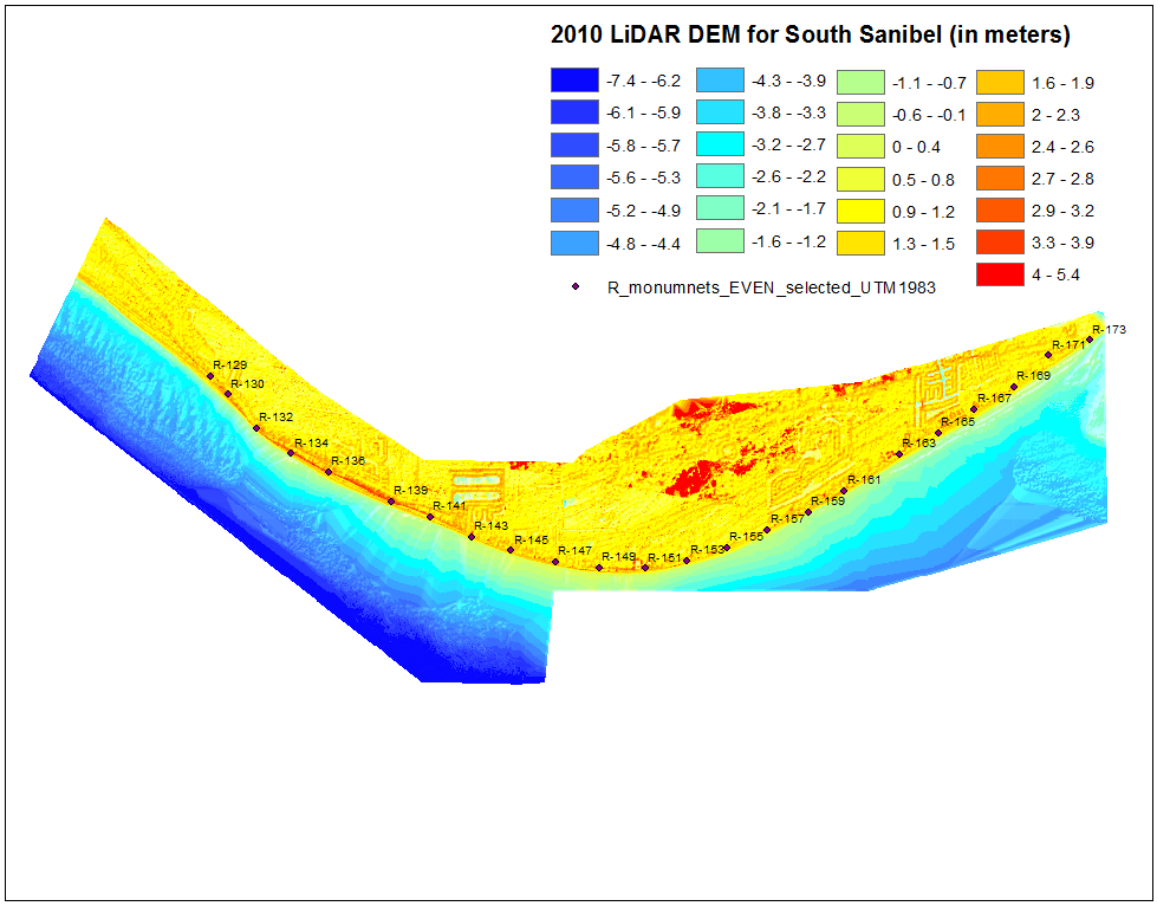


Figure 12. 2010 LiDAR Digital Elevation Model (DEM) for South Sanibel. Elevations in meters and relative to NAVD88.

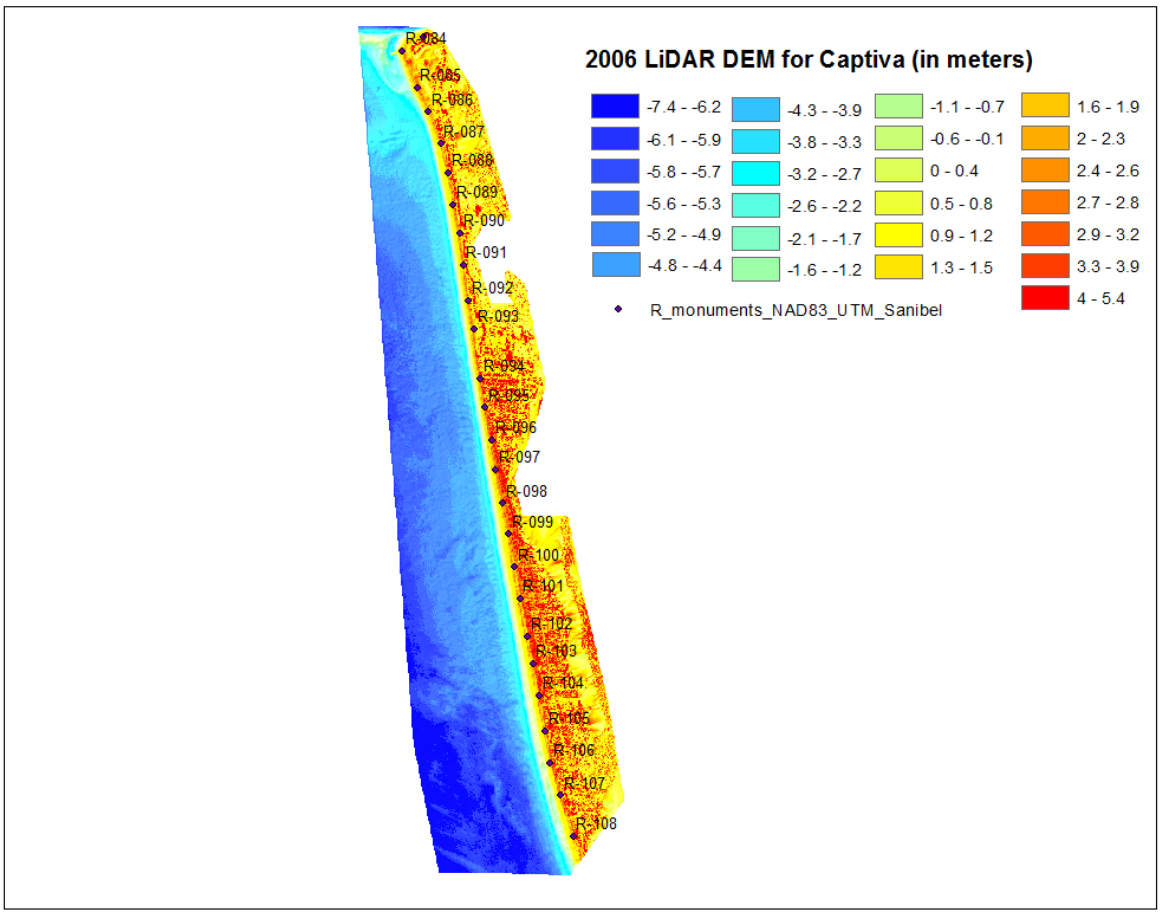


Figure 13. 2006 LiDAR Digital Elevation Model (DEM) for Captiva Island. Elevations in meters and relative to NAVD88.

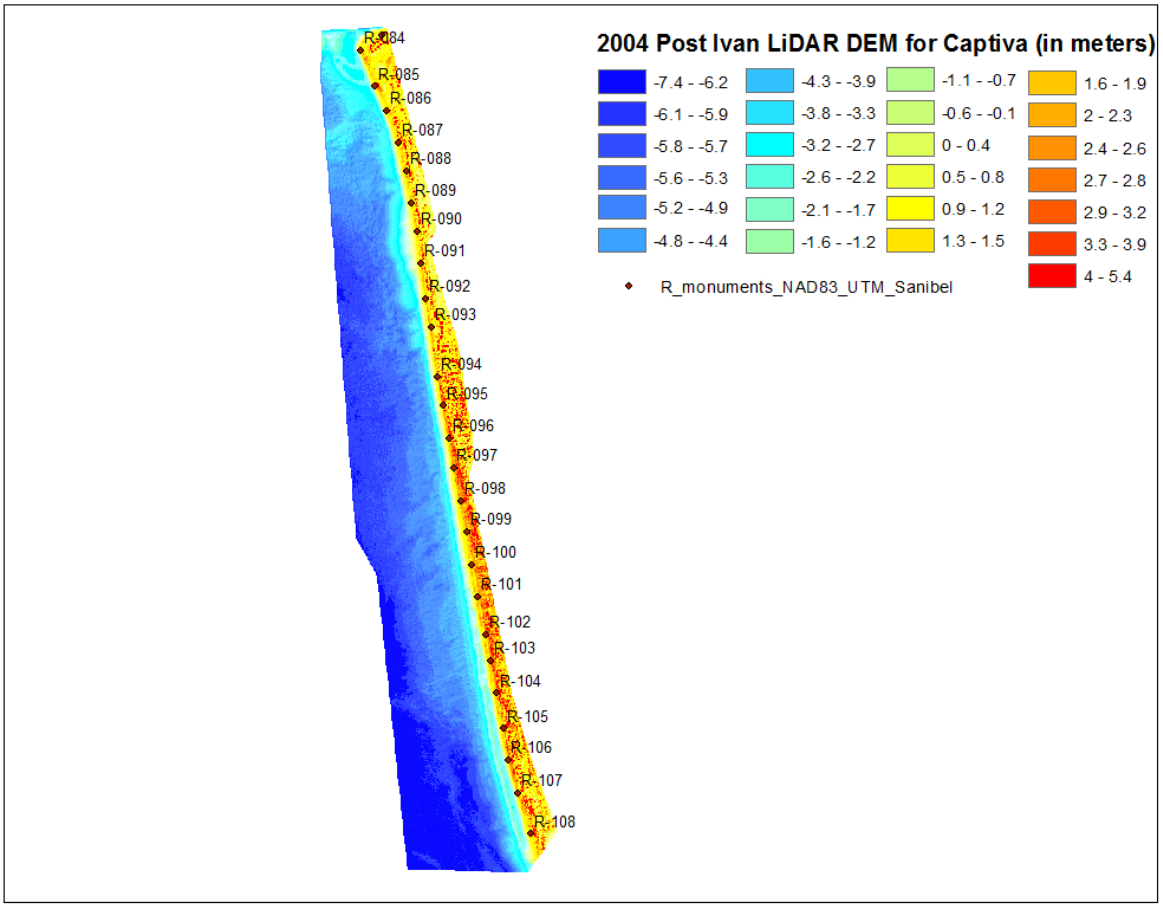


Figure 14. 2004 Post Hurricane Ivan LiDAR Digital Elevation Model (DEM) for Captiva Island. Elevations in meters and relative to NAVD88.

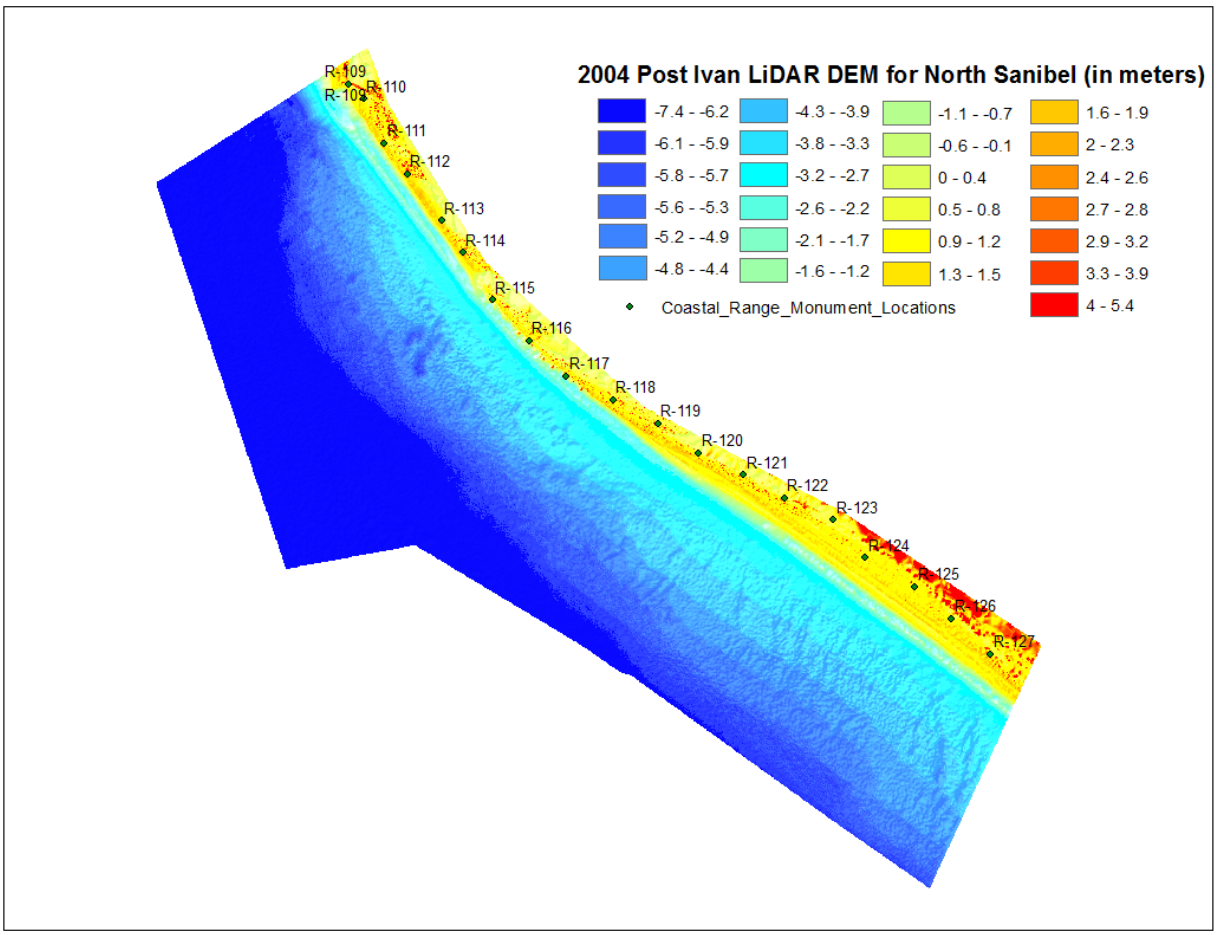


Figure 15. 2004 Post Hurricane Ivan LiDAR Digital Elevation Model (DEM) for North Sanibel Island. Elevations in meters and relative to NAVD88.

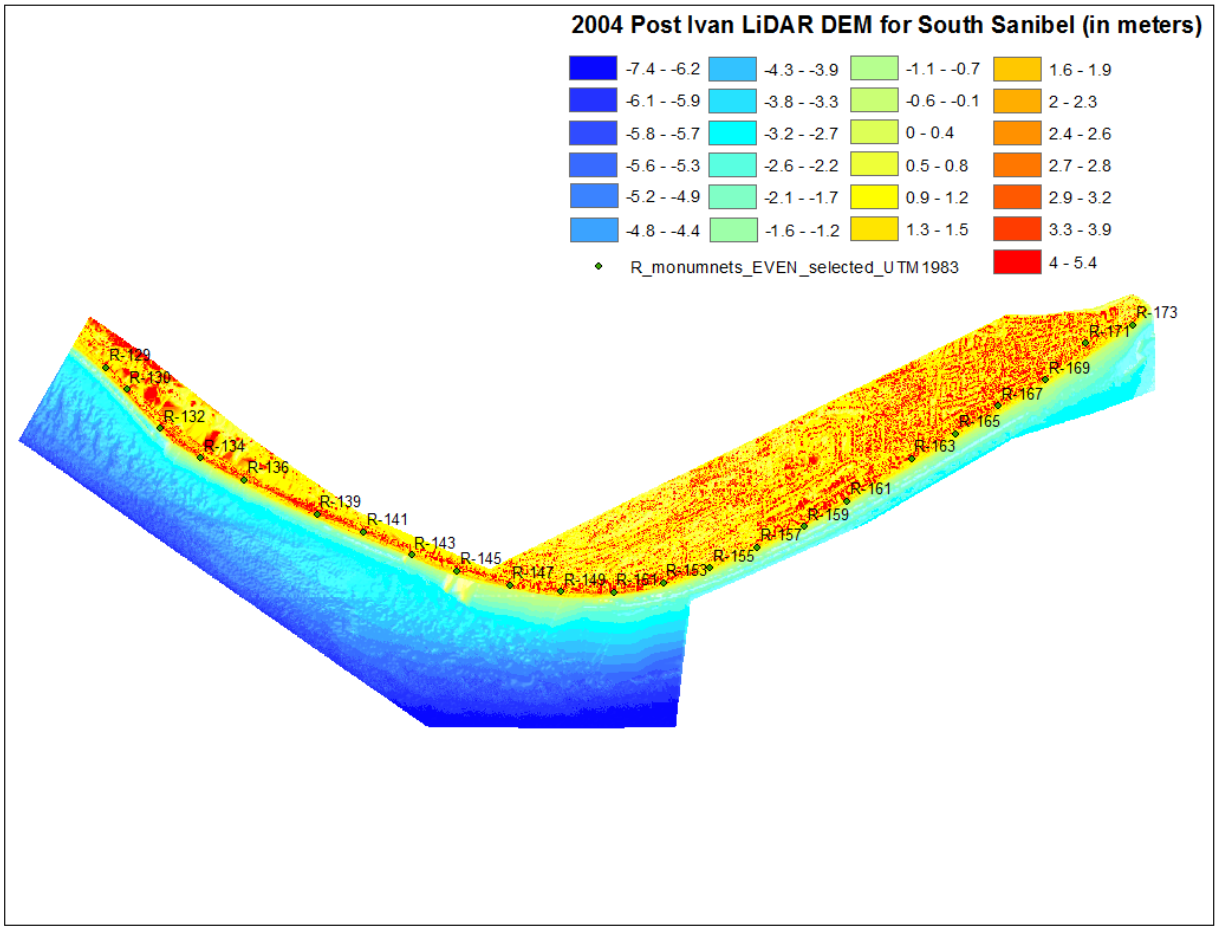


Figure 16. 2004 Post Hurricane Ivan LiDAR Digital Elevation Model (DEM) for South Sanibel Island. Elevations in meters and relative to NAVD88.

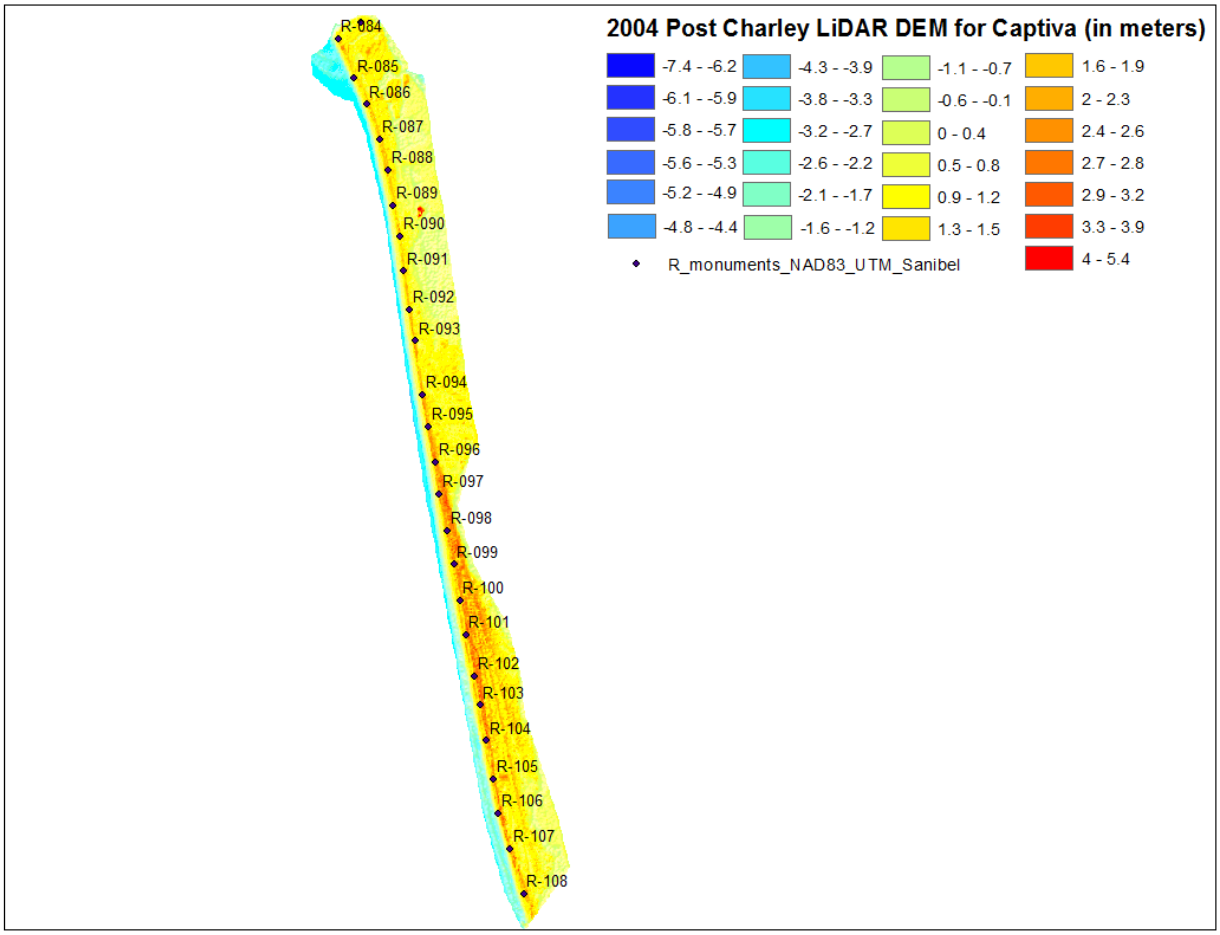


Figure 17. 2004 Post Hurricane Charley LiDAR Digital Elevation Model (DEM) for Captiva Island. Elevations in meters and relative to NAVD88.

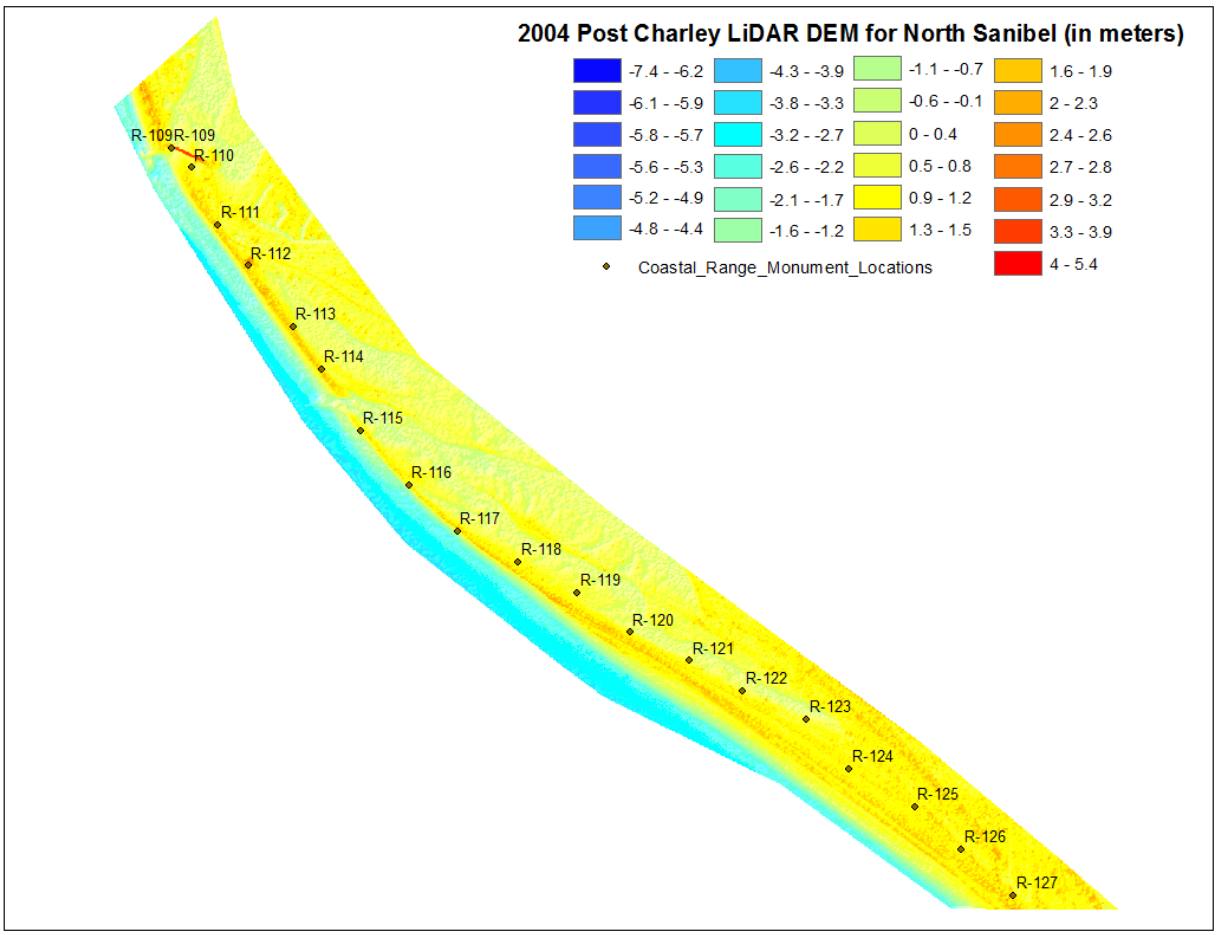


Figure 18. 2004 Post Hurricane Charley LiDAR Digital Elevation Model (DEM) for North Sanibel Island. Elevations in meters and relative to NAVD88.

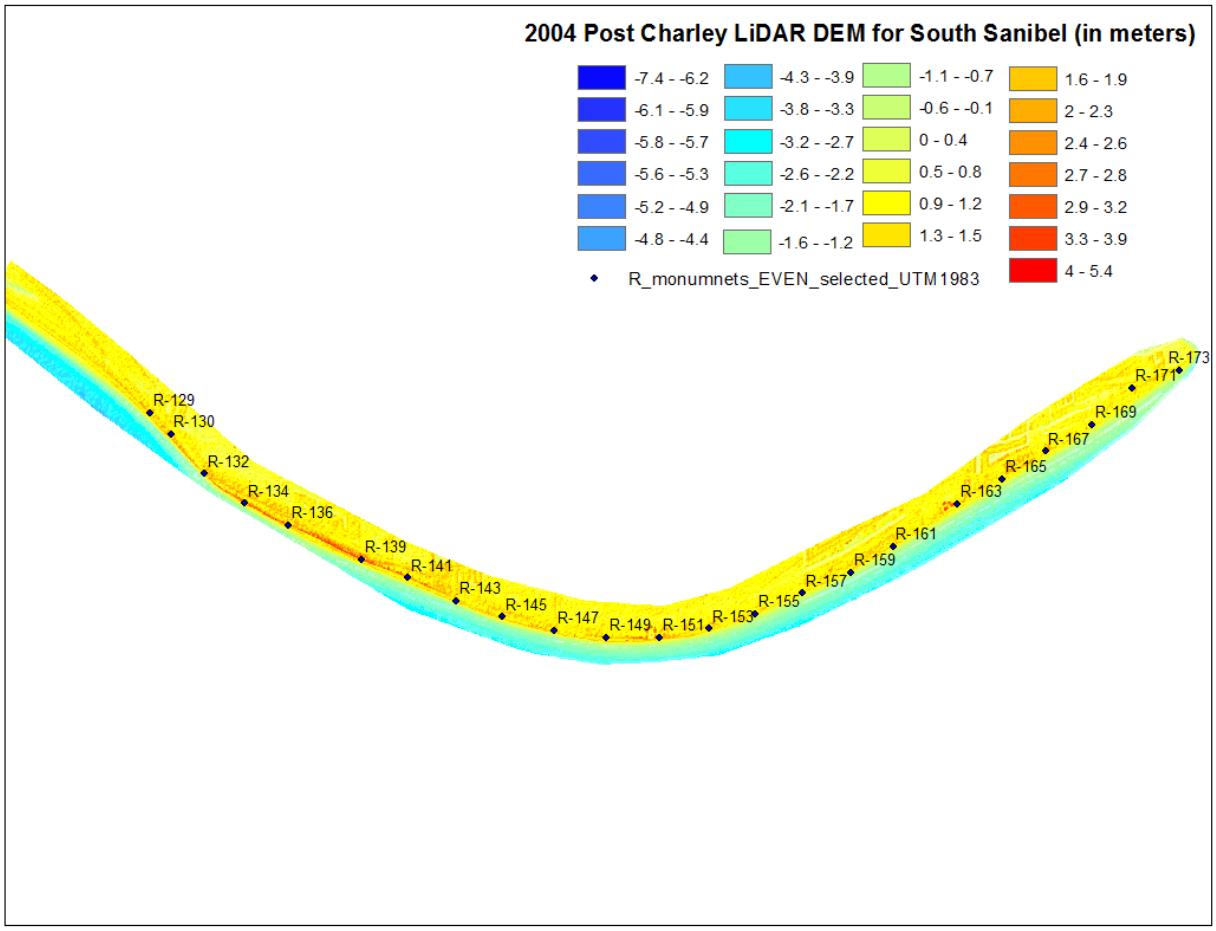


Figure 19. 2004 Post Hurricane Charley LiDAR Digital Elevation Model (DEM) for South Sanibel Island. Elevations in meters and relative to NAVD88.

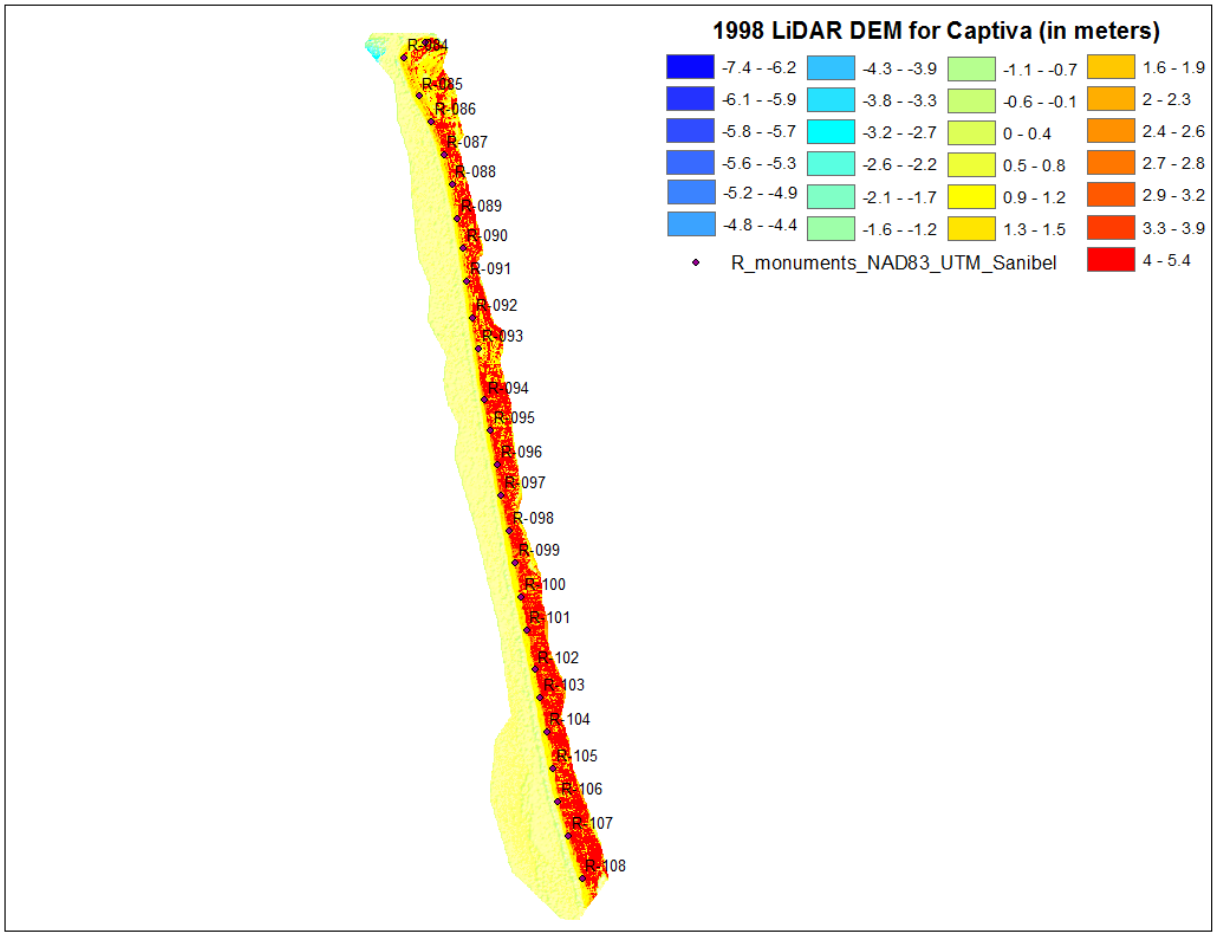


Figure 20. 1998 LiDAR Digital Elevation Model (DEM) for Captiva Island. Elevations in meters and relative to NAVD88. Though the 1998 DEMs may represent relative elevational differences across the landscape, the absolute elevation values are flawed and should be dismissed.

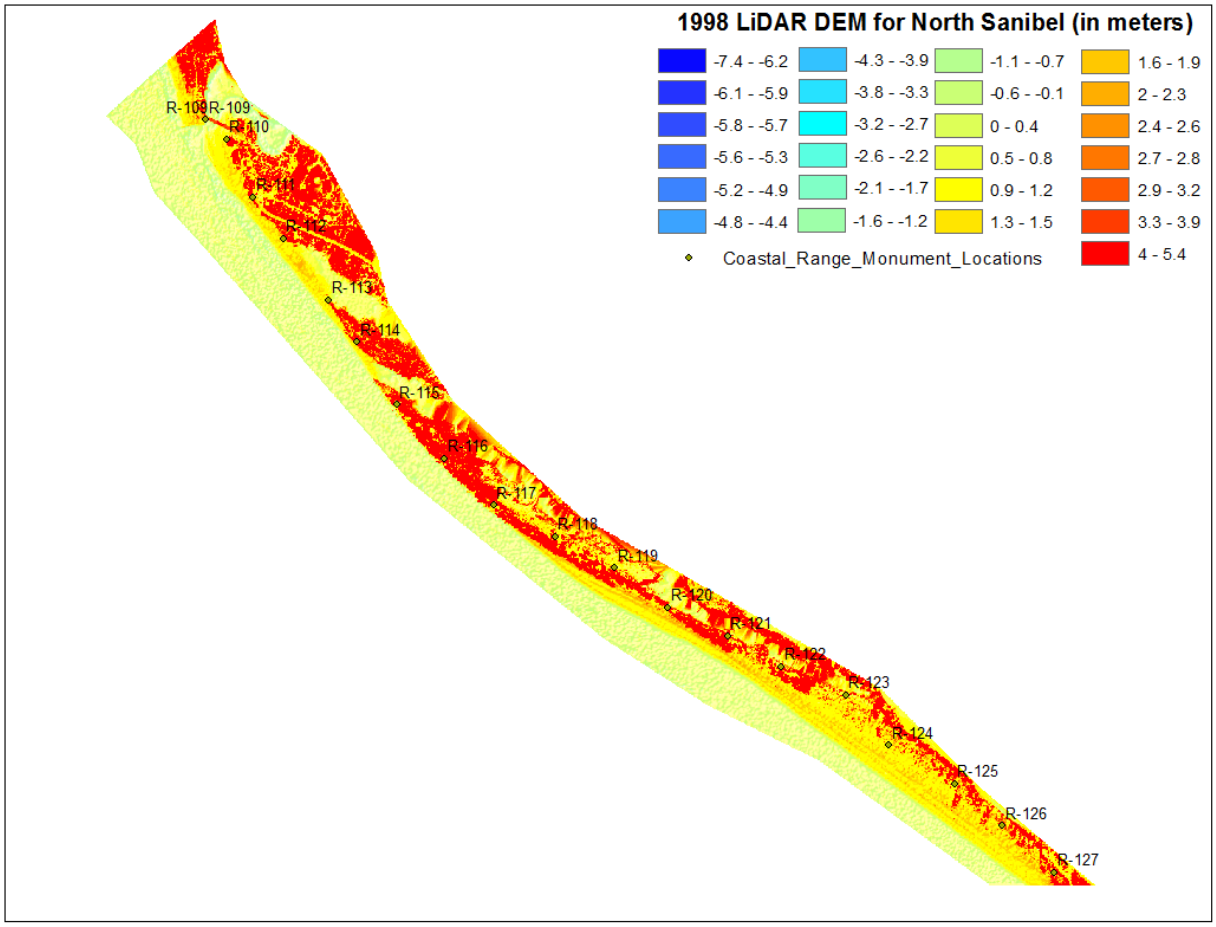


Figure 21. 1998 LiDAR Digital Elevation Model (DEM) for North Sanibel Island. Elevations in meters and relative to NAVD88. Though the 1998 DEMs may represent relative elevational differences across the landscape, the absolute elevation values are flawed and should be dismissed.

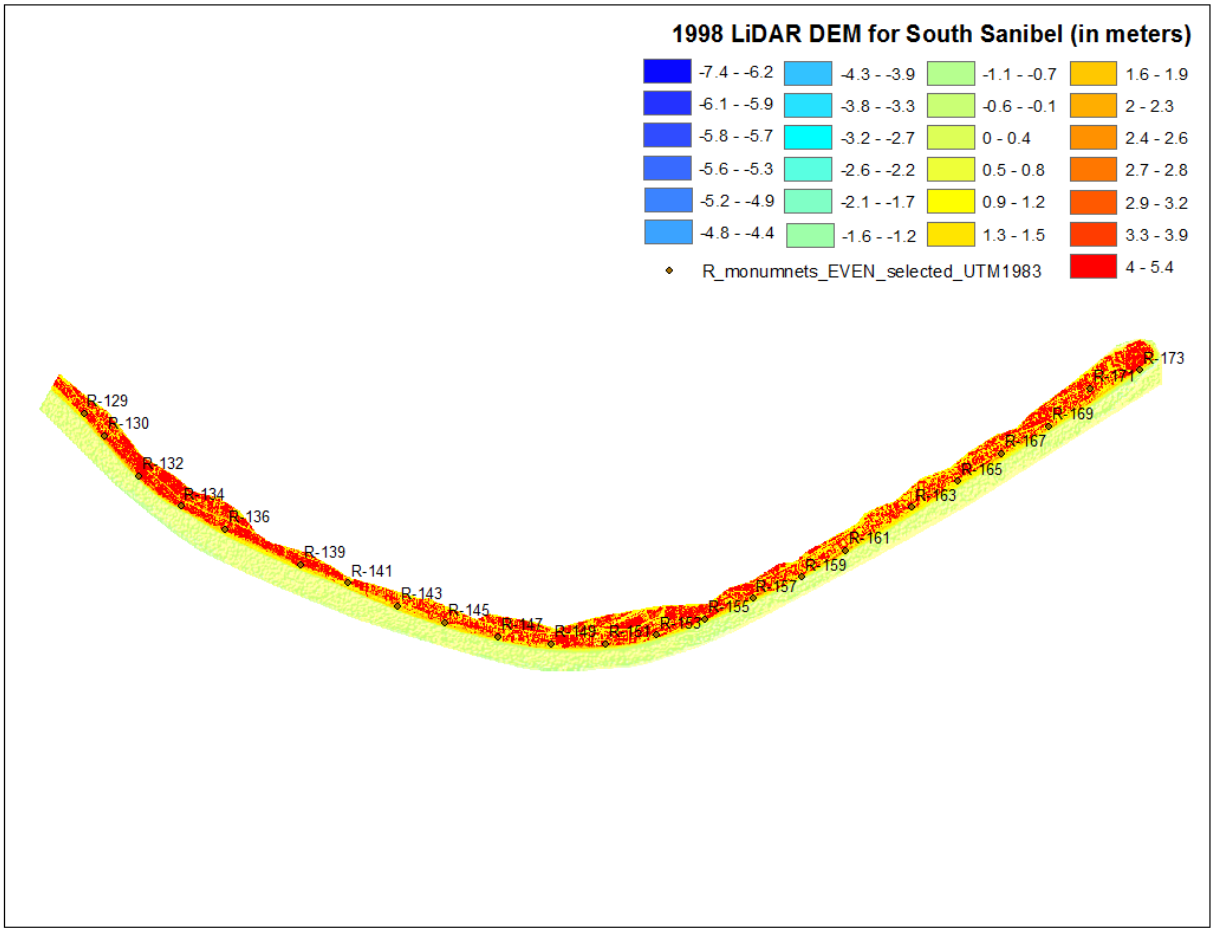


Figure 22. 1998 LiDAR Digital Elevation Model (DEM) for South Sanibel Island. Elevations in meters and relative to NAVD88. Though the 1998 DEMs may represent relative elevational differences across the landscape, the absolute elevation values are flawed and should be dismissed.

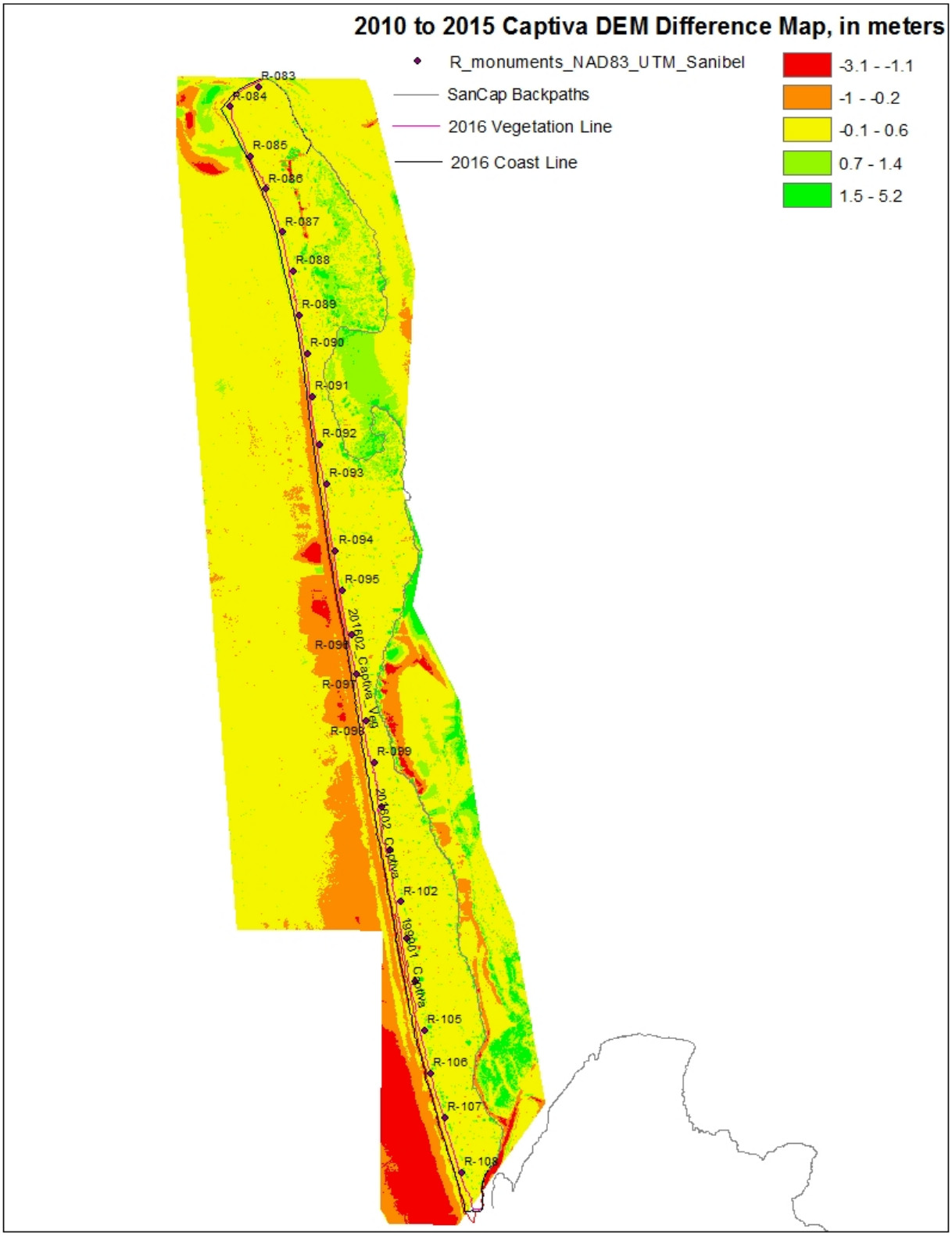


Figure 23. 2010 to 2015 Captiva Elevation Difference Map. Also shown are the positions of gulf-side shoreline, bay-side shoreline (SanCap Backpaths), and vegetation line in 2016.

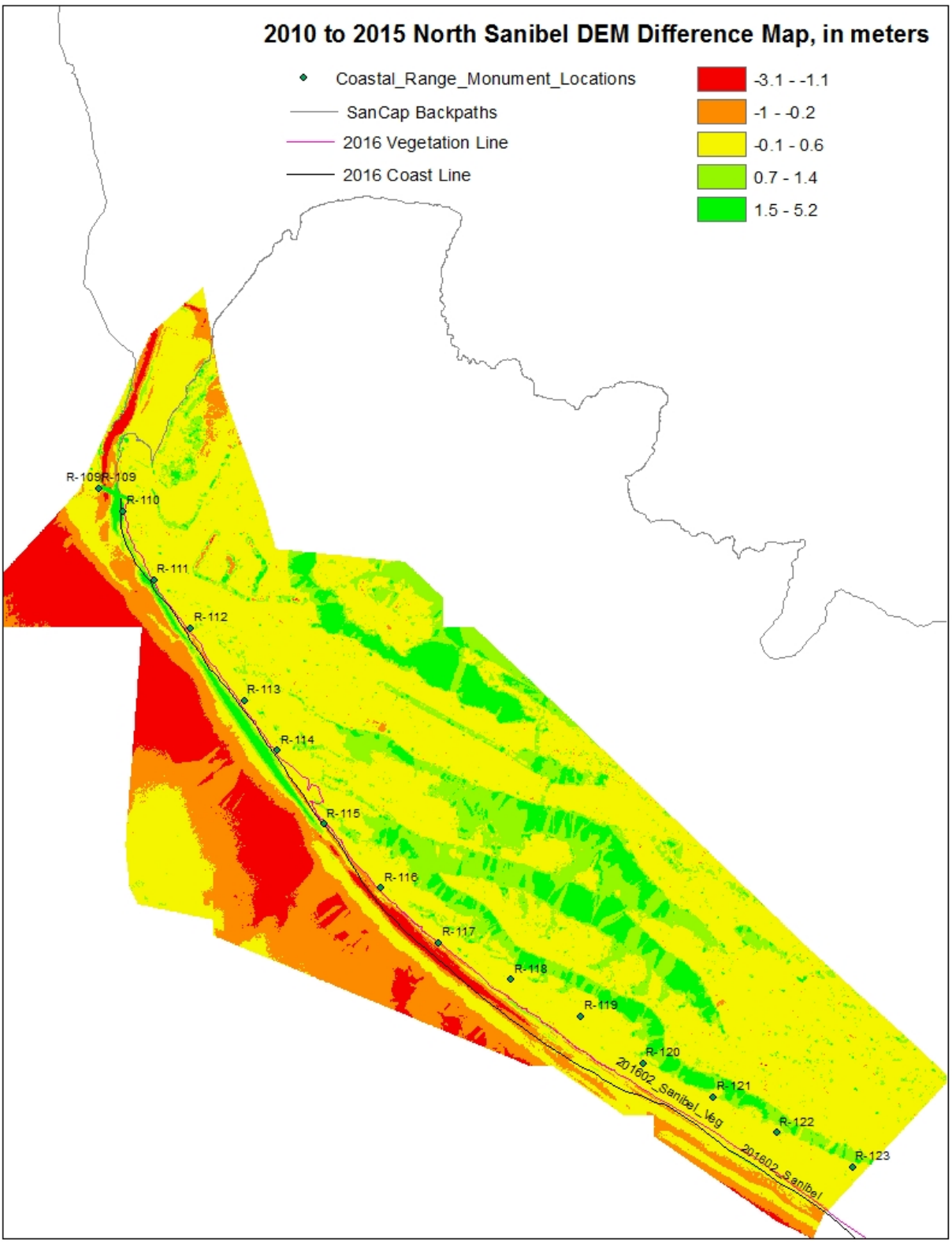


Figure 24. 2010 to 2015 North Sanibel Elevation Difference Map. Also shown are the positions of gulf-side shoreline, bay-side shoreline (SanCap Backpaths), and vegetation line in 2016.

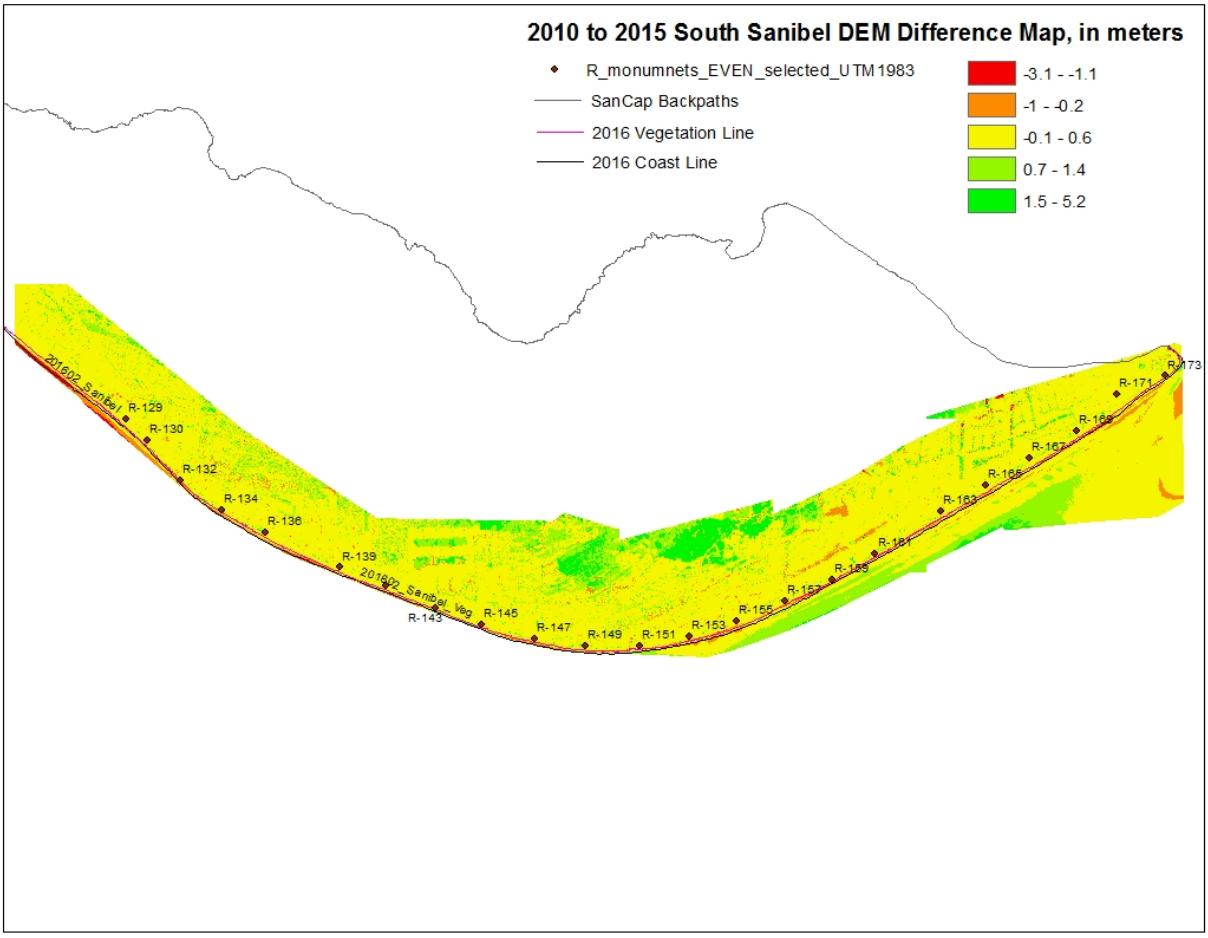


Figure 25. 2010 to 2015 South Sanibel Elevation Difference Map. Also shown are the positions of gulf-side shoreline, bay-side shoreline (SanCap Backpaths), and vegetation line in 2016.

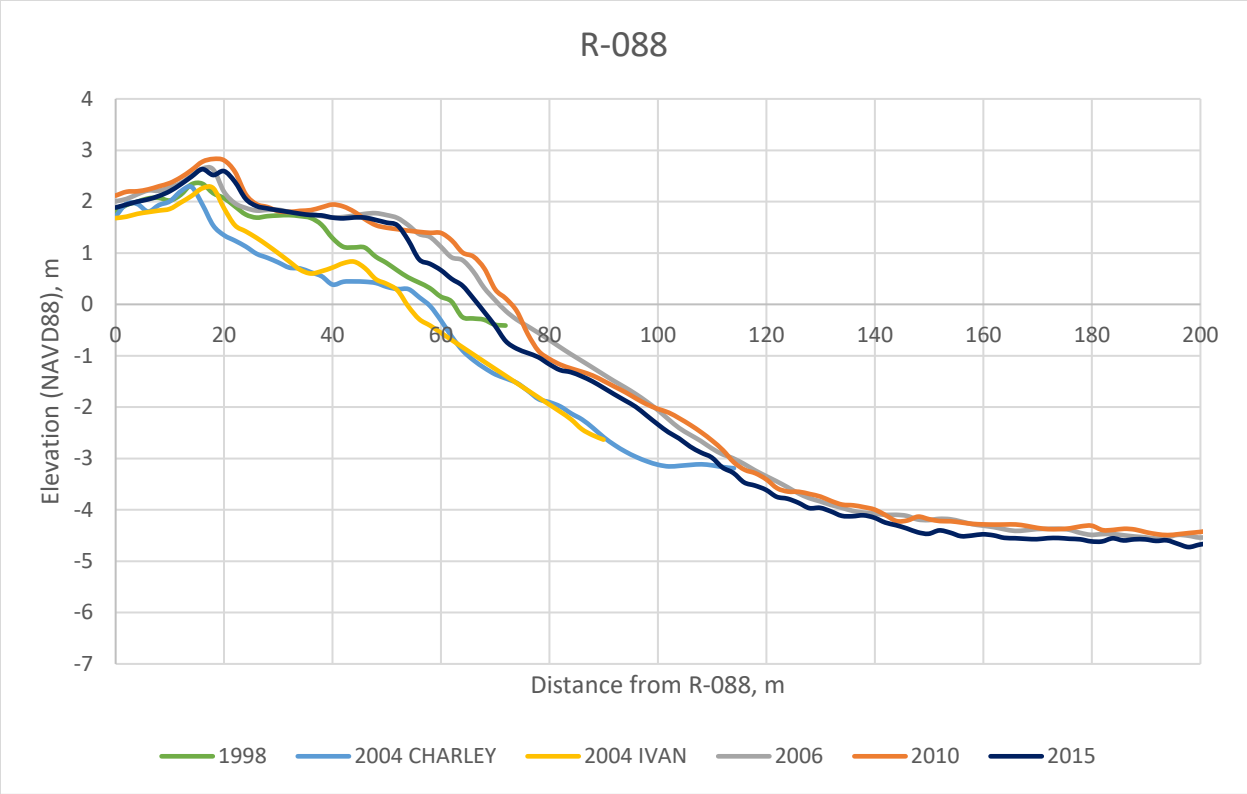


Figure 26. Beach profiles at R-088 extracted from LiDAR surveys. Elevations shown with respect to NAVD88. 0 m on x-axis represents the position of the R-monument; distance increases in the seaward direction.

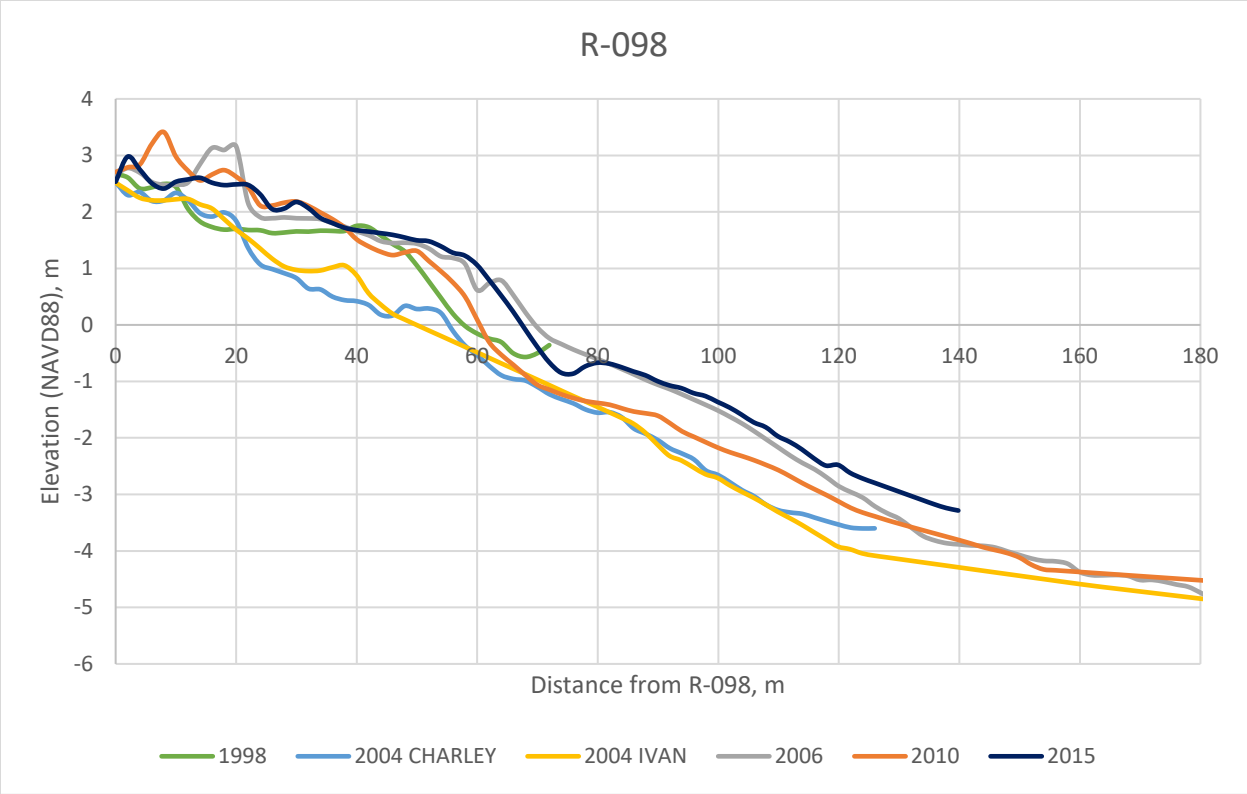


Figure 27. Beach profiles at R-098 extracted from LiDAR surveys. Elevations shown with respect to NAVD88. 0 m on x-axis represents the position of the R-monument; distance increases in the seaward direction.

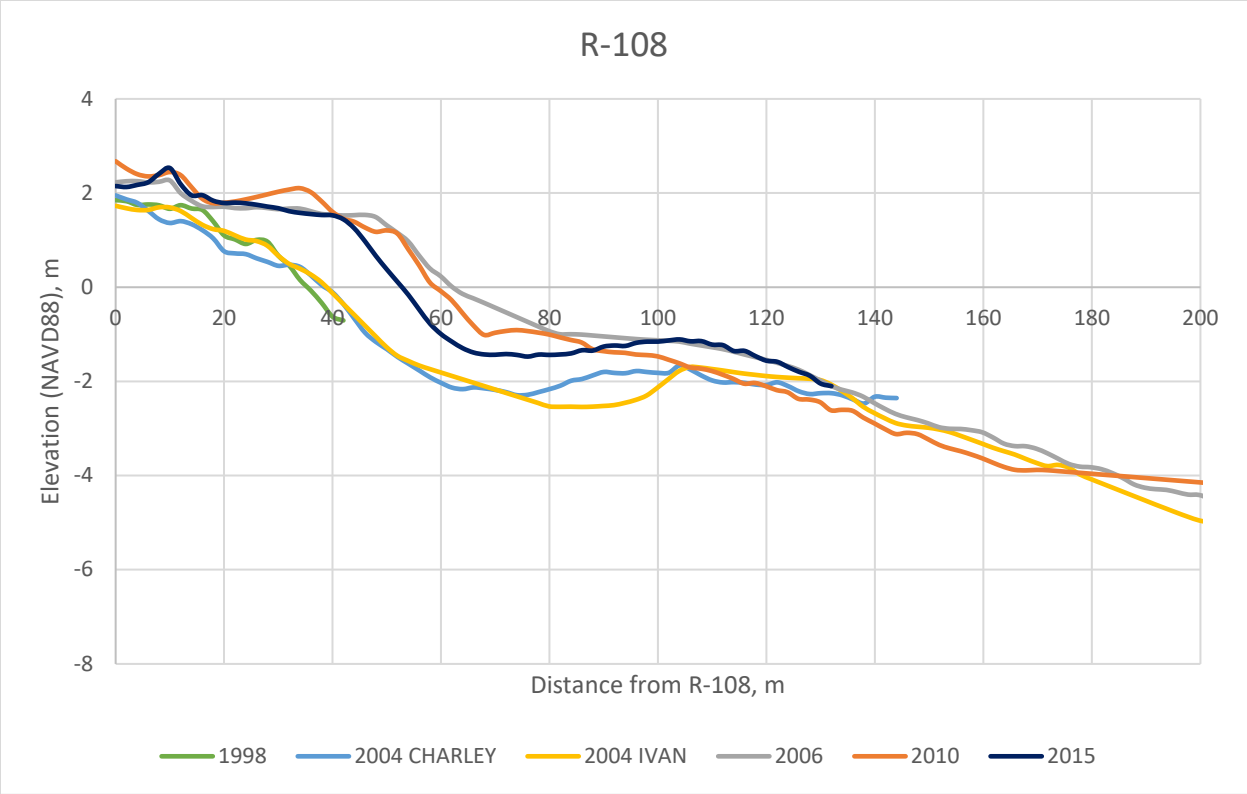


Figure 28. Beach profiles at R-108 extracted from LiDAR surveys. Elevations shown with respect to NAVD88. 0 m on x-axis represents the position of the R-monument; distance increases in the seaward direction.

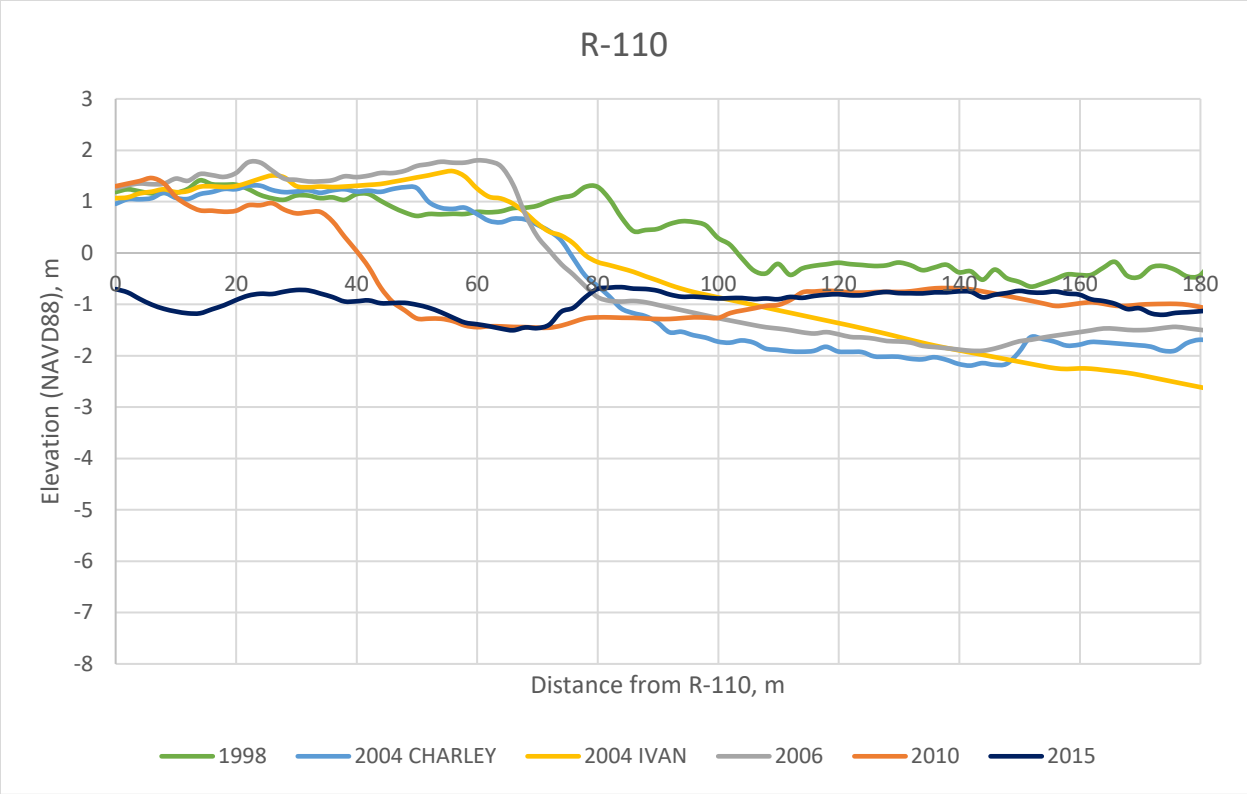


Figure 29. Beach profiles at R-110 extracted from LiDAR surveys, showing extensive erosion in the Santiva area. Elevations shown with respect to NAVD88. 0 m on x-axis represents the position of the R-monument; distance increases in the seaward direction.

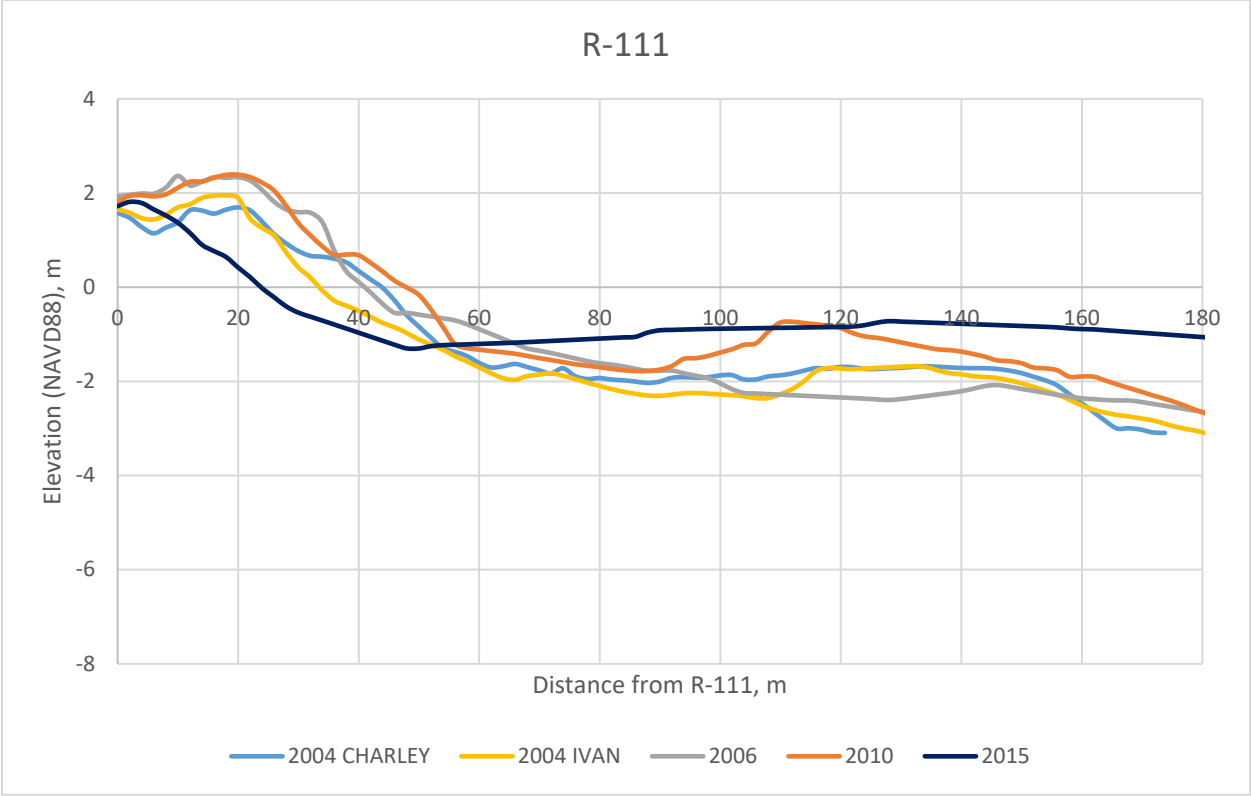


Figure 30. Beach profiles at R-111 extracted from LiDAR surveys, showing extensive erosion in the Santiva area. Elevations shown with respect to NAVD88. 0 m on x-axis represents the position of the R-monument; distance increases in the seaward direction.

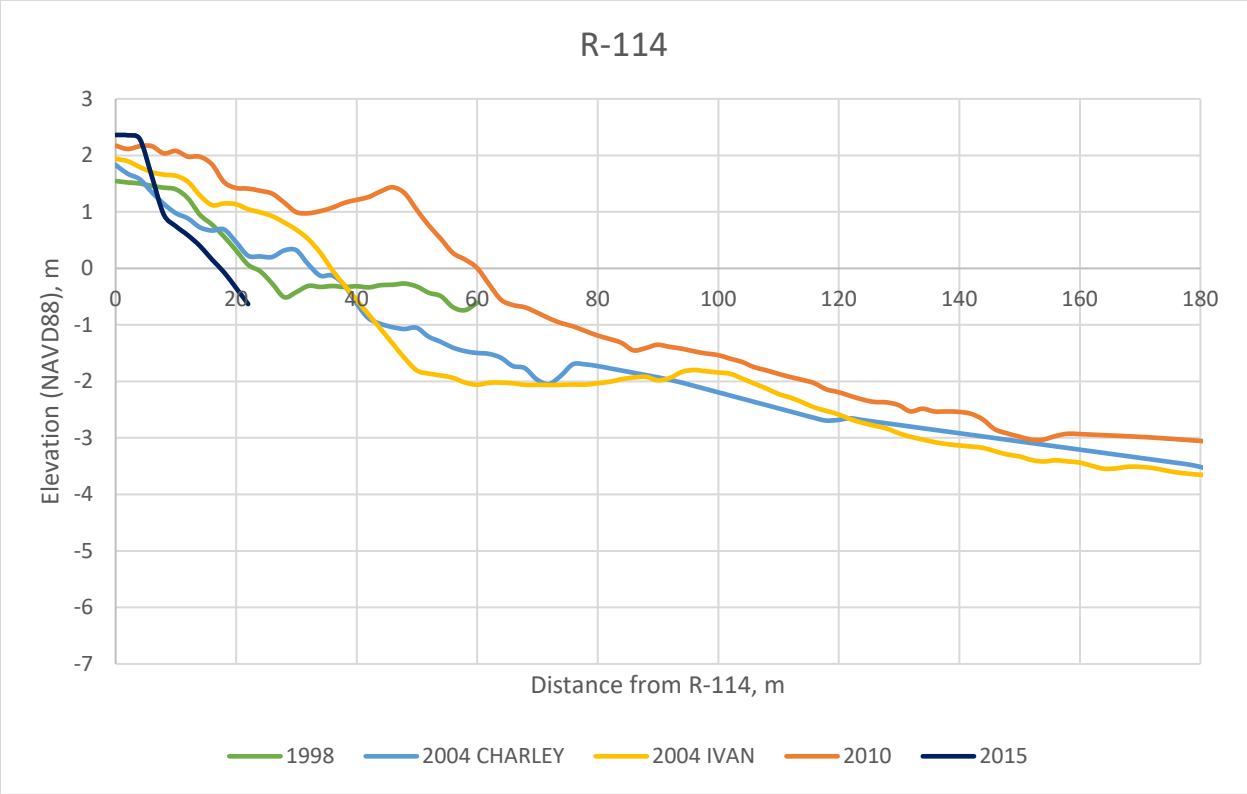


Figure 31. Beach profiles at R-114 extracted from LiDAR surveys. Elevations shown with respect to NAVD88. 0 m on x-axis represents the position of the R-monument; distance increases in the seaward direction.

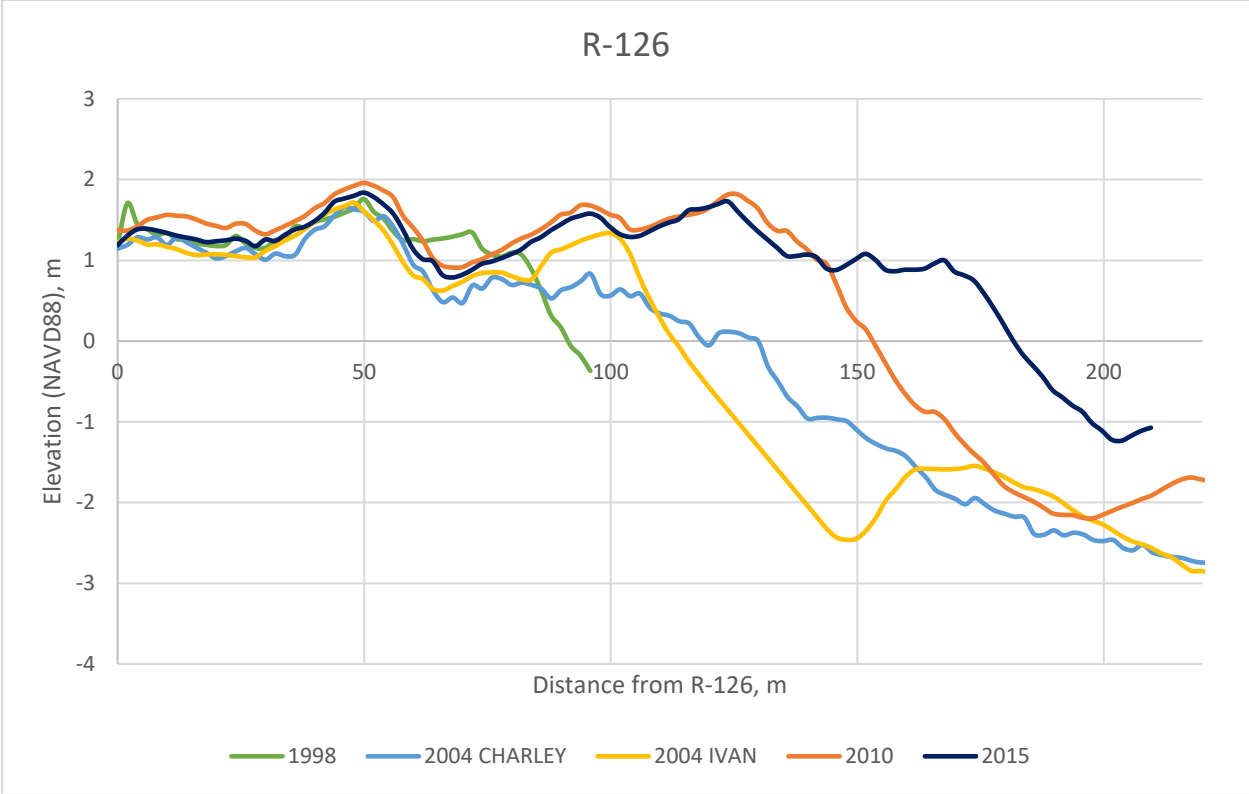


Figure 32. Beach profiles at R-126 extracted from LiDAR surveys, showing major accretion. Elevations shown with respect to NAVD88. 0 m on x-axis represents the position of the R-monument; distance increases in the seaward direction.

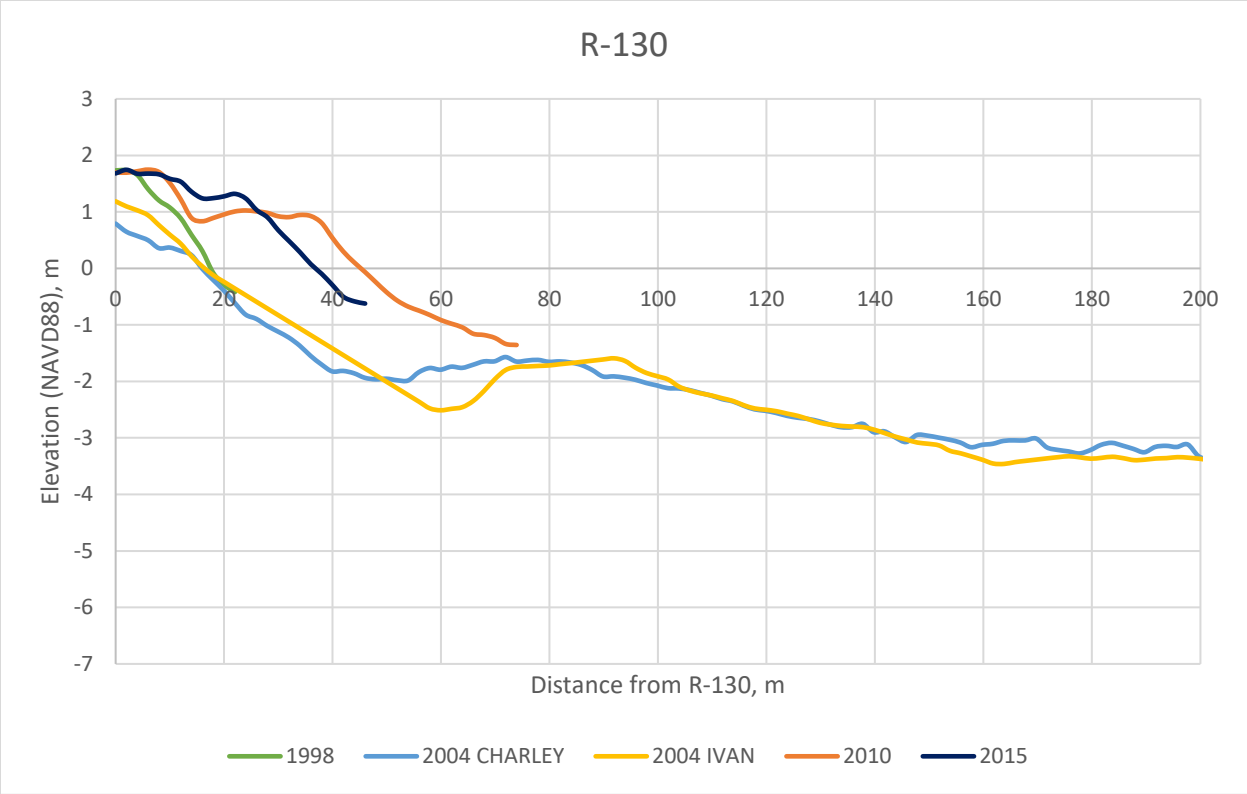


Figure 33. Beach profiles at R-130 extracted from LiDAR surveys. Elevations shown with respect to NAVD88. 0 m on x-axis represents the position of the R-monument; distance increases in the seaward direction.

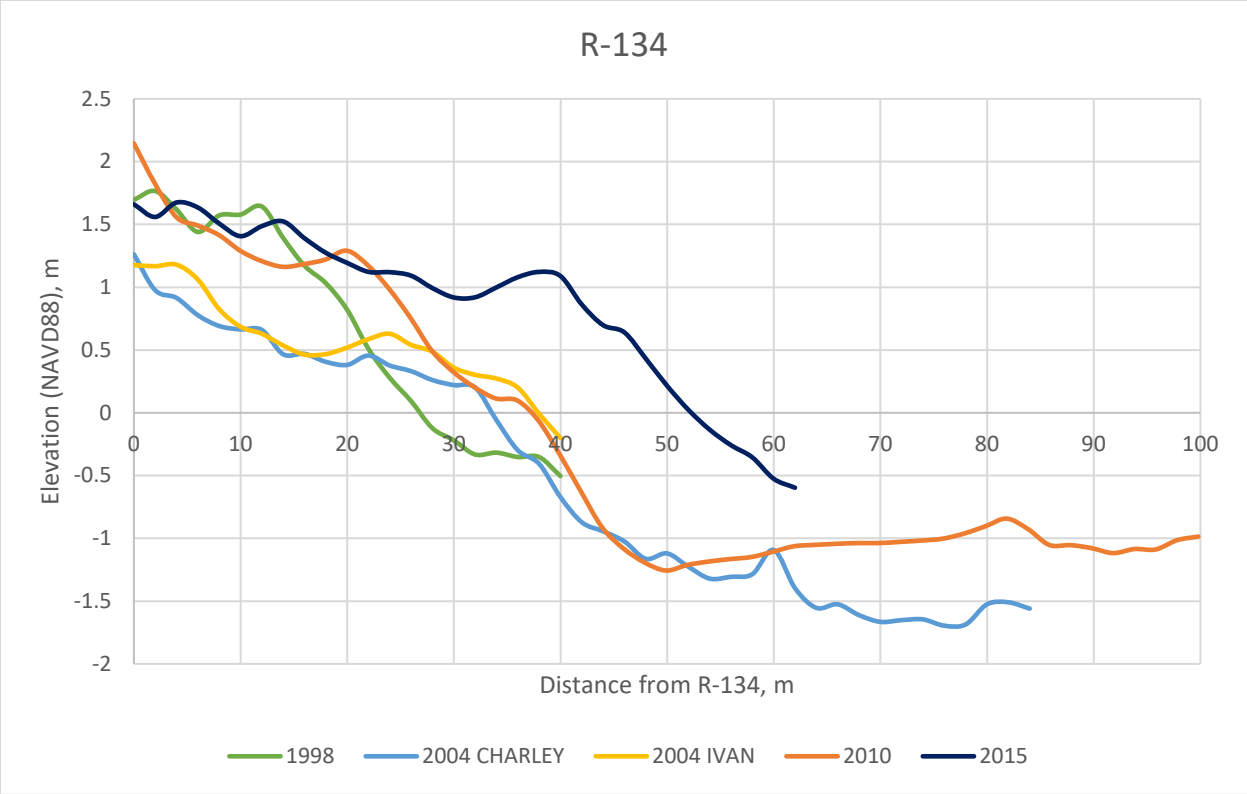


Figure 34. Beach profiles at R-134 extracted from LiDAR surveys. Elevations shown with respect to NAVD88. 0 m on x-axis represents the position of the R-monument; distance increases in the seaward direction.

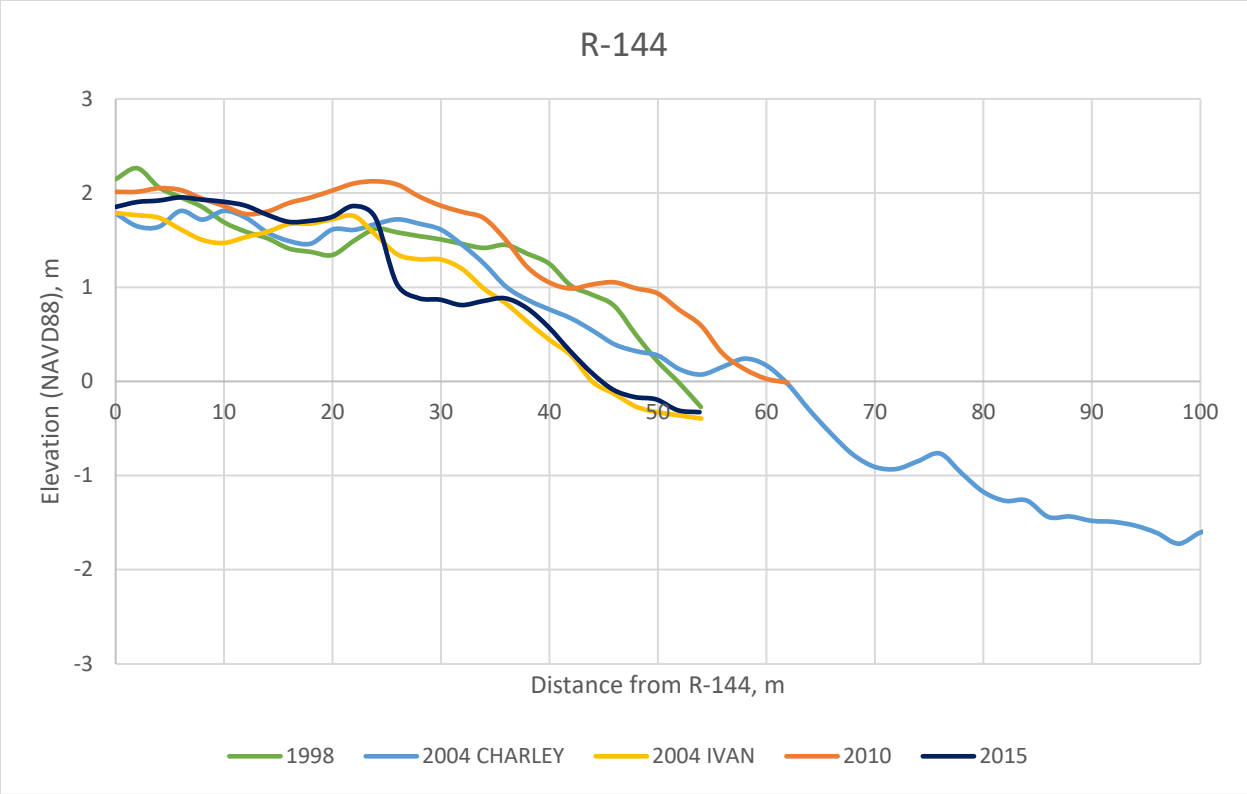


Figure 35. Beach profiles at R-144 extracted from LiDAR surveys. Elevations shown with respect to NAVD88. 0 m on x-axis represents the position of the R-monument; distance increases in the seaward direction.

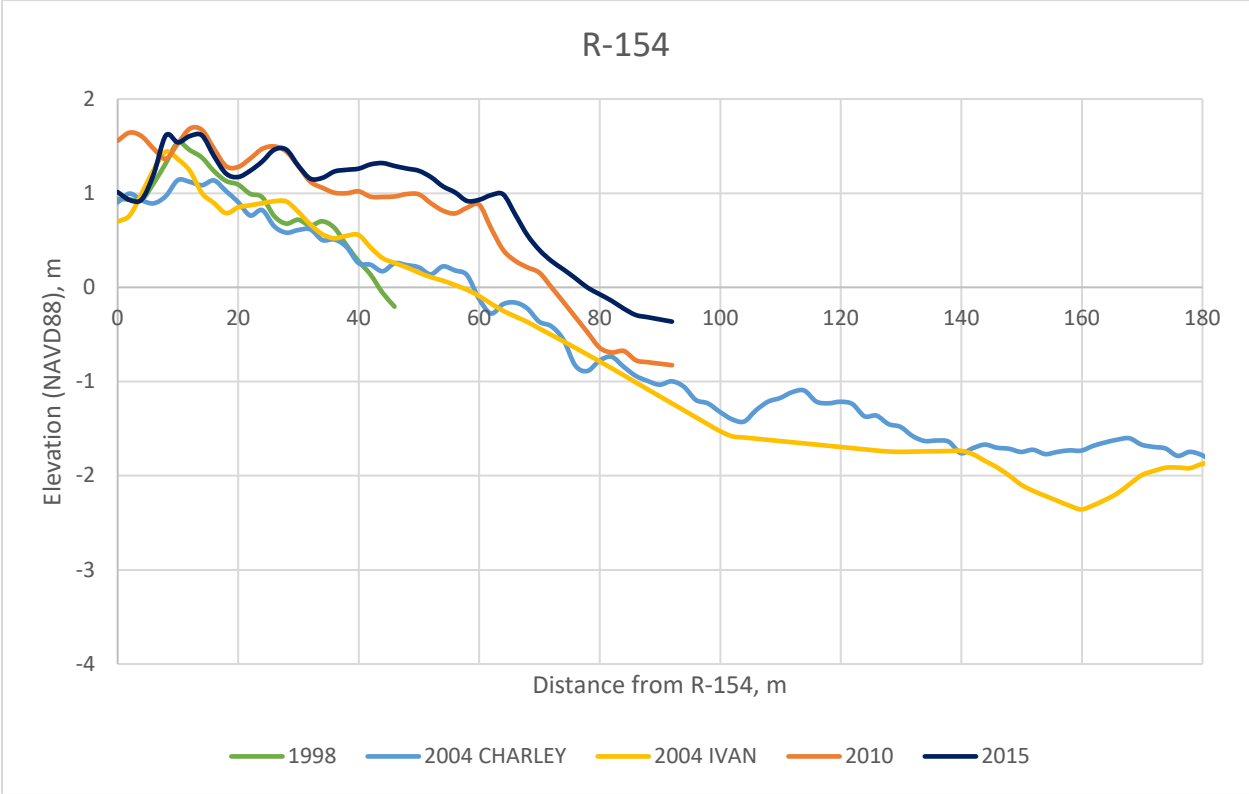


Figure 36. Beach profiles at R-154 extracted from LiDAR surveys. Elevations shown with respect to NAVD88. 0 m on x-axis represents the position of the R-monument; distance increases in the seaward direction.

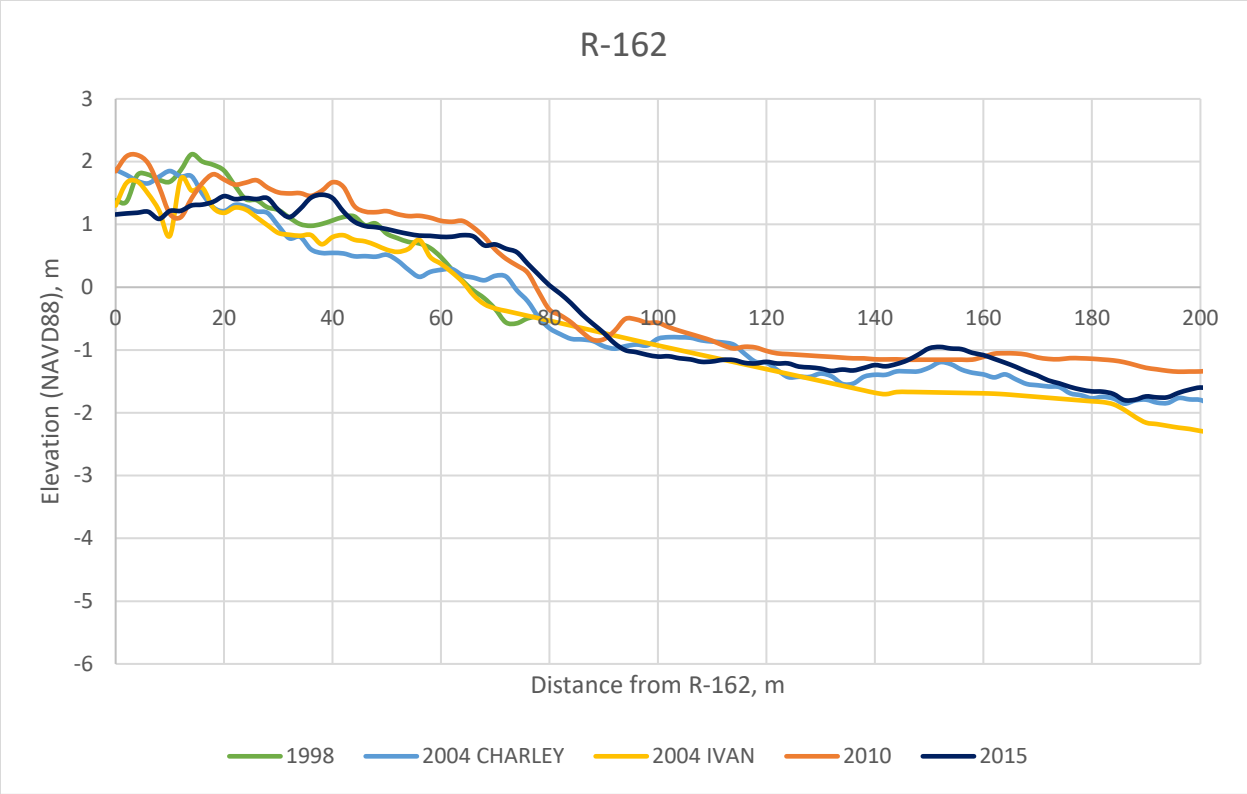


Figure 37. Beach profiles at R-162 extracted from LiDAR surveys. Elevations shown with respect to NAVD88. 0 m on x-axis represents the position of the R-monument; distance increases in the seaward direction.

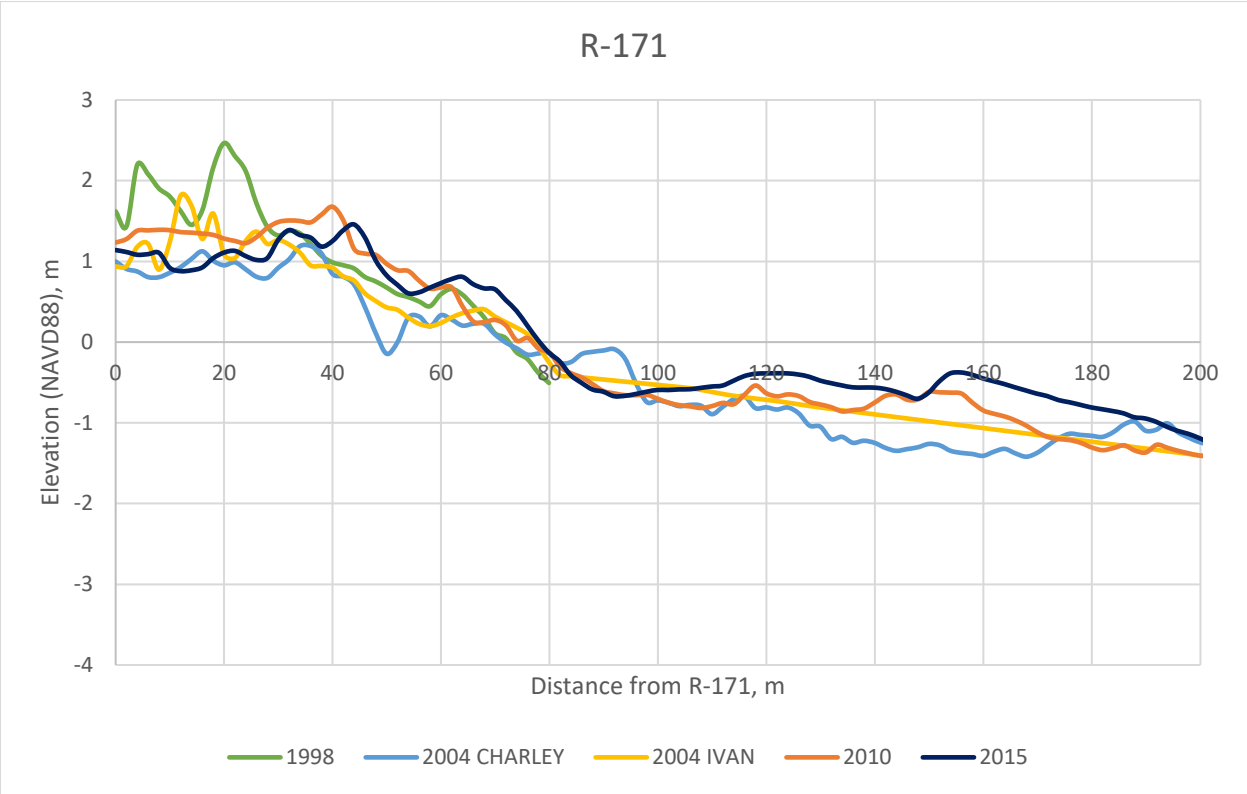


Figure 38. Beach profiles at R-171 extracted from LiDAR surveys. Elevations shown with respect to NAVD88. 0 m on x-axis represents the position of the R-monument; distance increases in the seaward direction.

Figure 39. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Captiva Island.

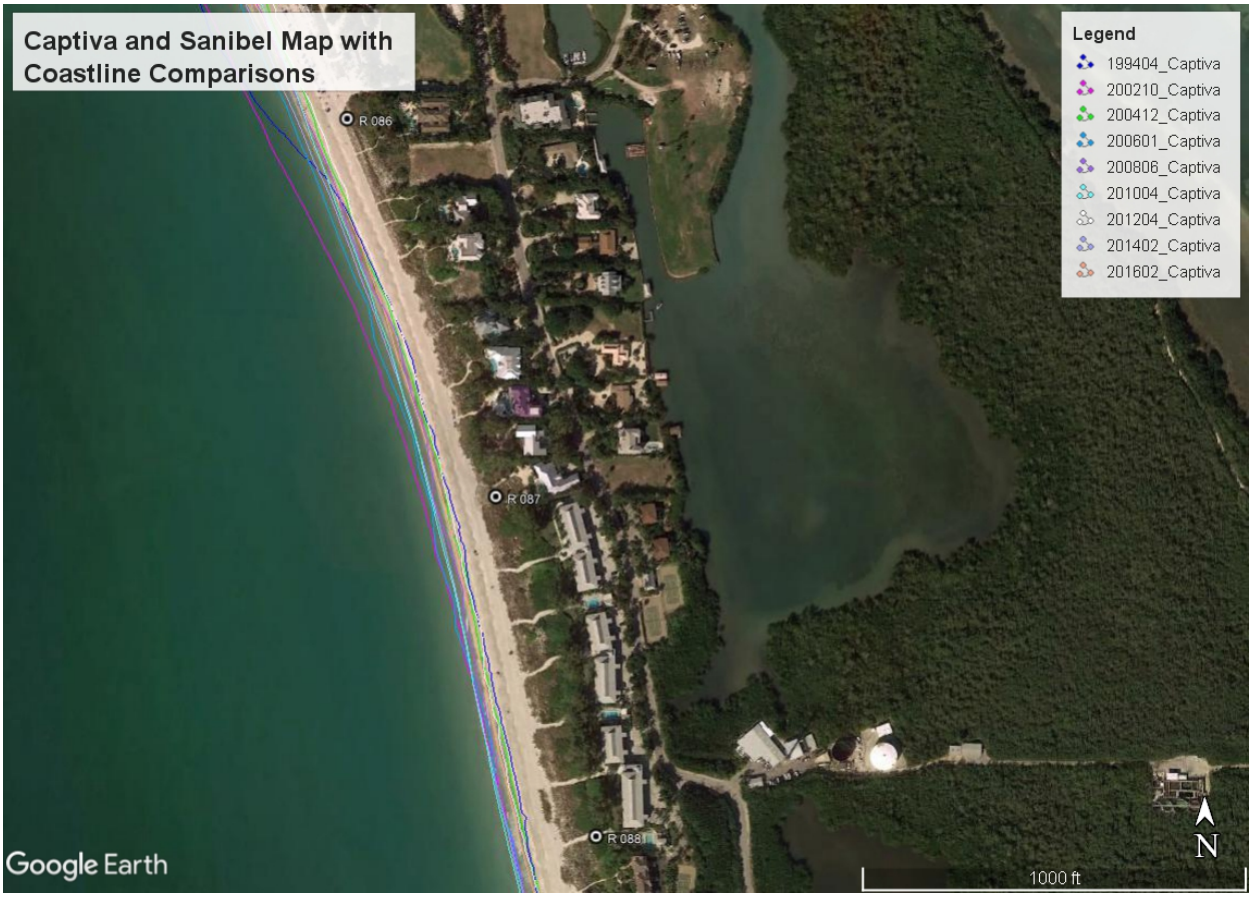


Figure 40. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Captiva Island.

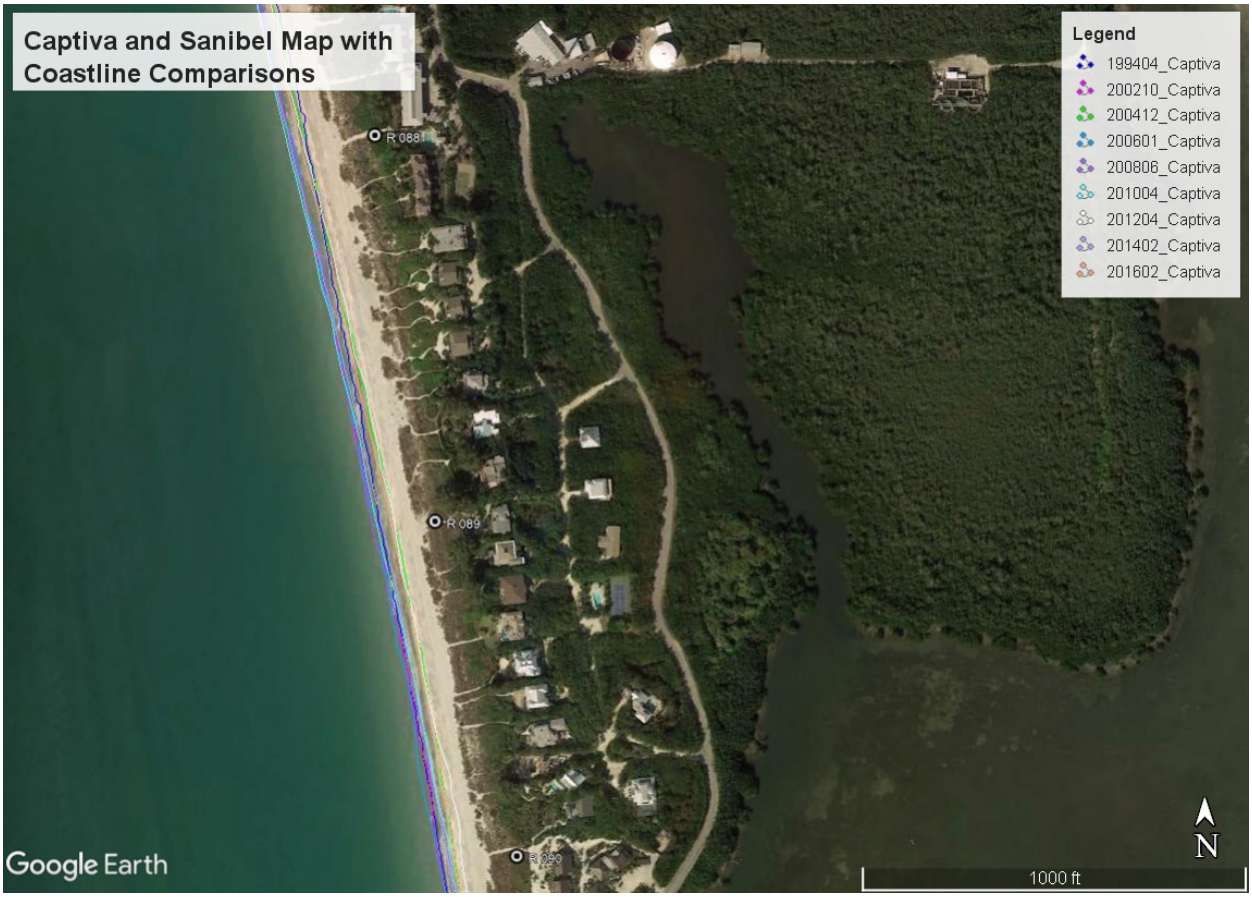


Figure 41. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Captiva Island.

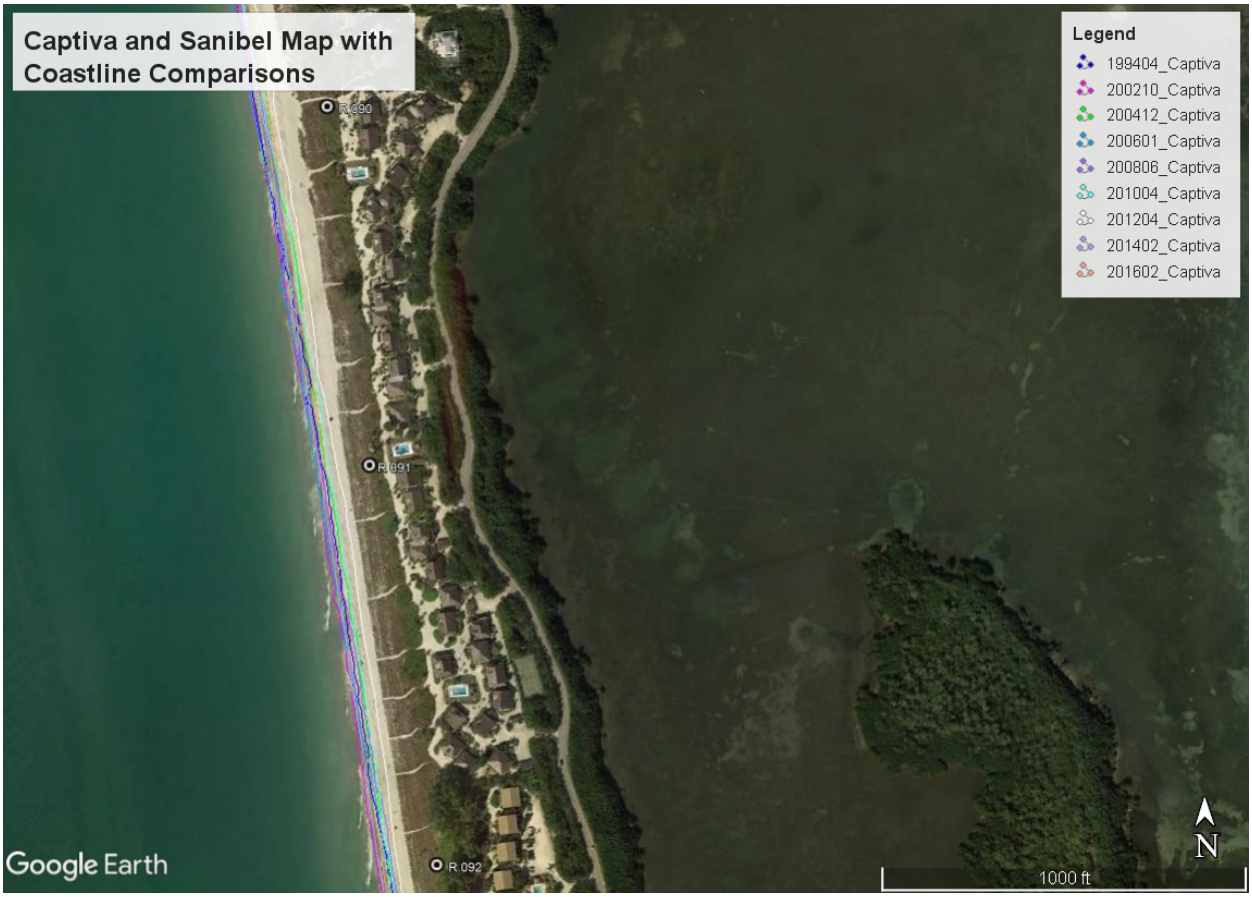


Figure 42. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Captiva Island.

Figure 43. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Captiva Island.

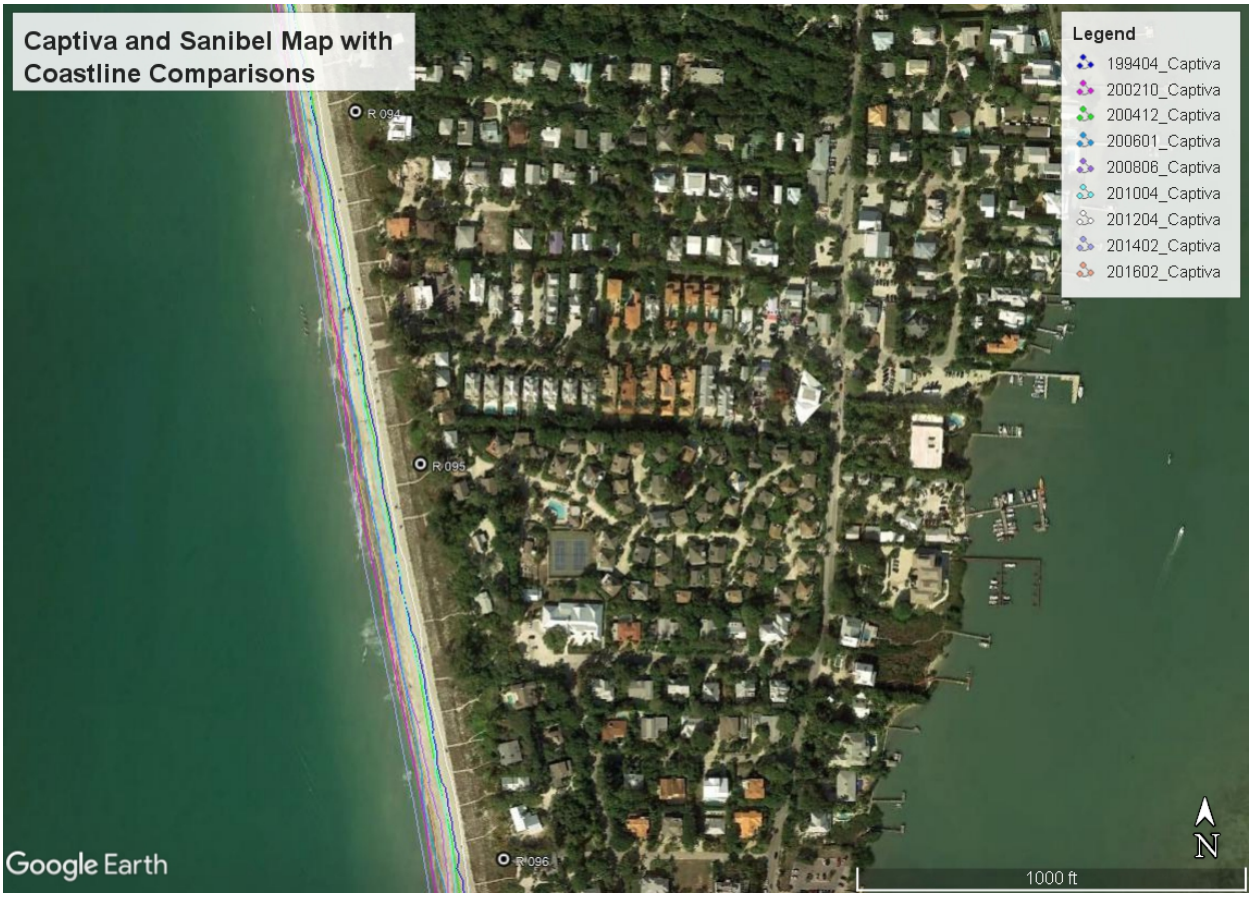


Figure 44. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Captiva Island.

Figure 45. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Captiva Island.

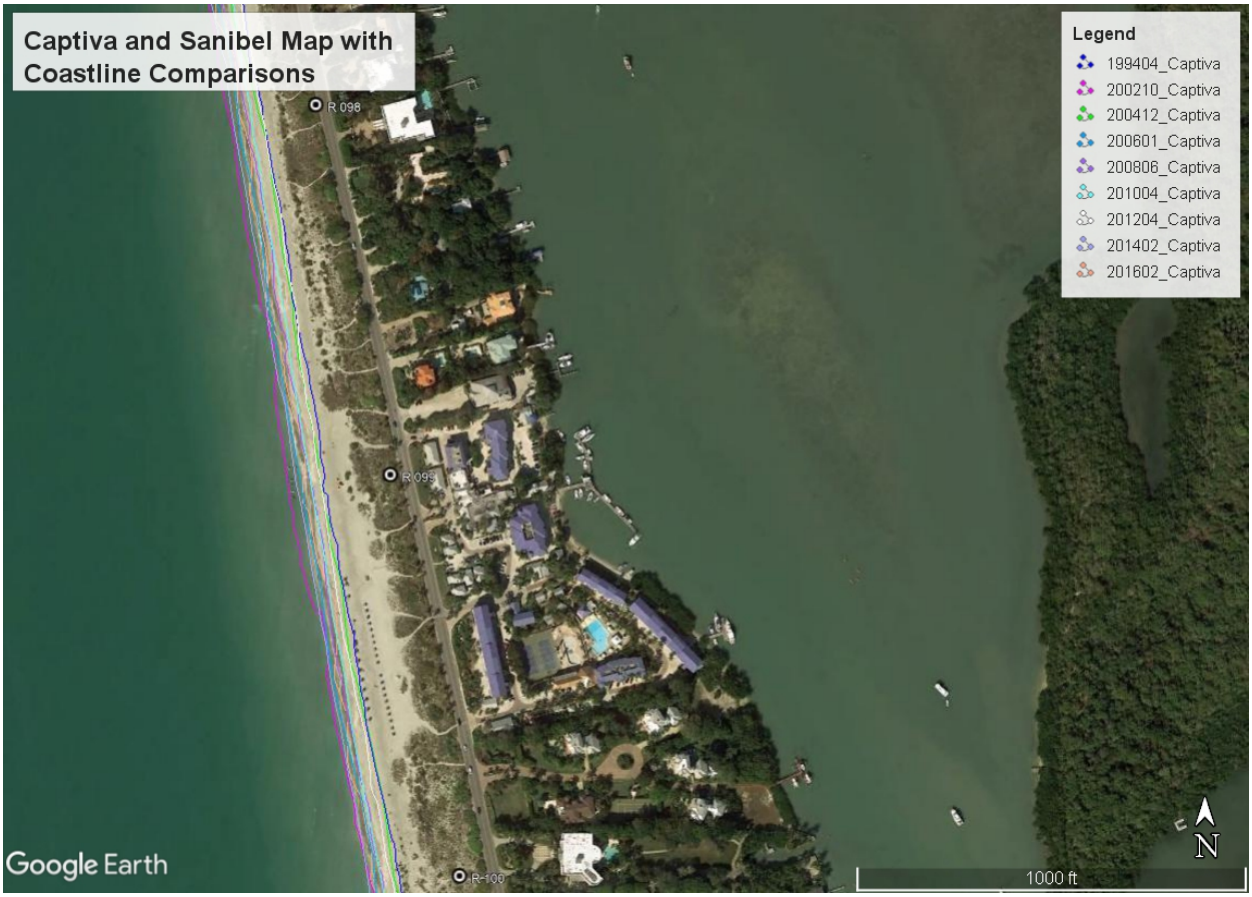


Figure 46. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Captiva Island.

Figure 47. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Captiva Island.

Figure 48. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Captiva Island.

Figure 49. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Captiva Island.

Figure 50. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Captiva Island.

Figure 51. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Captiva Island.

Figure 52. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 53. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 54. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 55. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 56. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 57. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 58. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 59. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

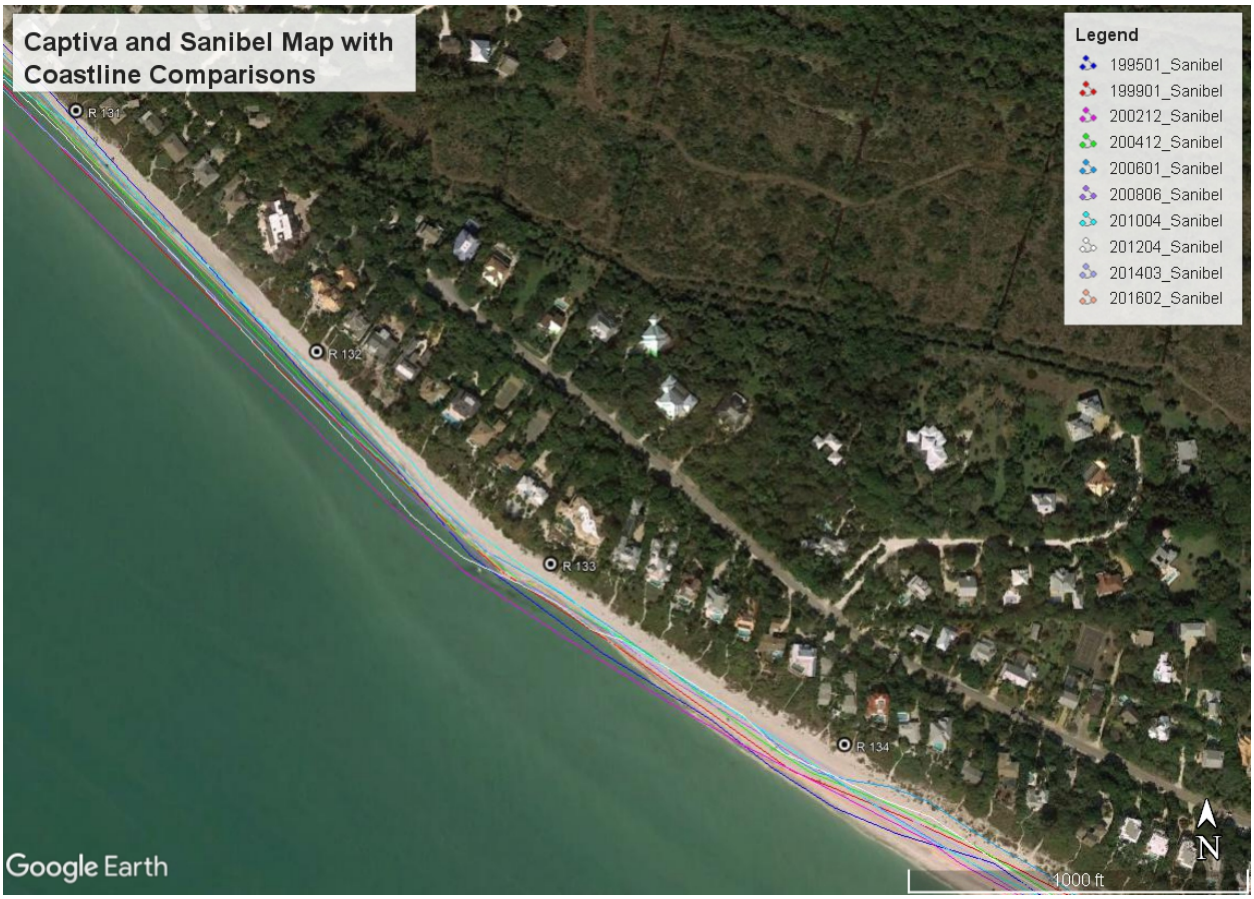


Figure 60. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 61. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 62. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 63. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 64. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

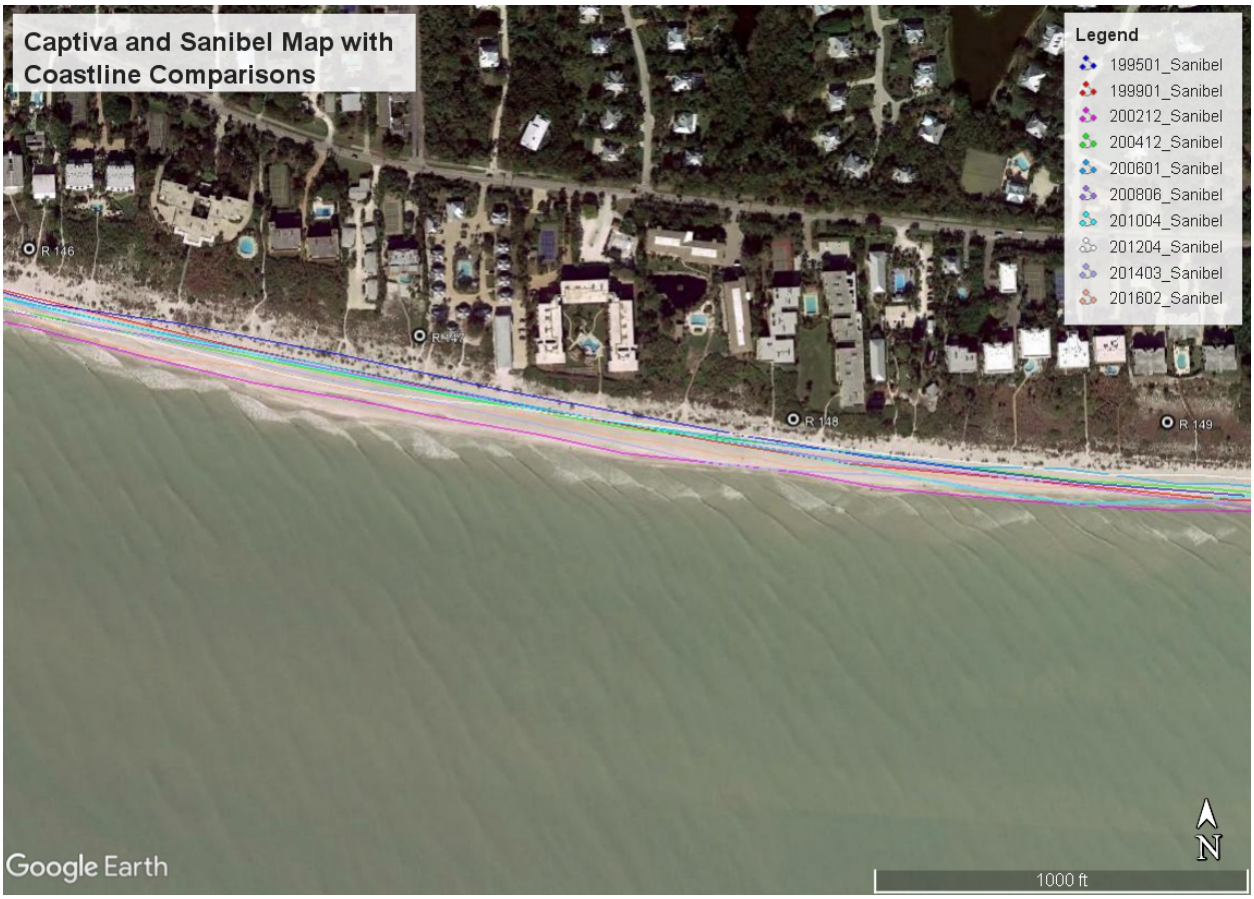


Figure 65. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 66. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 67. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 68. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 69. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

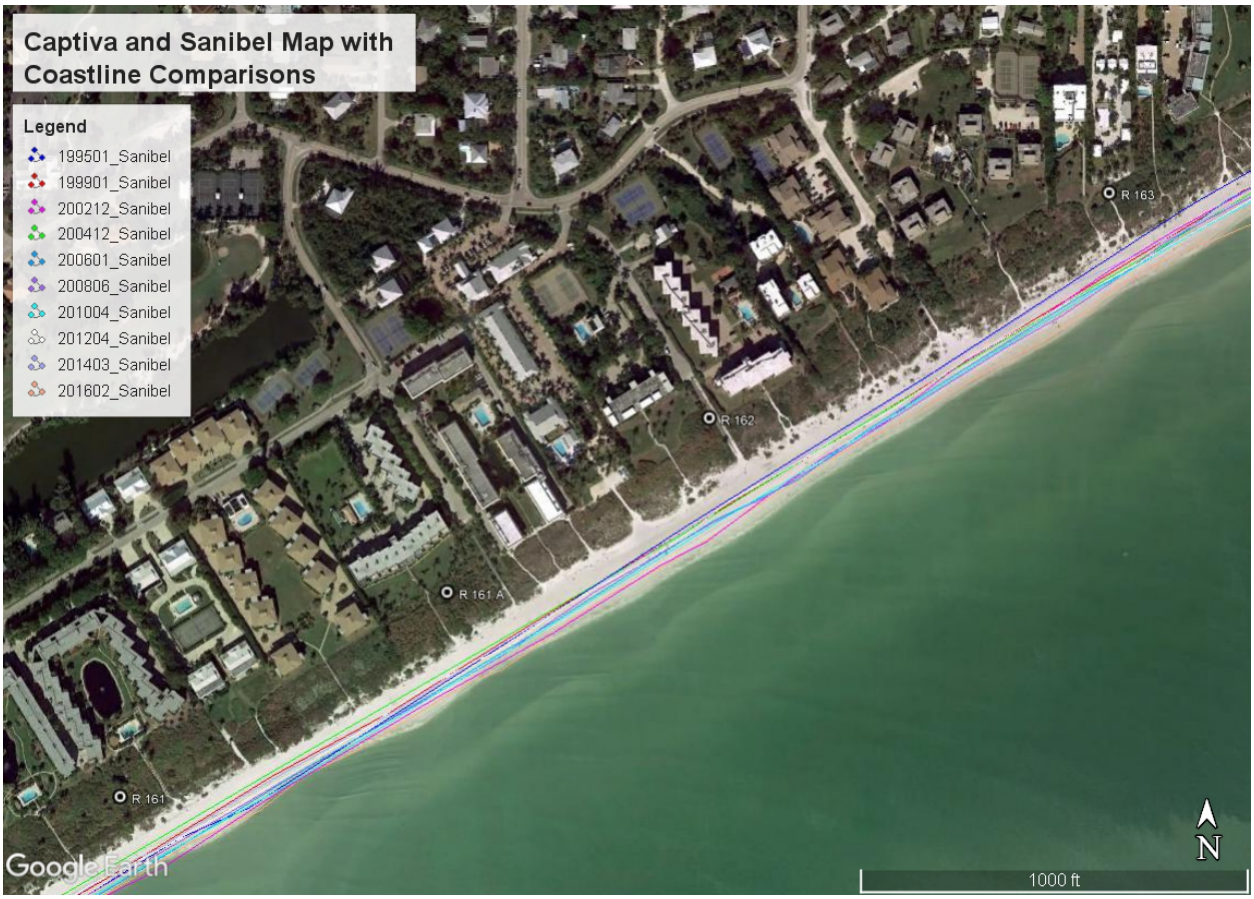


Figure 70. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 71. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 72. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

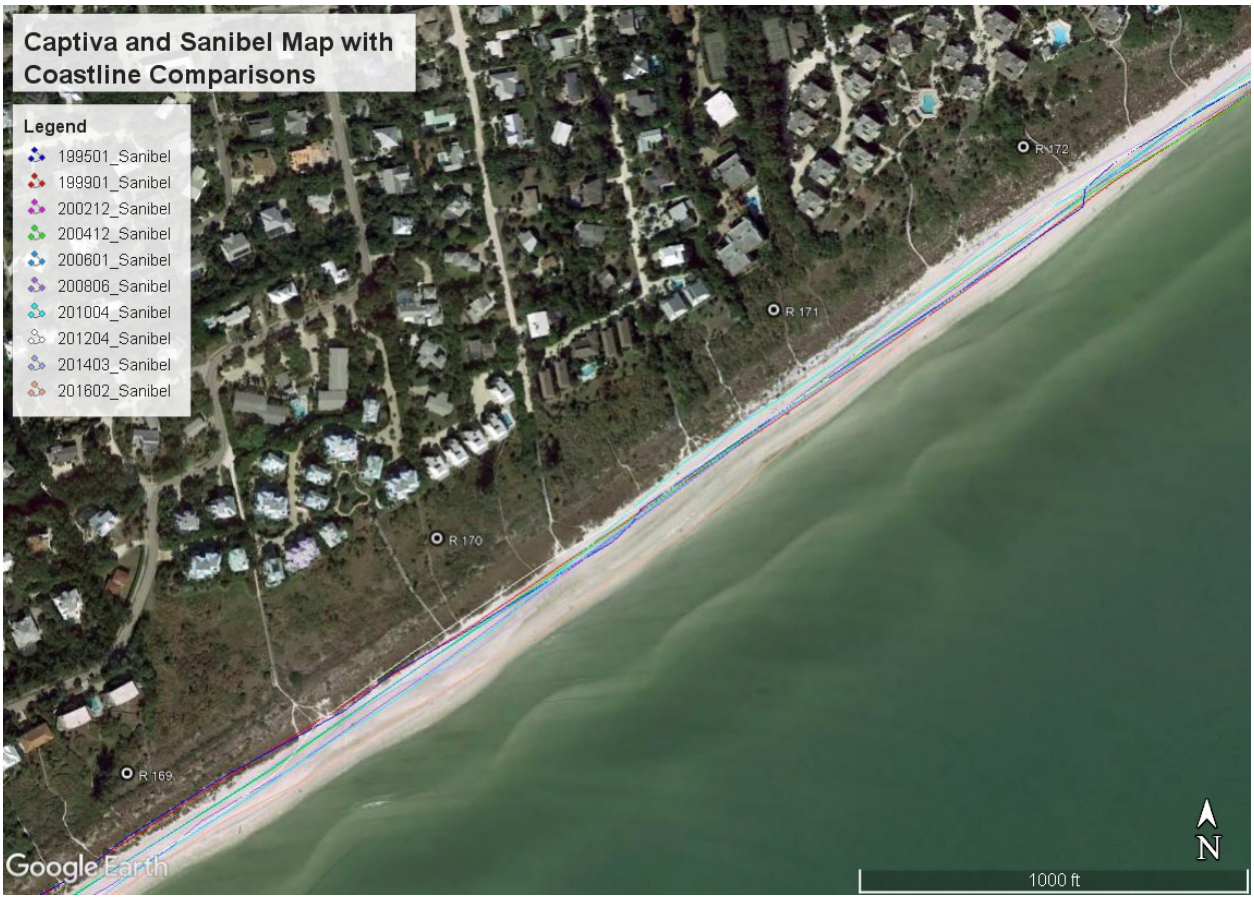


Figure 73. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 74. Map showing the positions of the shoreline through time superimposed upon a 2019 image of Sanibel Island.

Figure 75. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Captiva Island.

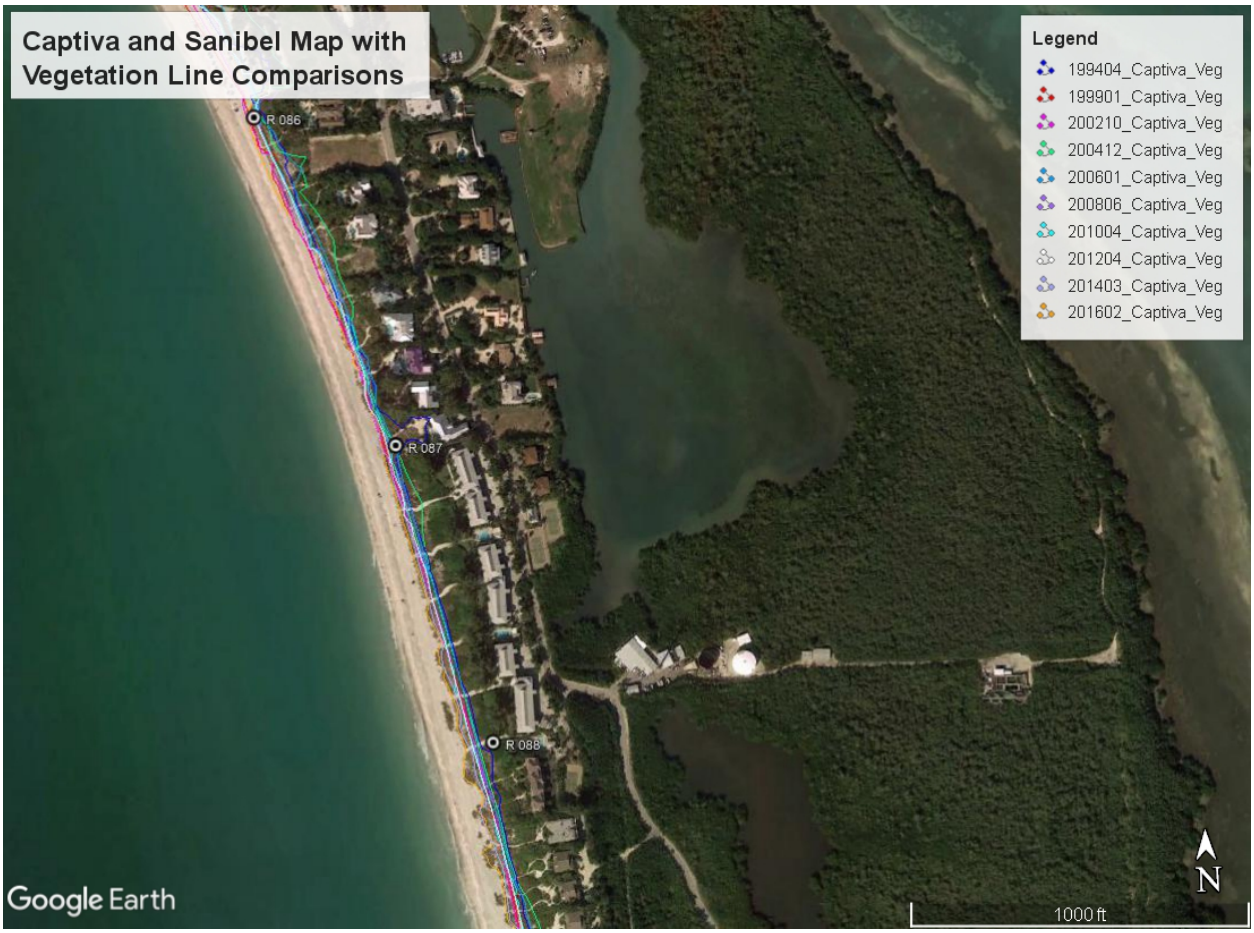


Figure 76. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Captiva Island.

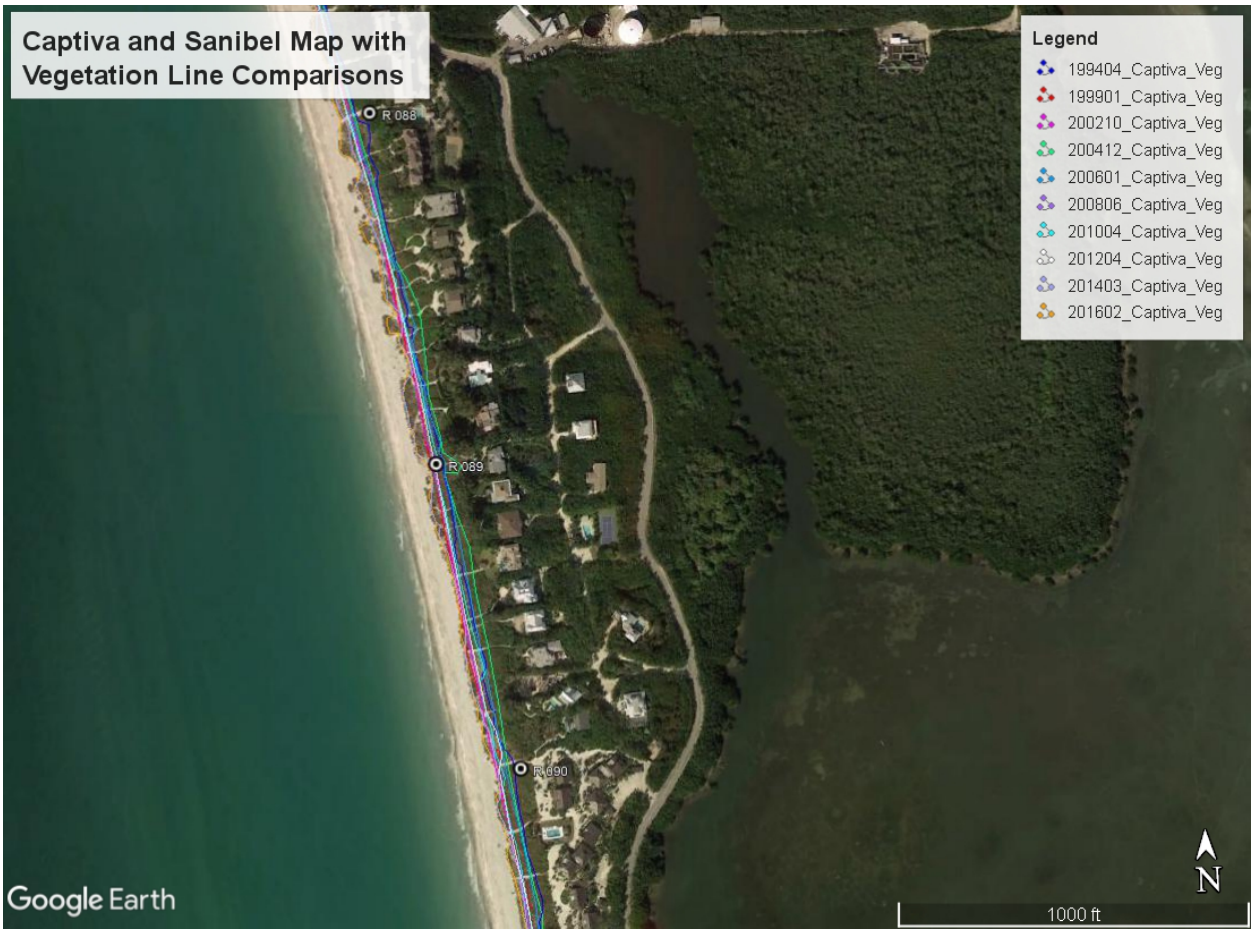


Figure 77. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Captiva Island.

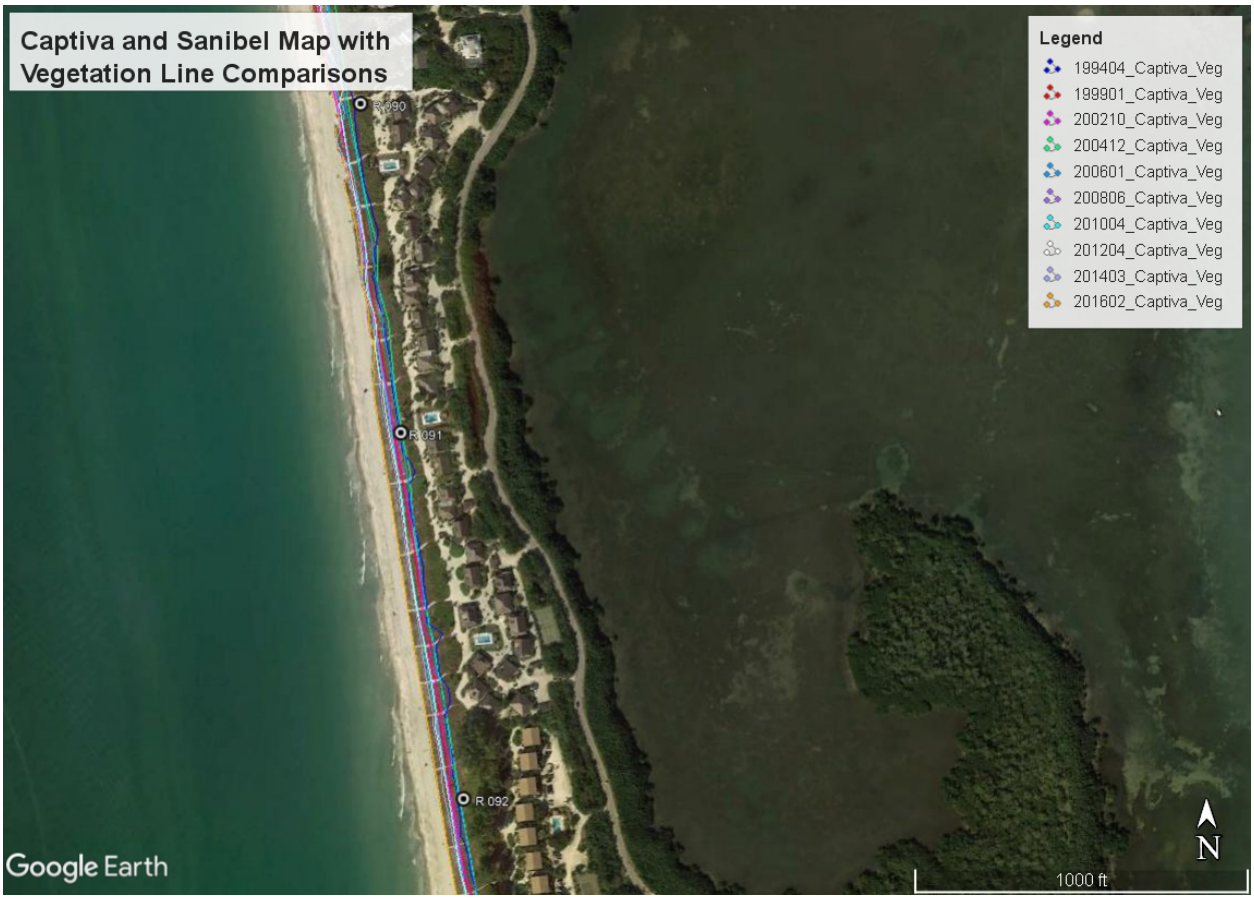


Figure 78. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Captiva Island.

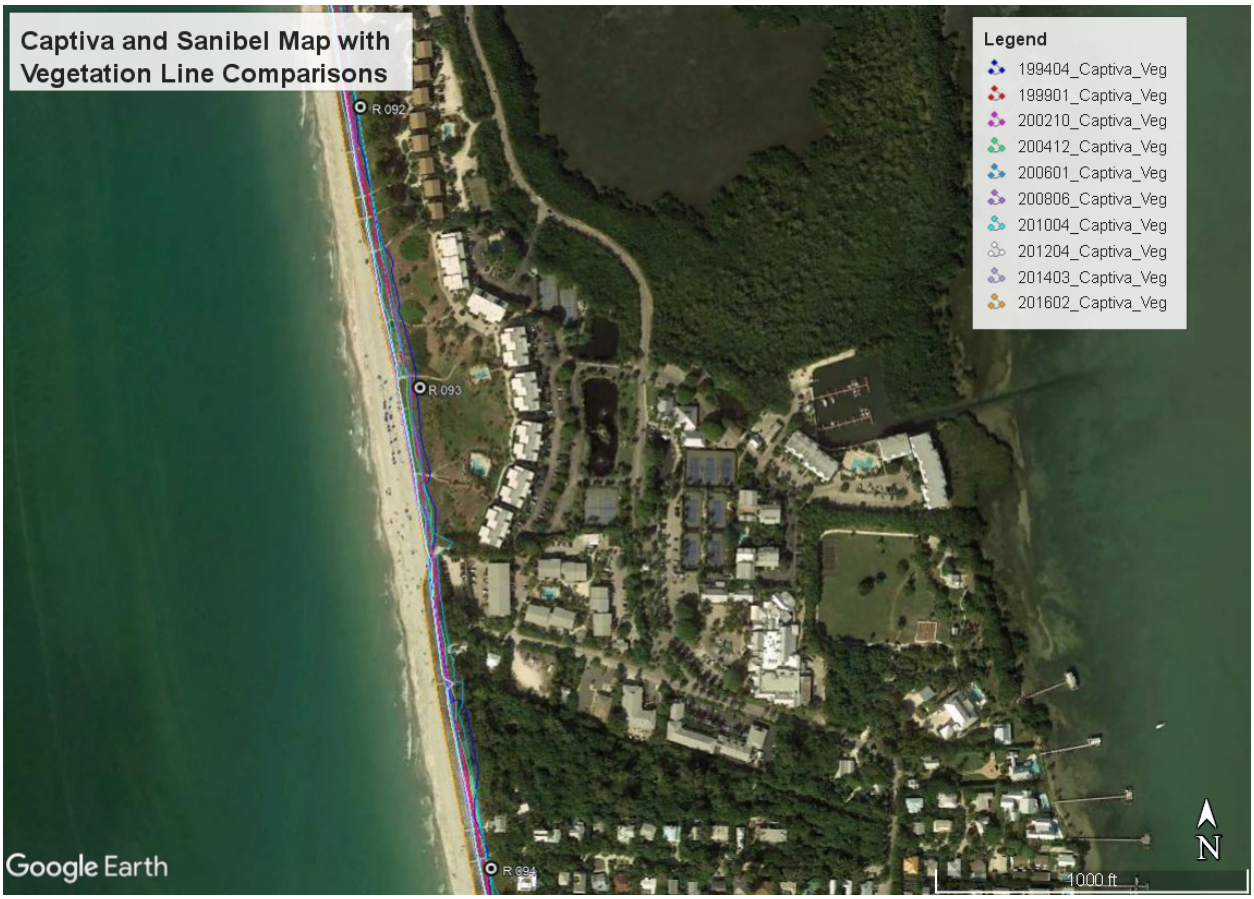


Figure 79. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Captiva Island.

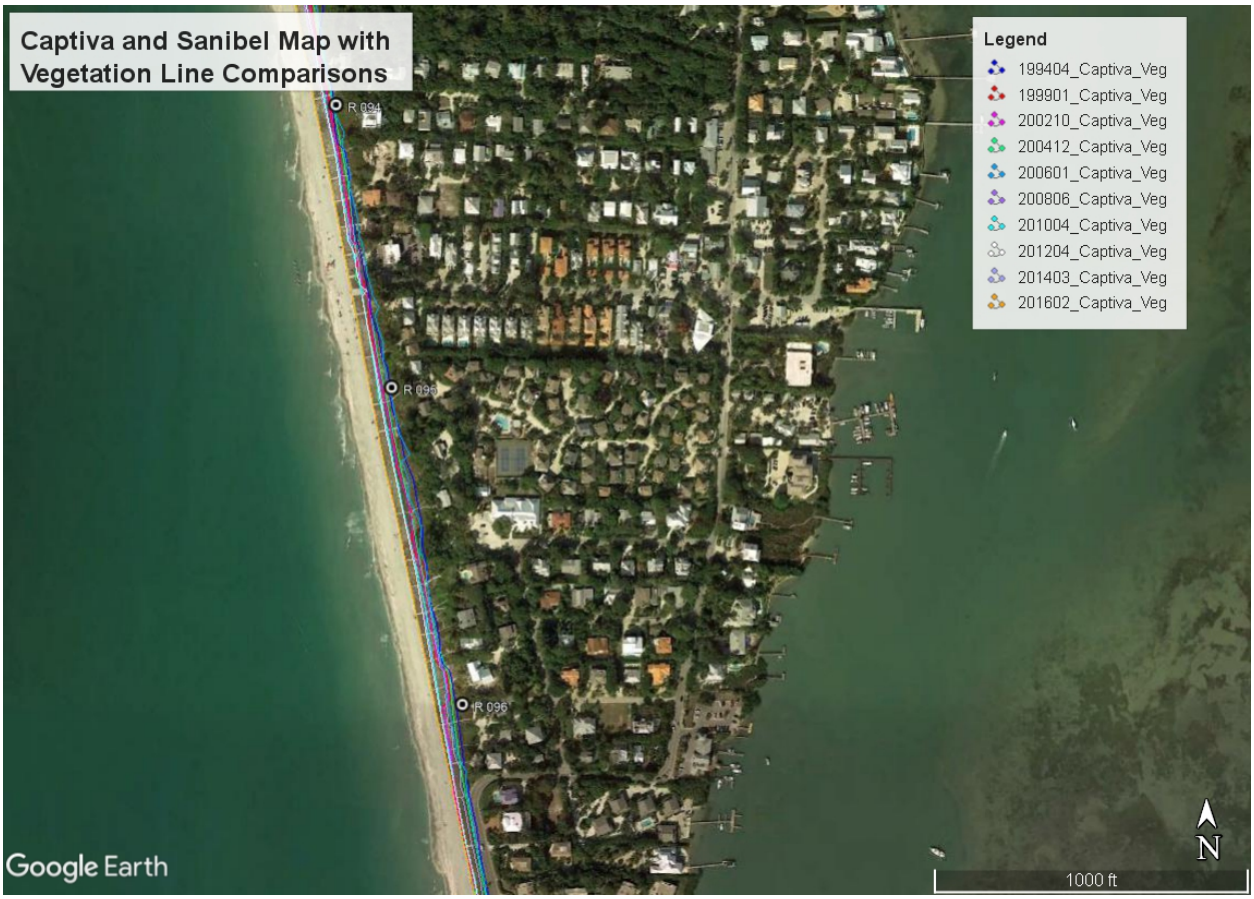


Figure 80. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Captiva Island.

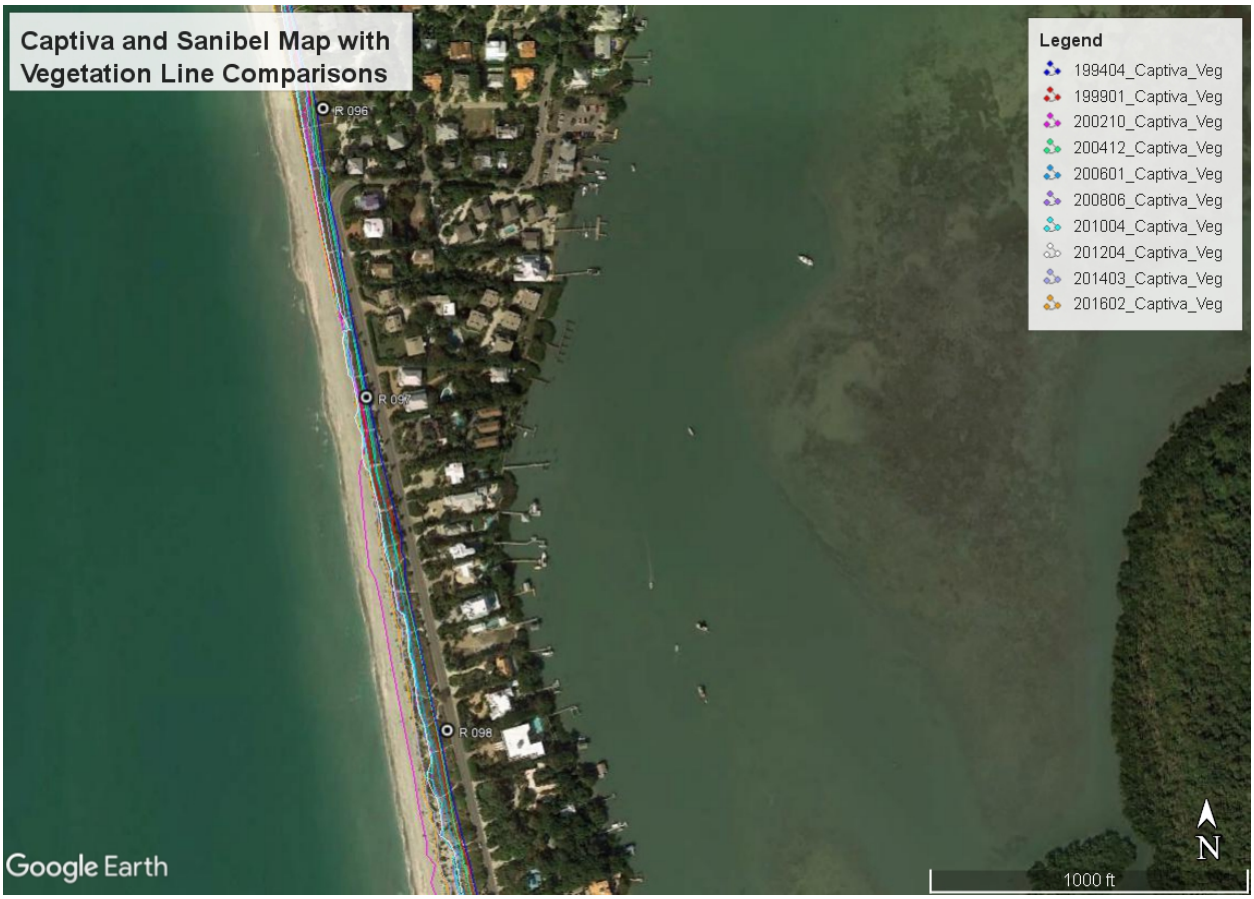


Figure 81. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Captiva Island.

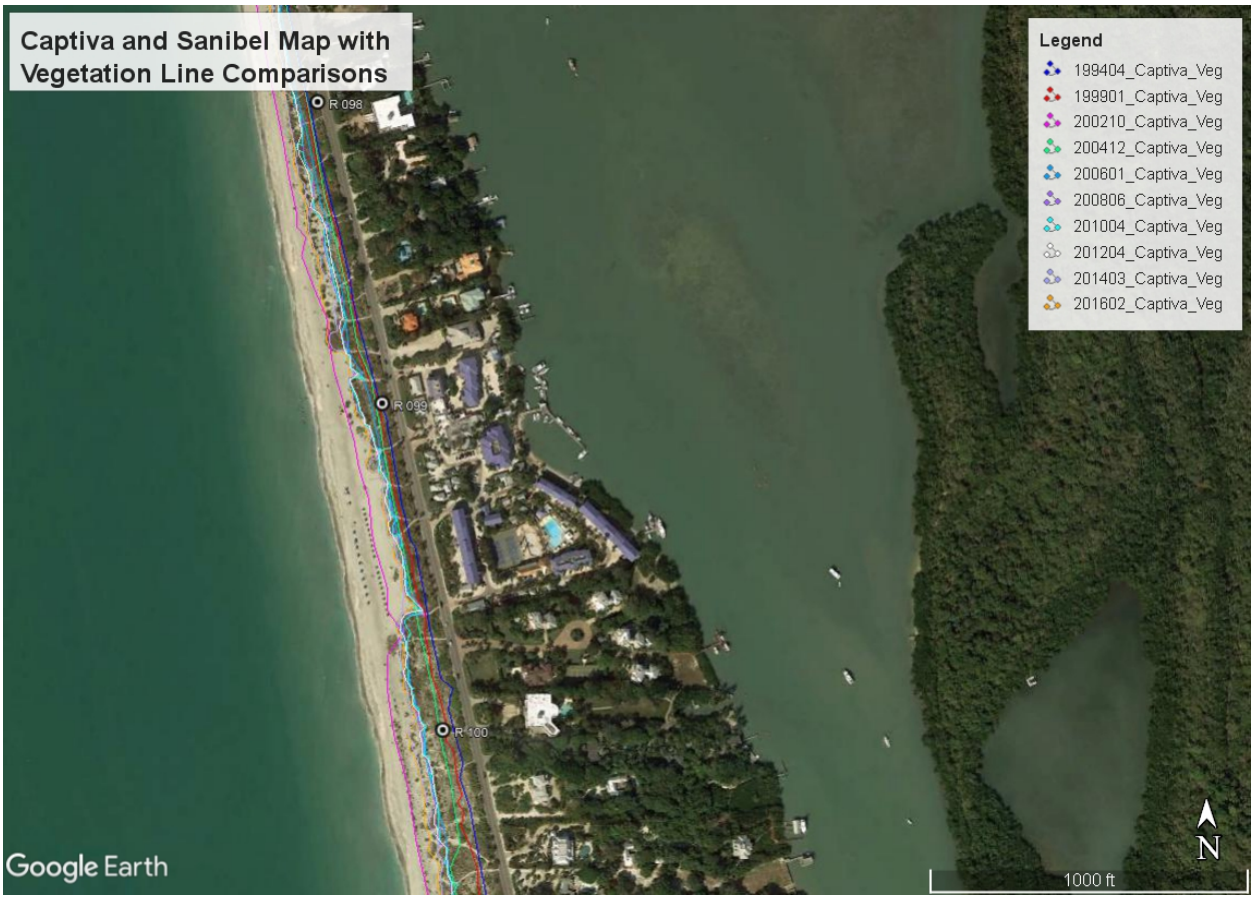


Figure 82. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Captiva Island.

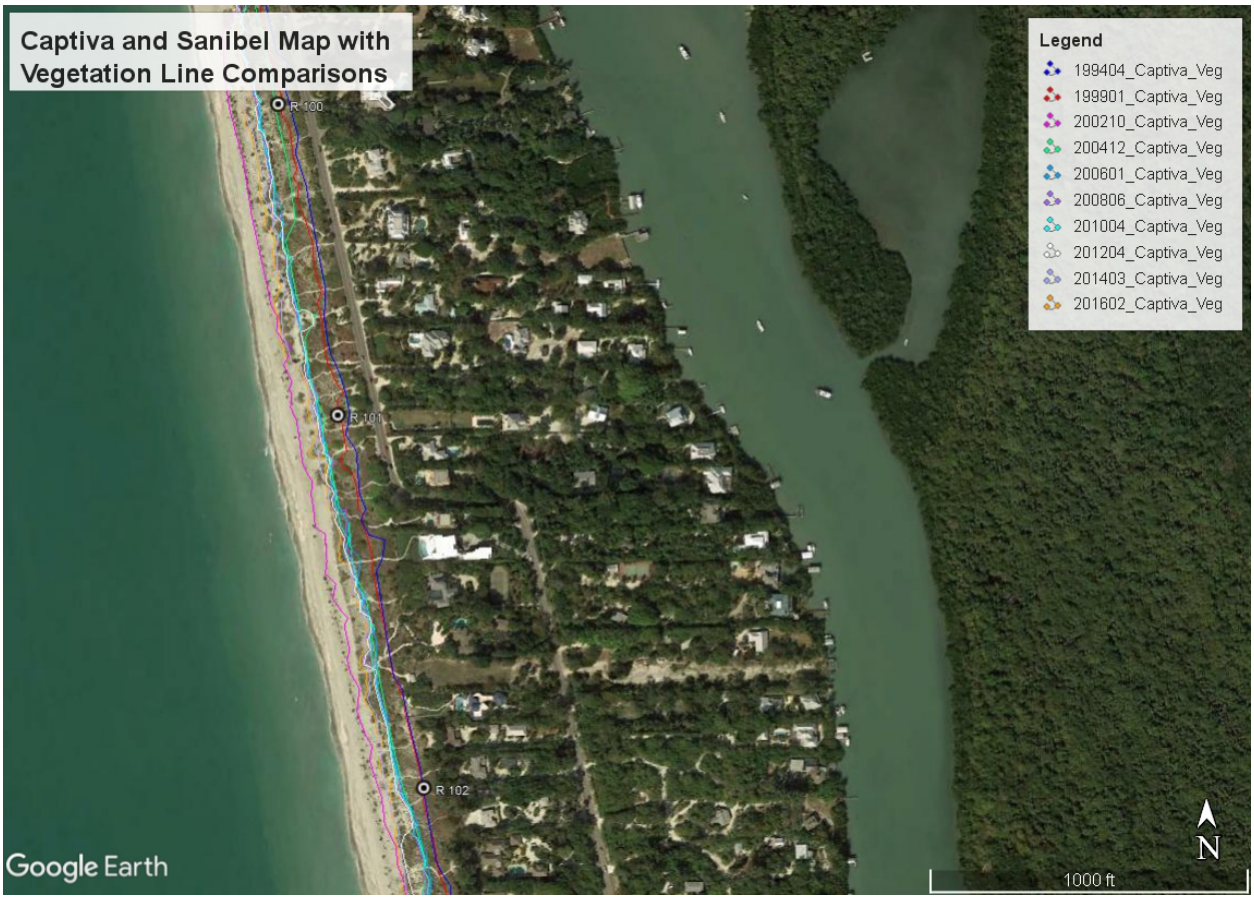


Figure 83. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Captiva Island.

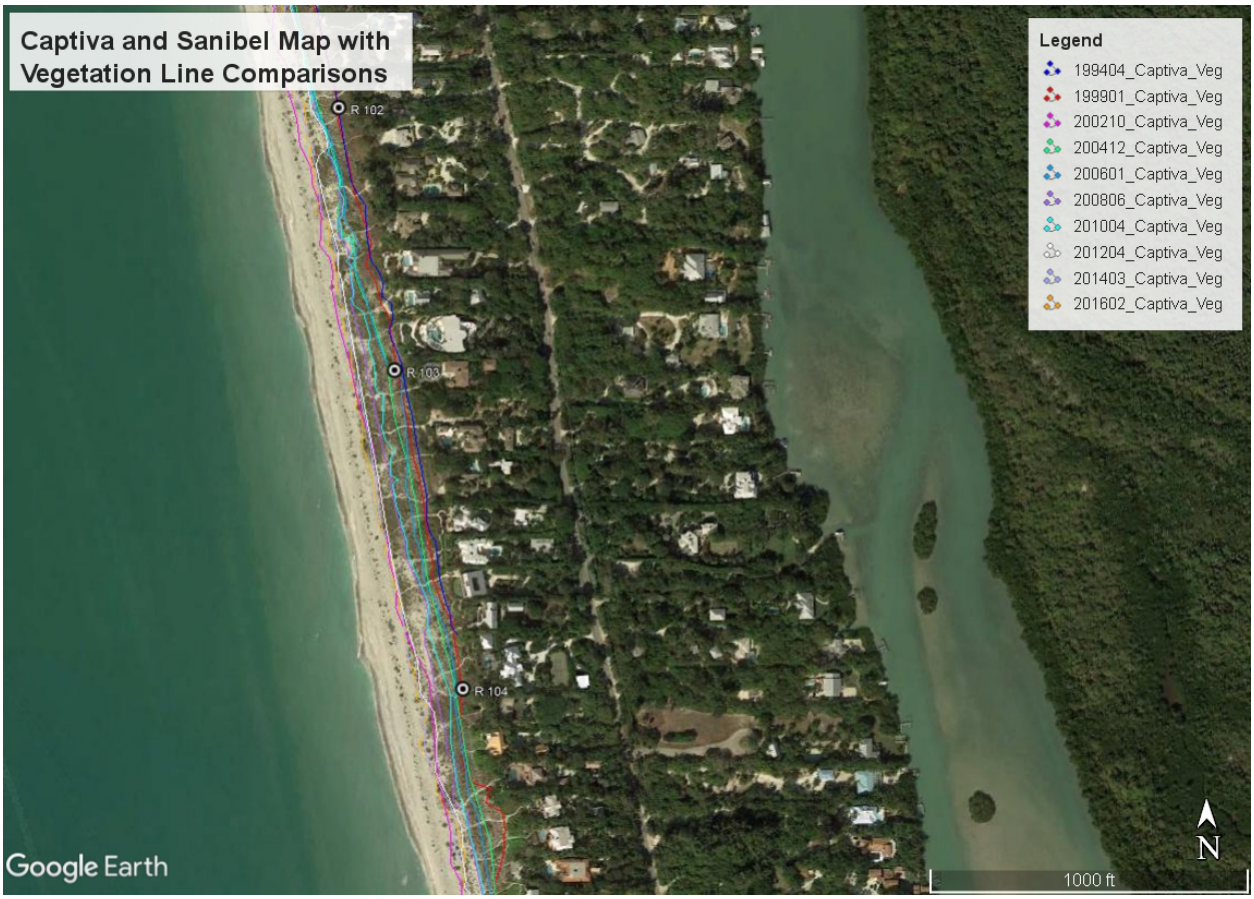


Figure 84. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Captiva Island.

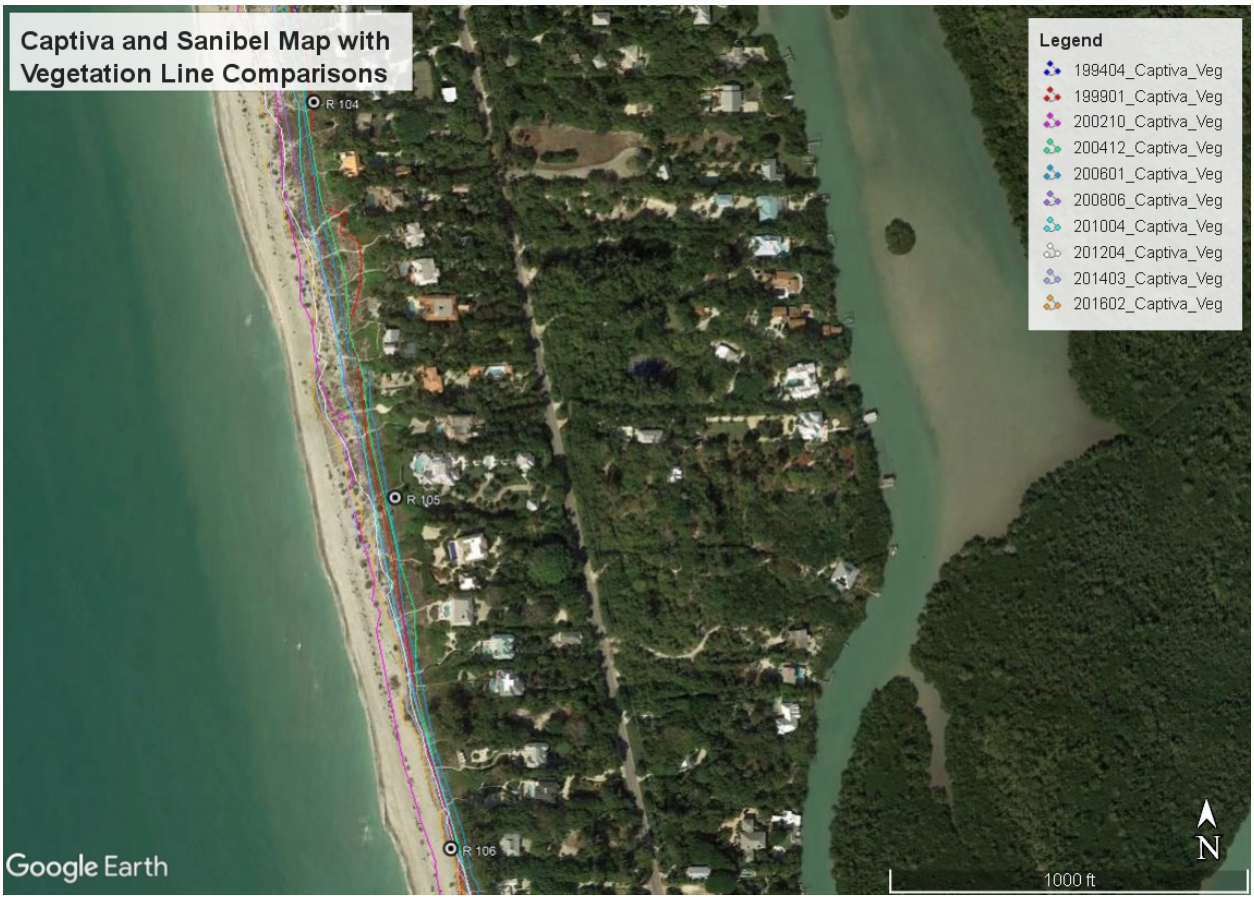


Figure 85. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Captiva Island.

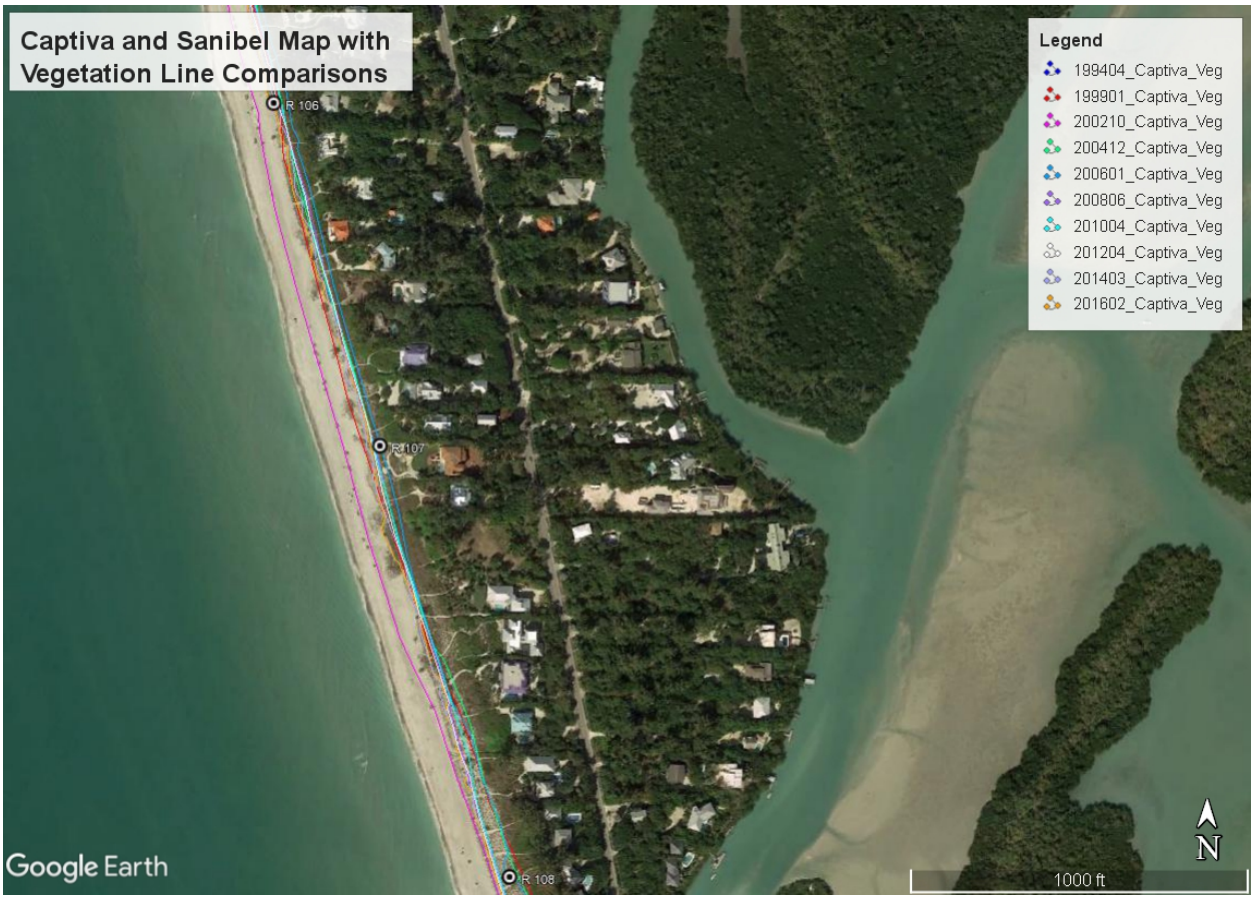


Figure 86. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Captiva Island.

Figure 87. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Captiva Island.

Figure 88. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

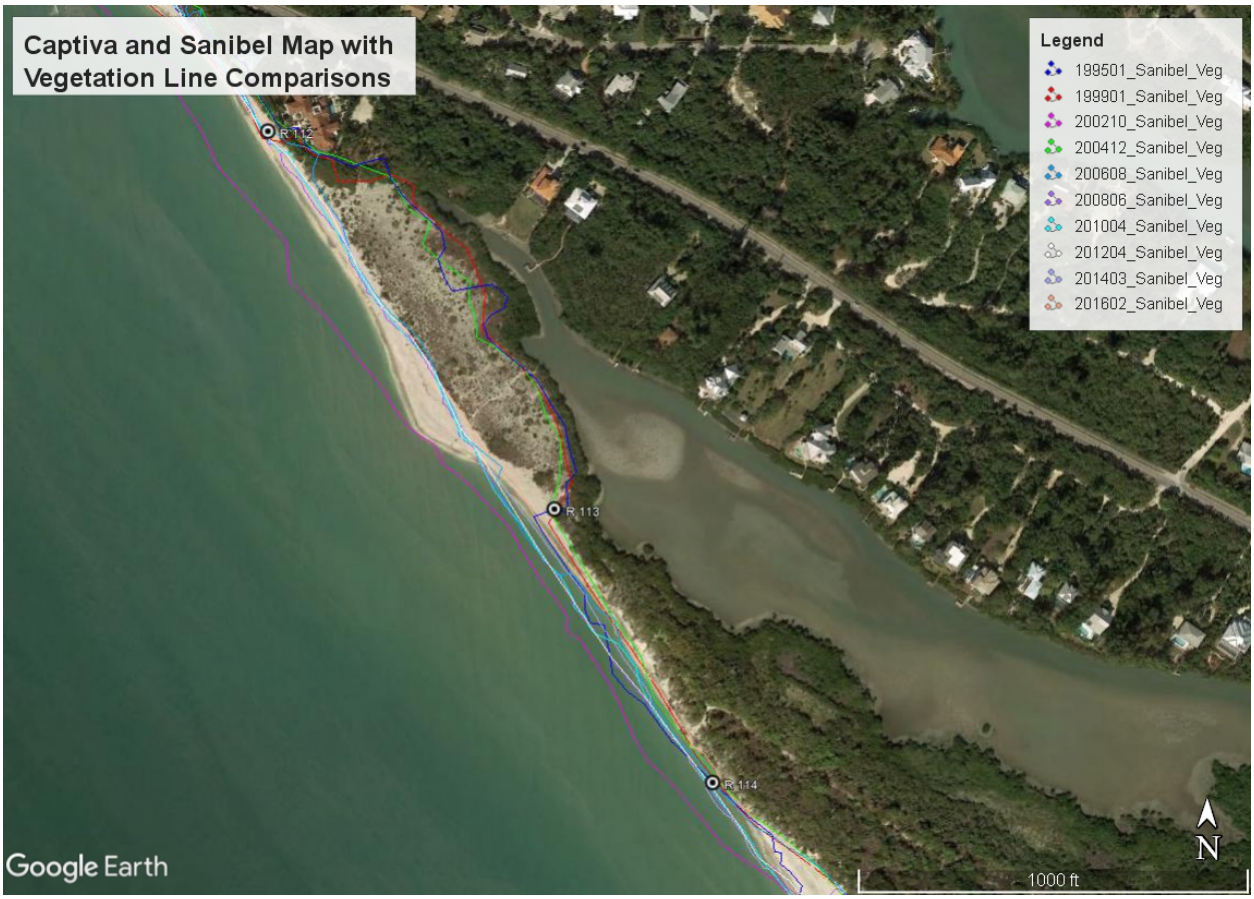


Figure 89. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

Figure 90. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

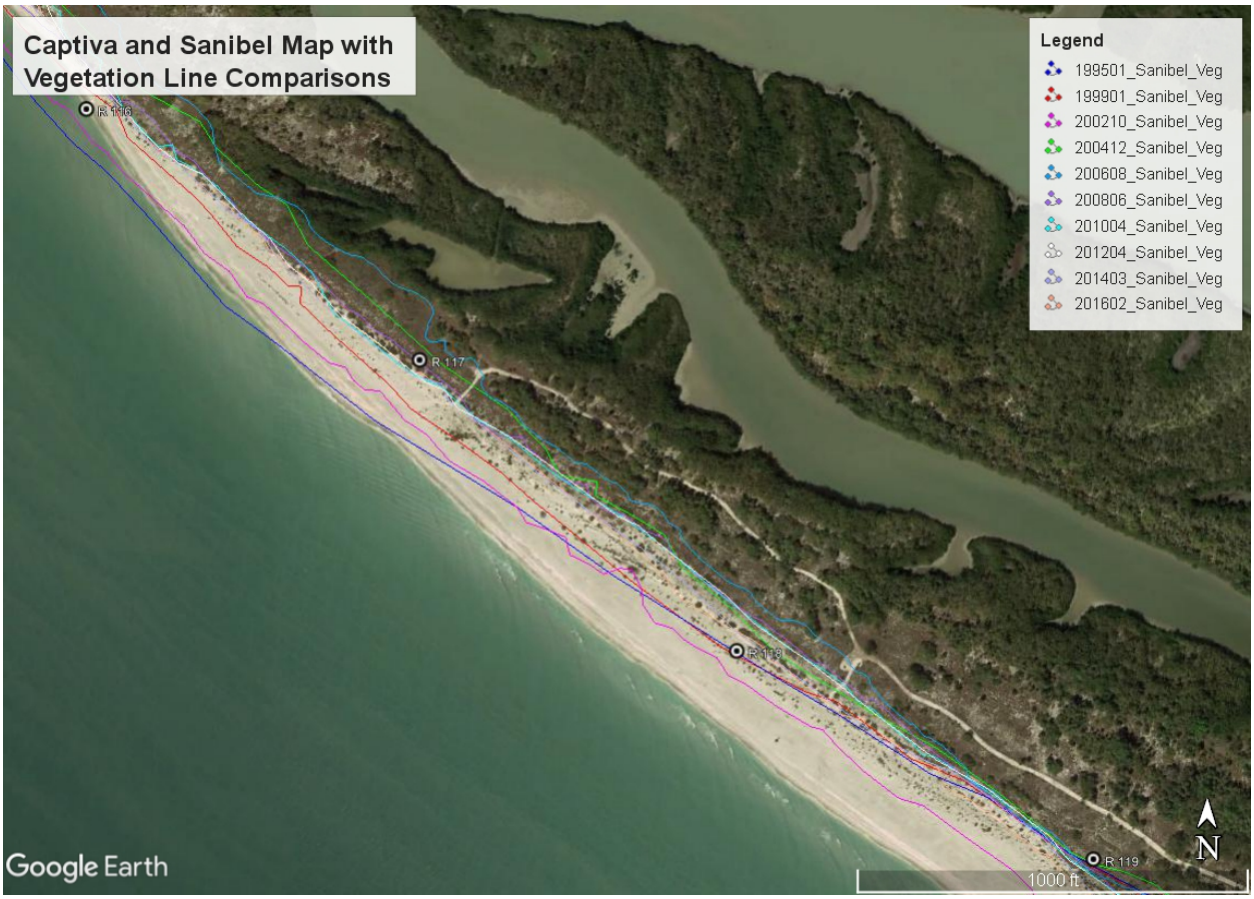


Figure 91. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

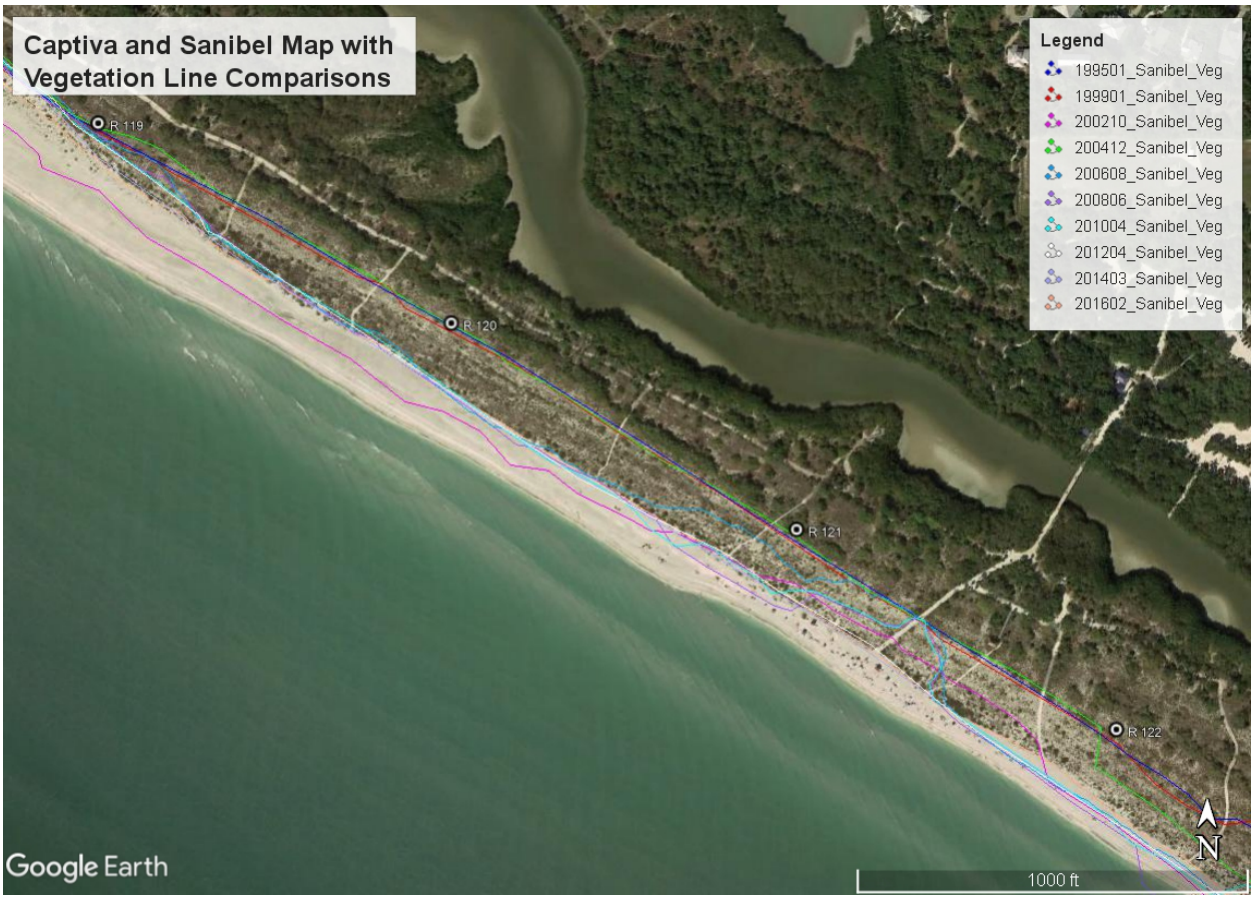


Figure 92. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

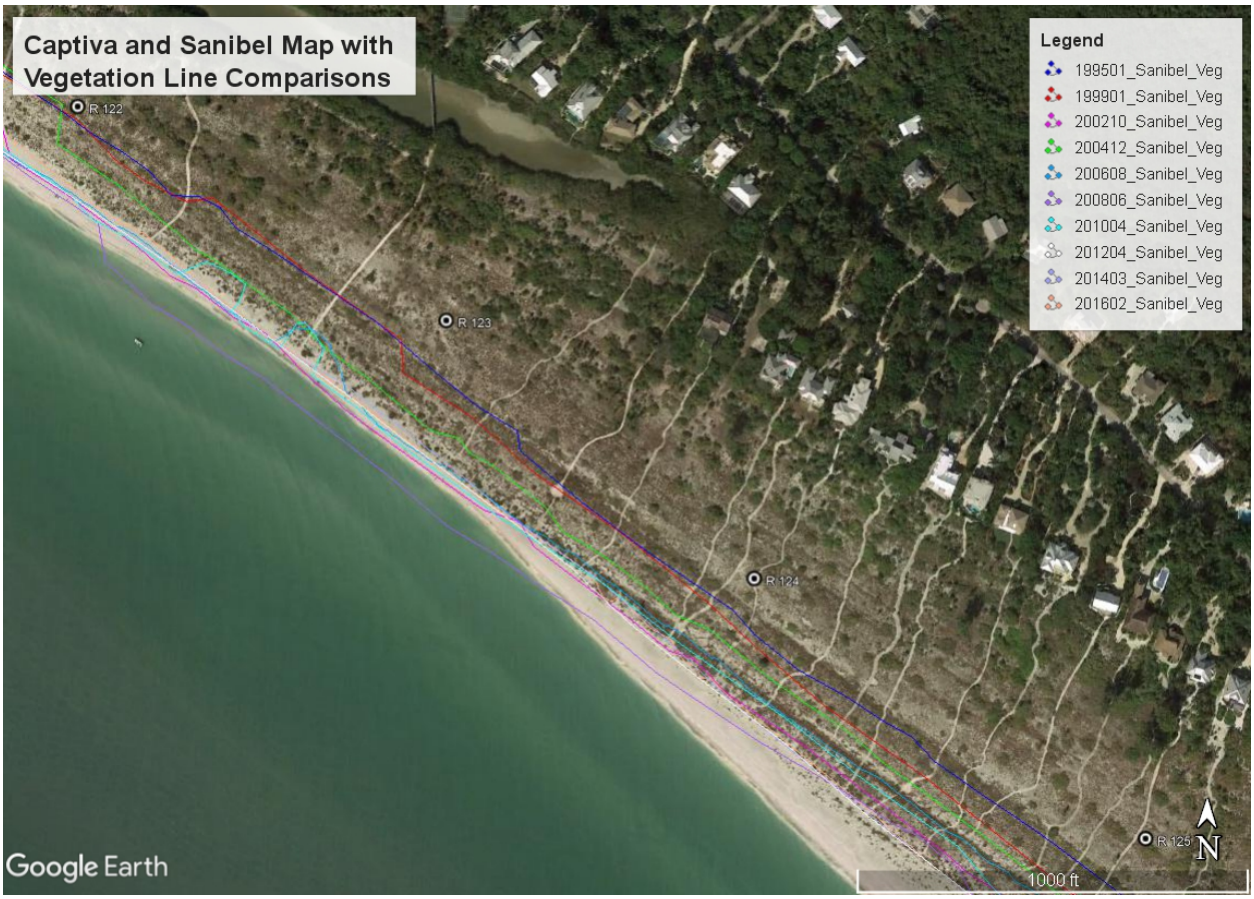


Figure 93. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

Figure 94. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

Figure 95. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

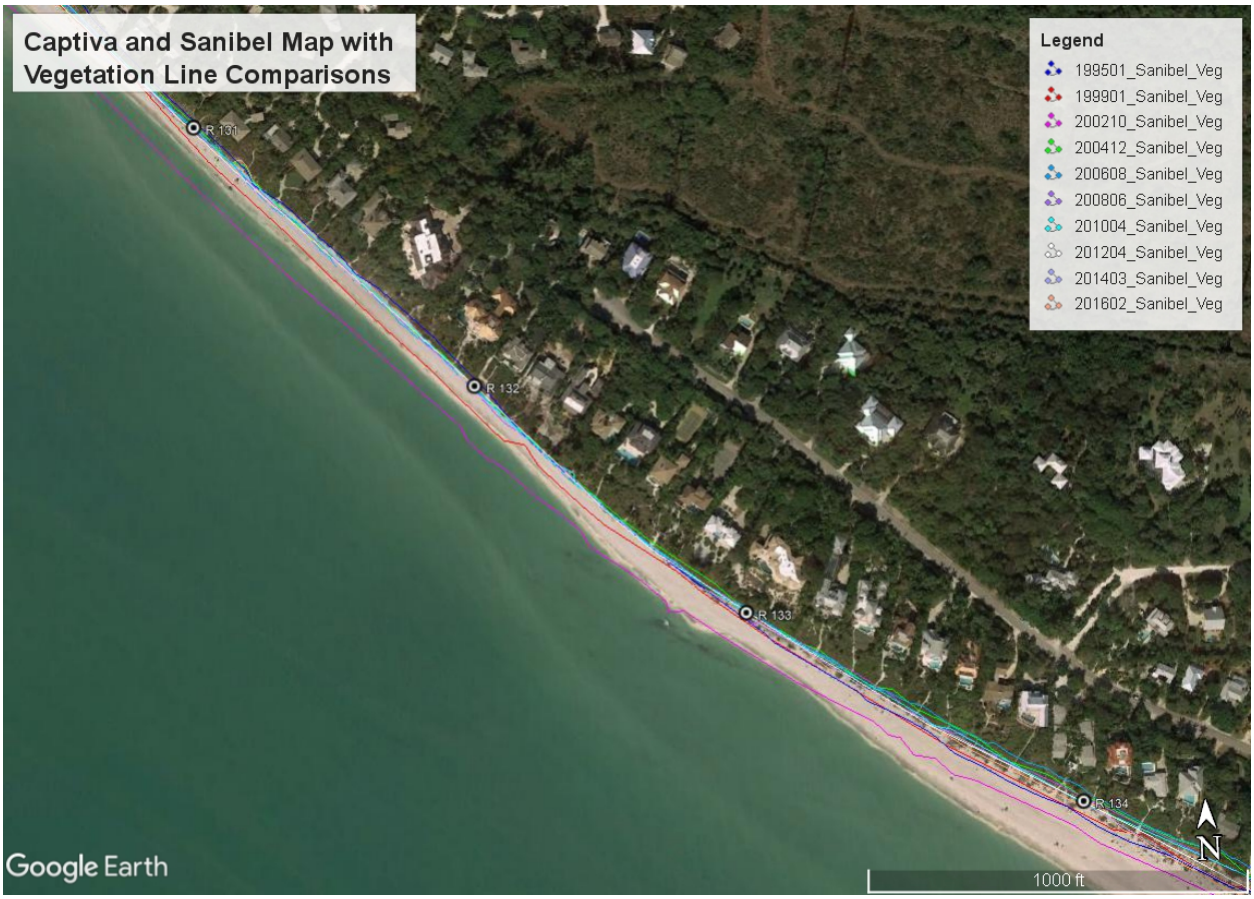


Figure 96. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

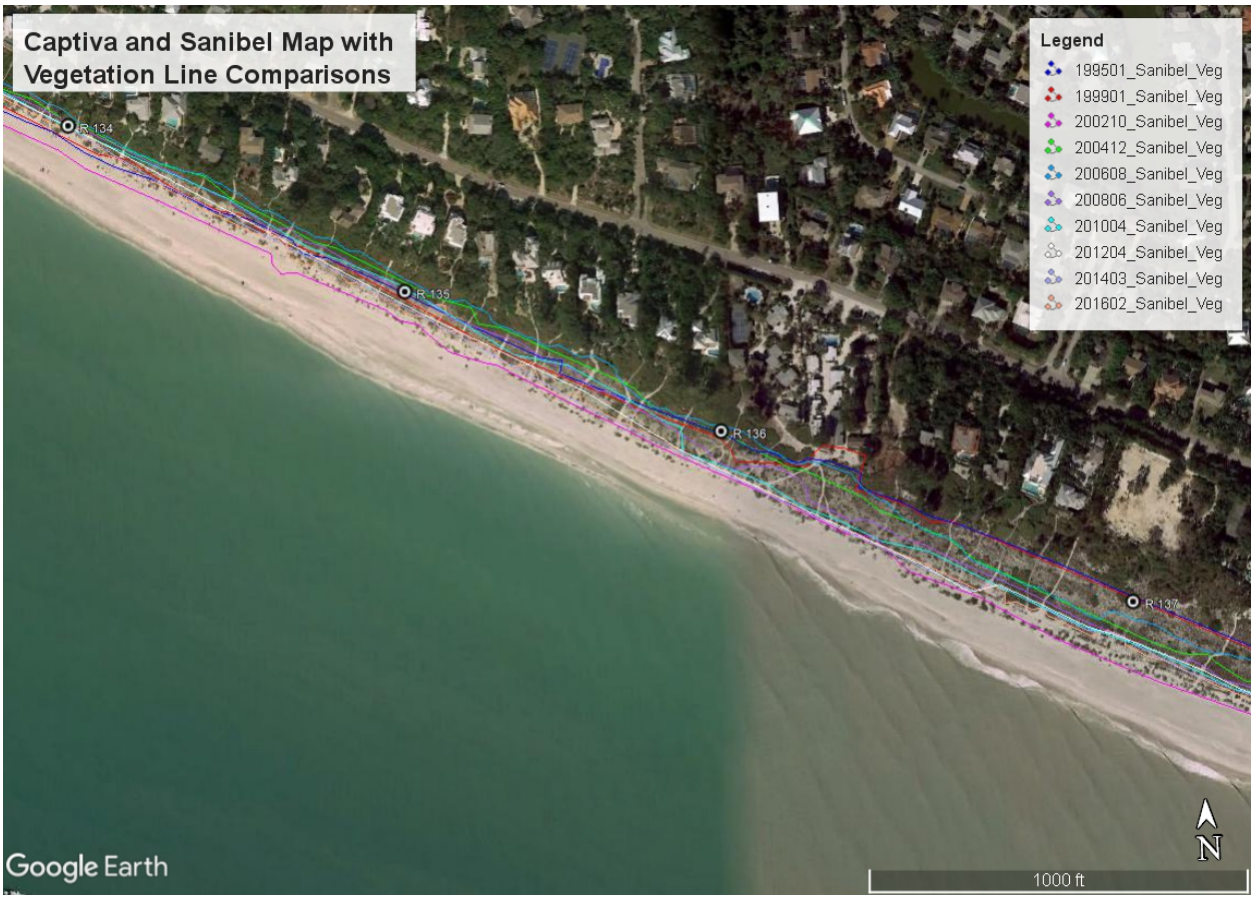


Figure 97. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

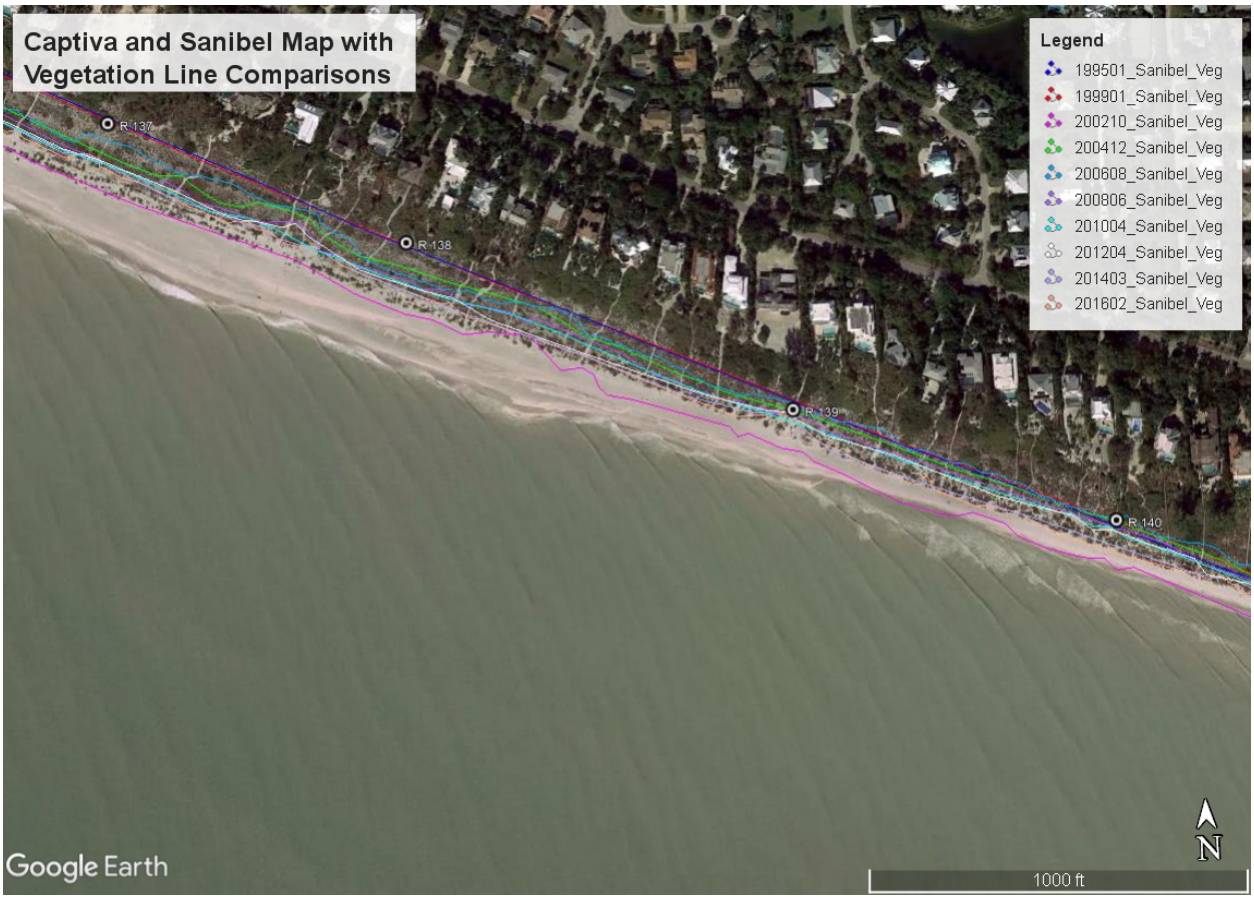


Figure 98. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

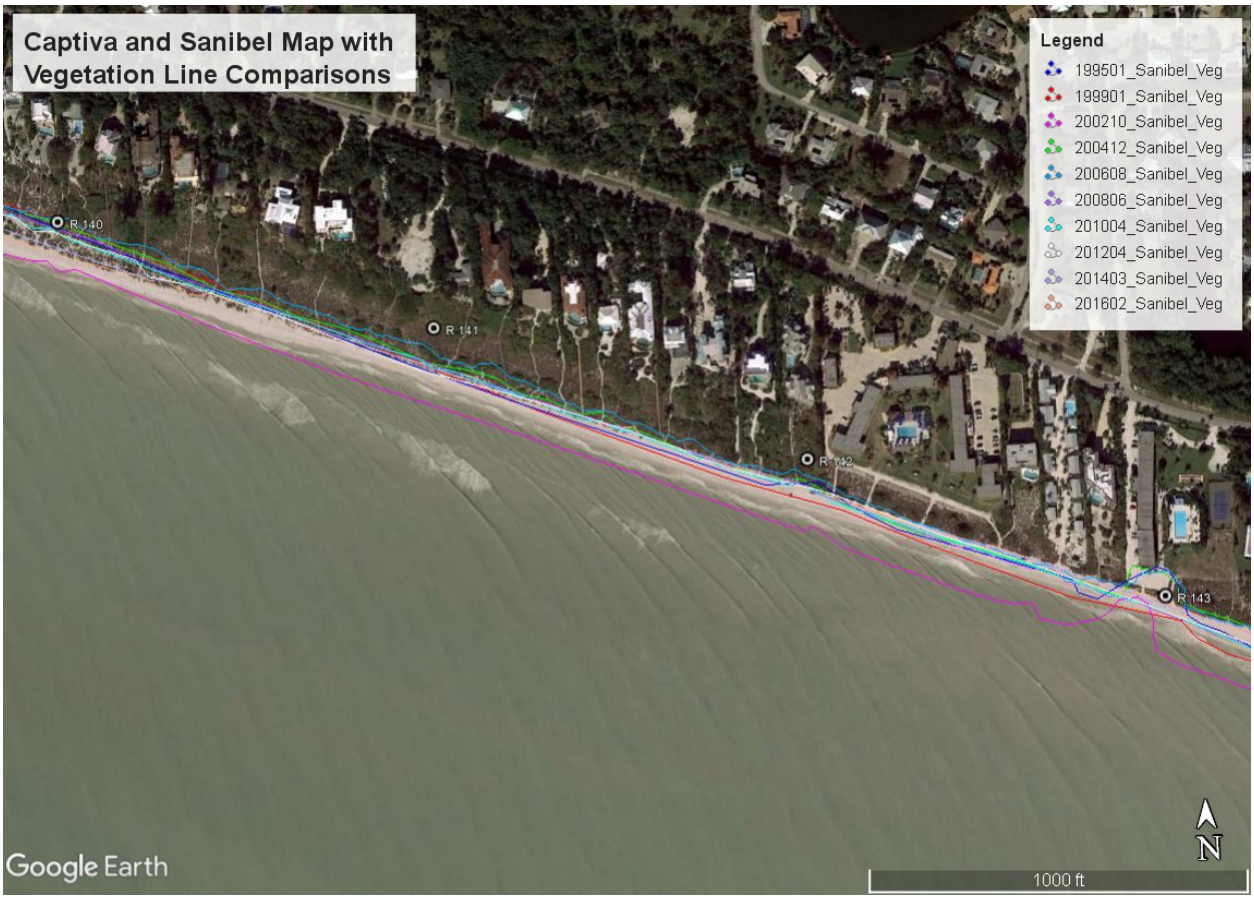


Figure 99. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

Figure 100. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

Figure 101. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

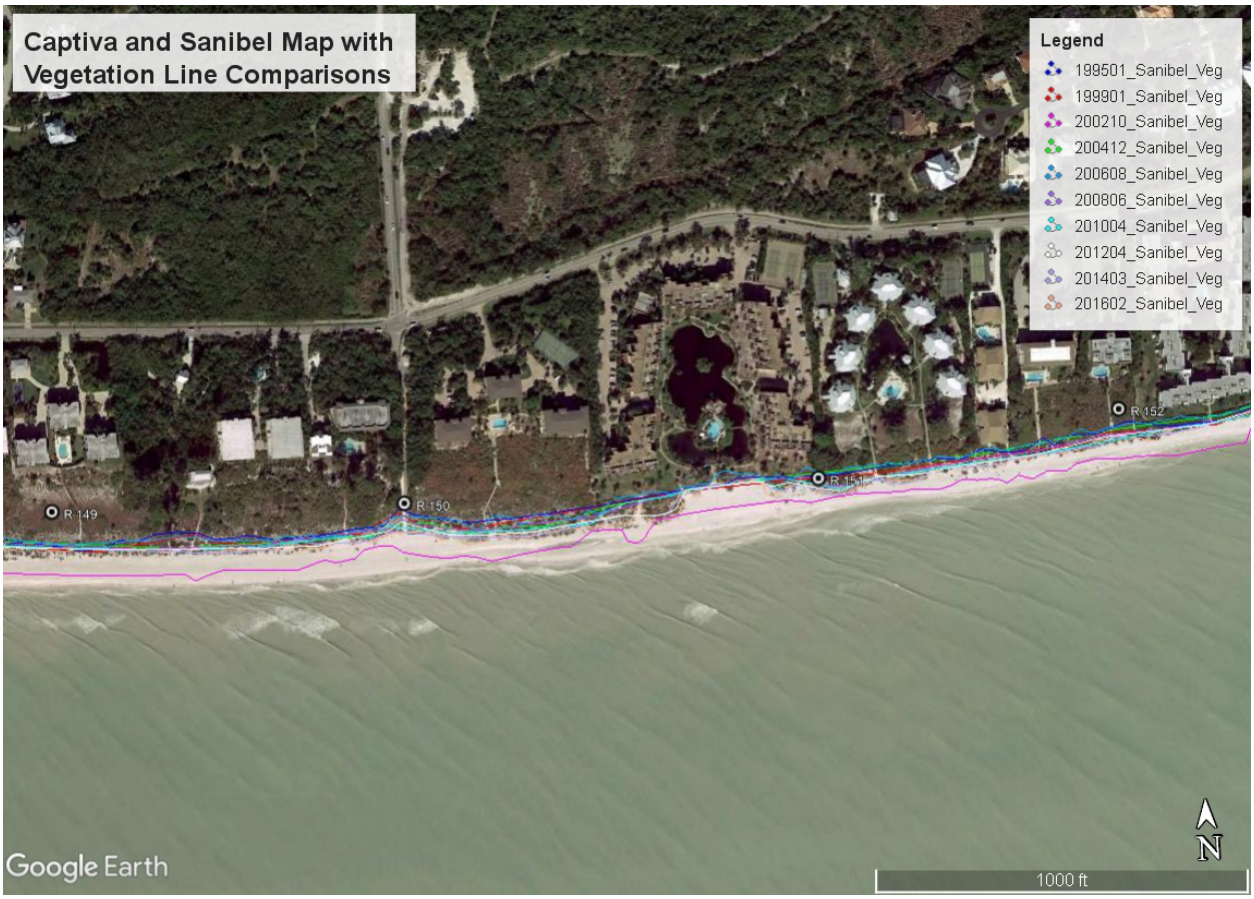


Figure 102. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

Figure 103. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

Figure 104. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

Figure 105. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

Figure 106. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

Figure 107. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

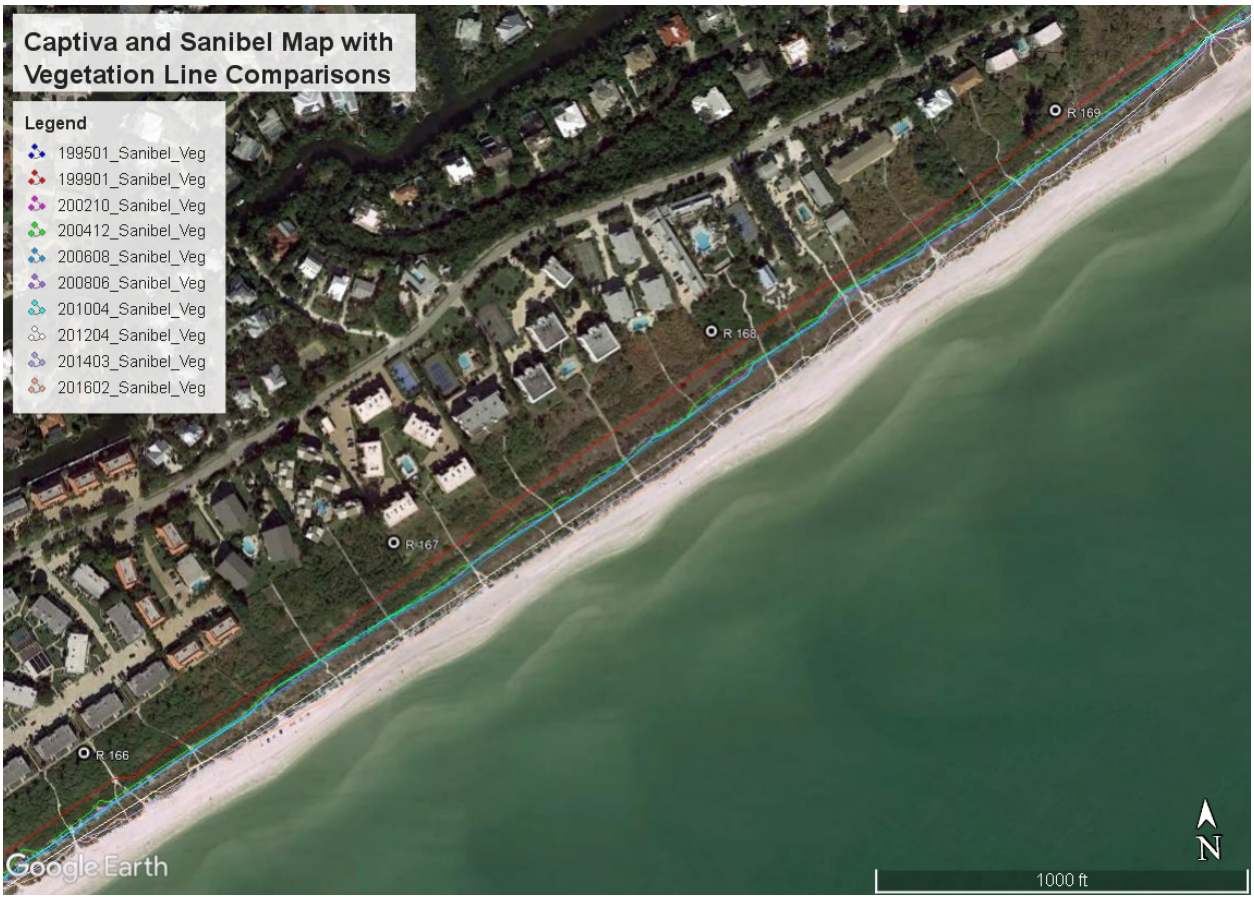


Figure 108. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

Figure 109. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

Figure 110. Map showing the positions of the seaward-most vegetation line through time superimposed upon a 2019 image of Sanibel Island.

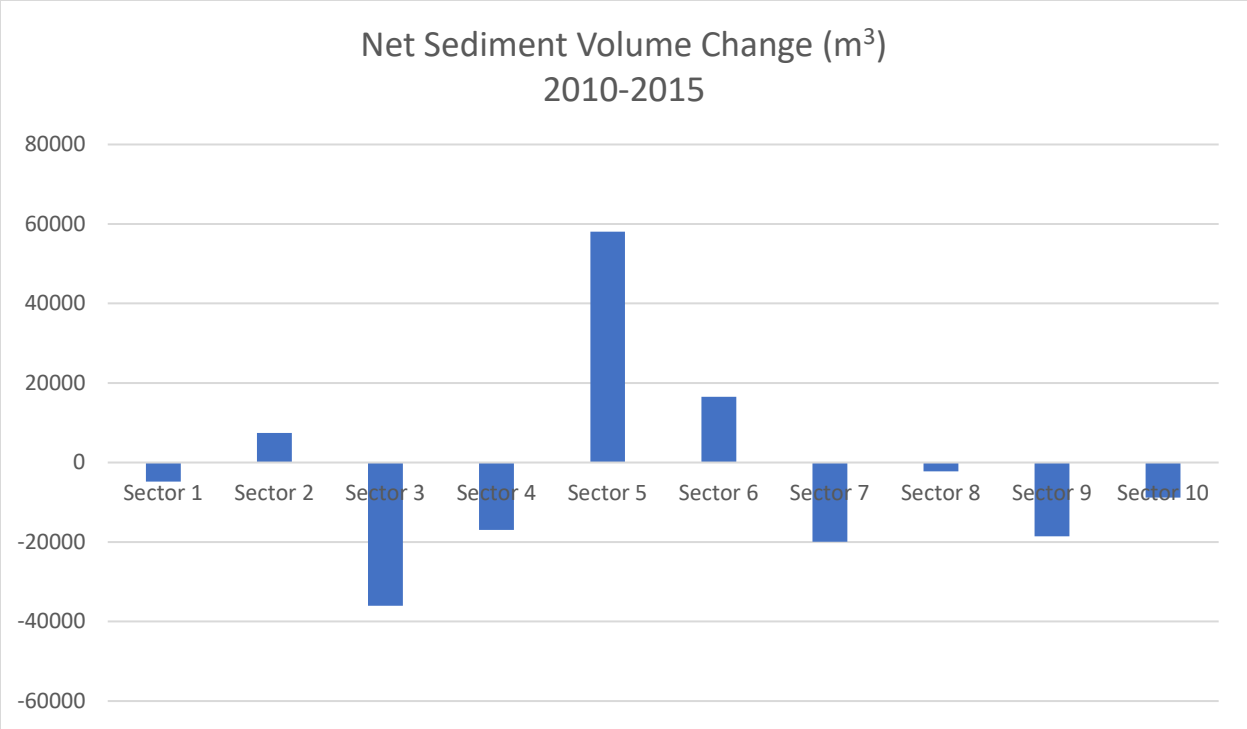


Figure 111. Graph showing the net sediment volume change (in m^3) in each of the 10 sectors between 2010 and 2015. Positive values represent net deposition; negative values represent net erosion.

Figure 112. Vulnerability map for Captiva, reflecting sediment budget values between 2010 and 2015.

Figure 113. Vulnerability map for North Sanibel, reflecting sediment budget values between 2010 and 2015.

Figure 114. Vulnerability map for South Sanibel, reflecting sediment budget values between 2010 and 2015.

Appendix I

Beach profiles for Sanibel and Captiva Islands, dating from 1998, 2004 post Hurricane Charley, 2004 post Hurricane Ivan, 2006, 2010, and 2015. These data are derived from LiDAR-generated digital elevation models (DEMs). They were used to conduct the sediment budgetary analysis.

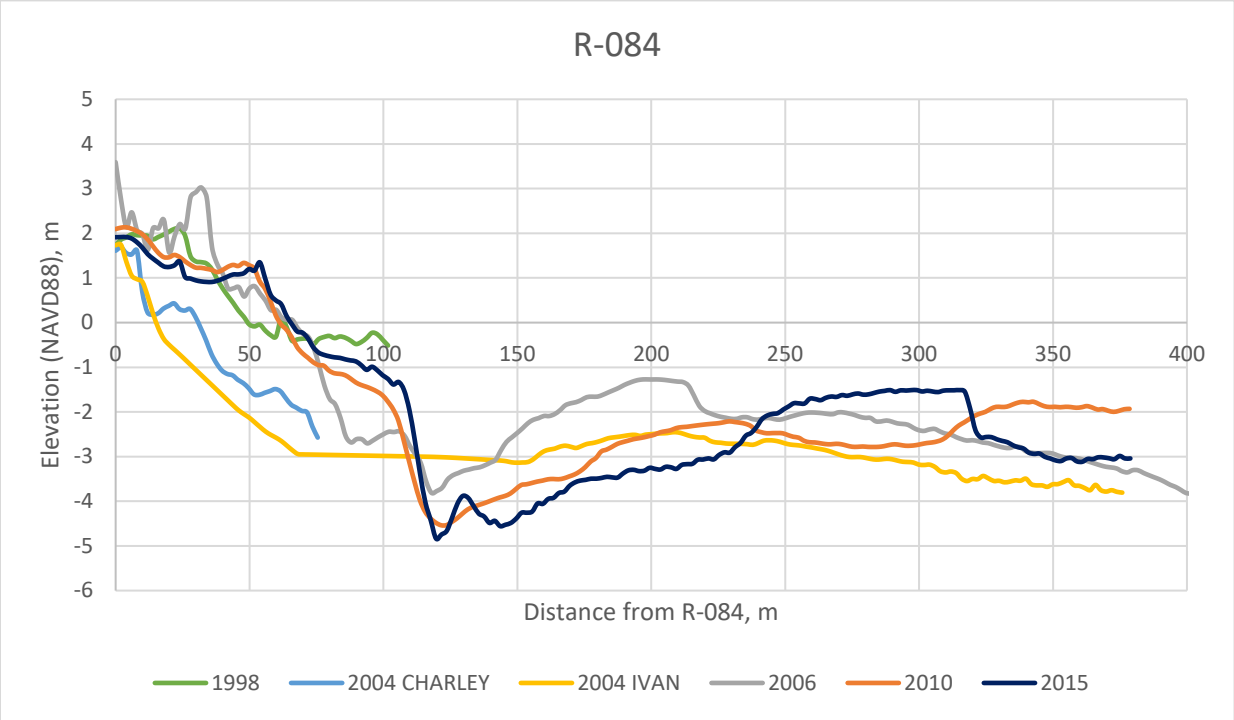


Figure A1.1. Beach profiles from LiDAR surveys with respect to NAVD88 at R-084.

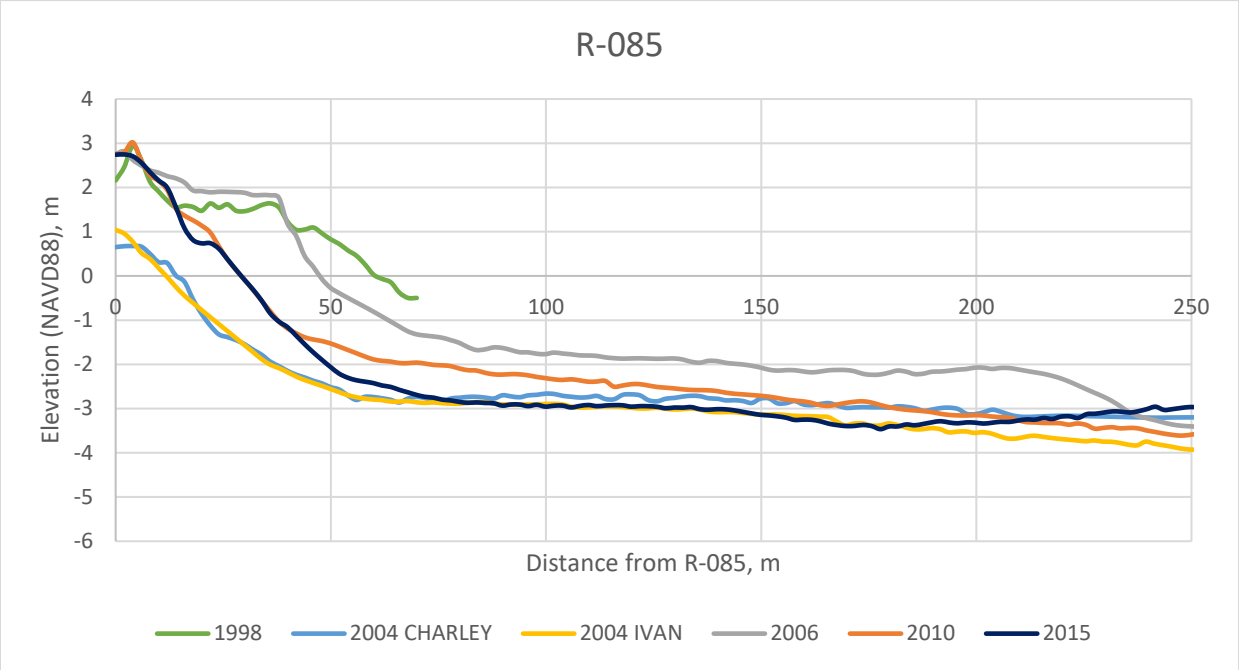


Figure A1.2. Beach profiles from LiDAR surveys with respect to NAVD88 at R-085.

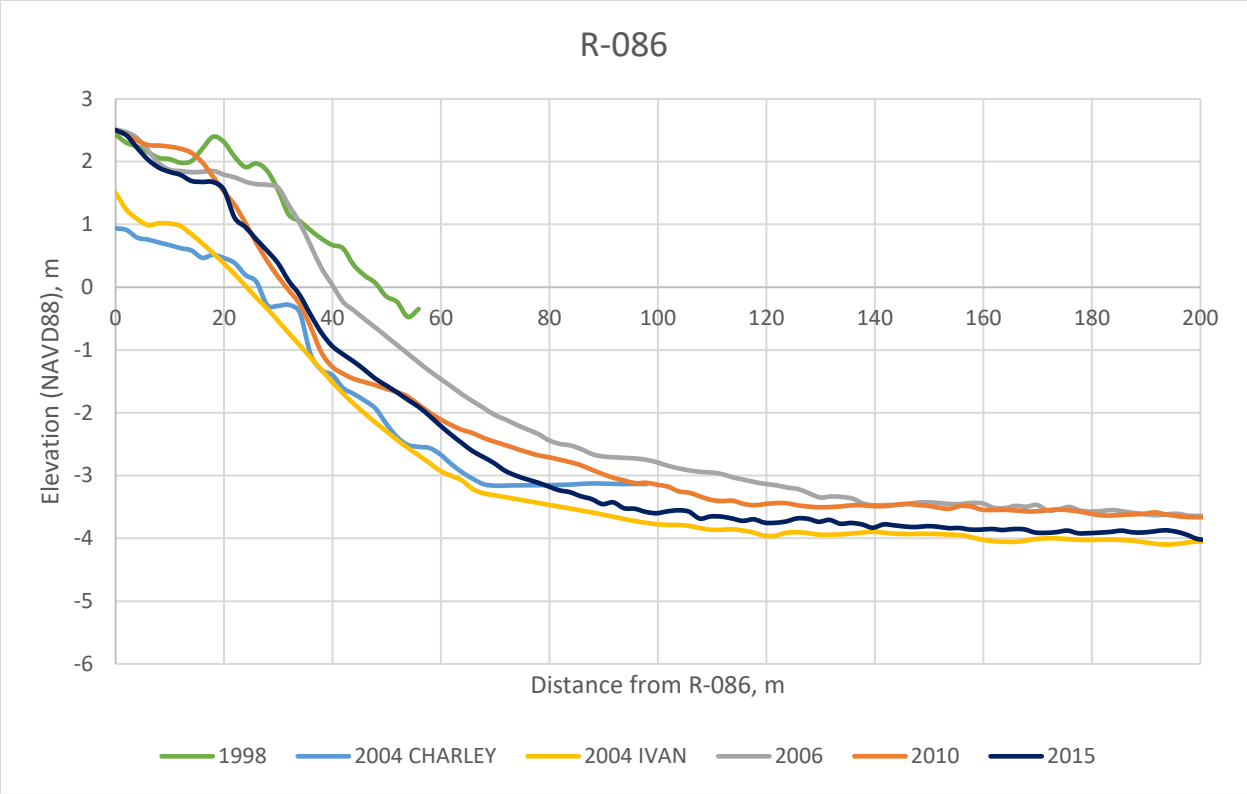


Figure A1.3. Beach profiles from LiDAR surveys with respect to NAVD88 at R-086.

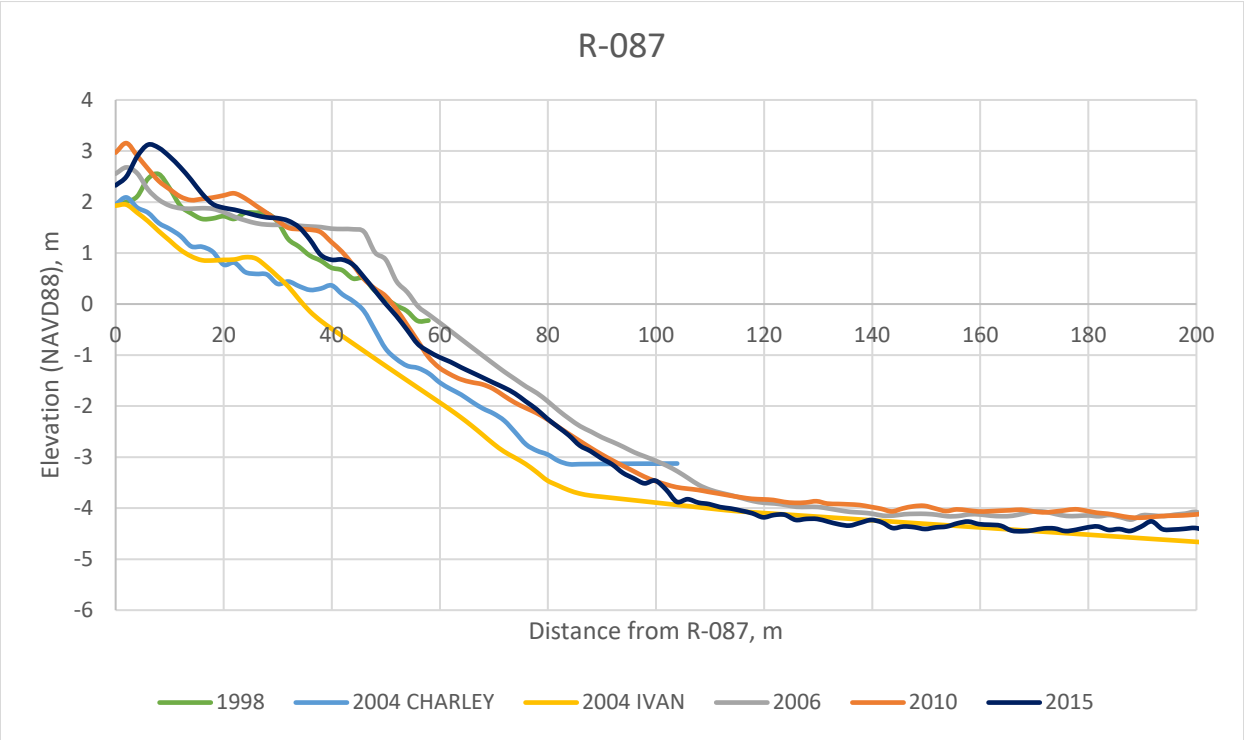


Figure A1.4. Beach profiles from LiDAR surveys with respect to NAVD88 at R-087.

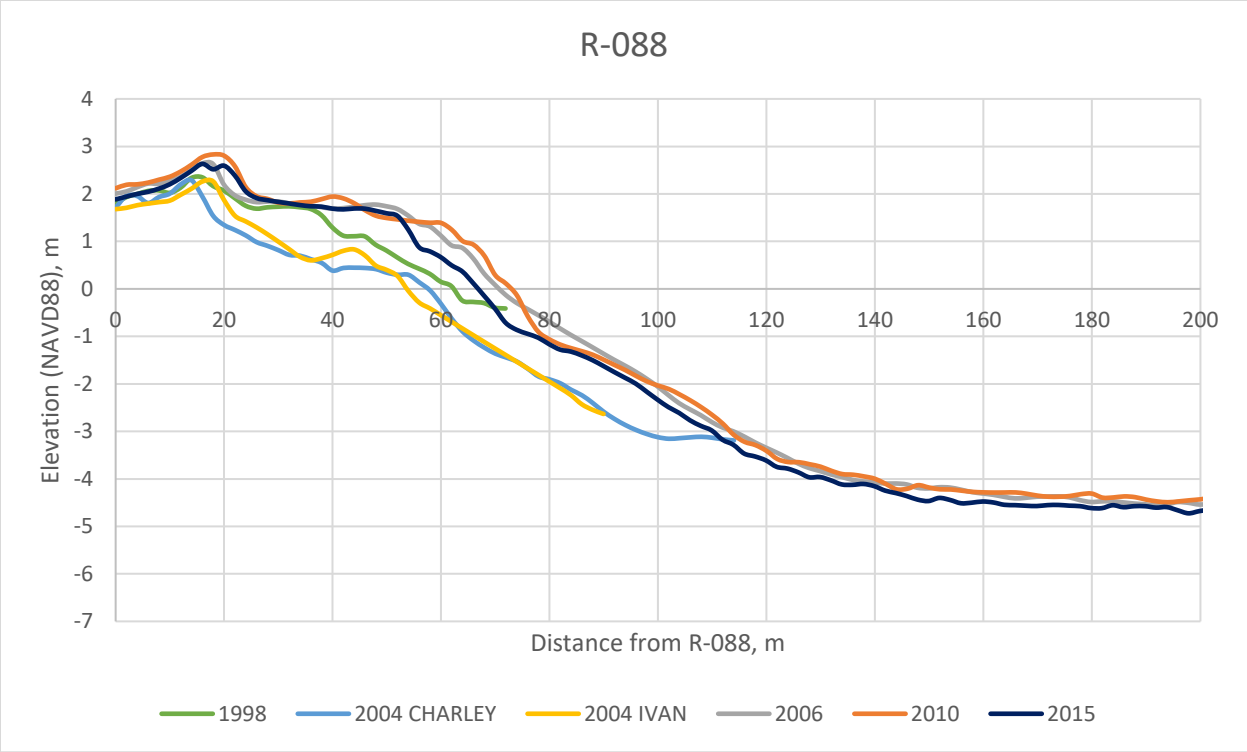


Figure A1.5. Beach profiles from LiDAR surveys with respect to NAVD88 at R-088.

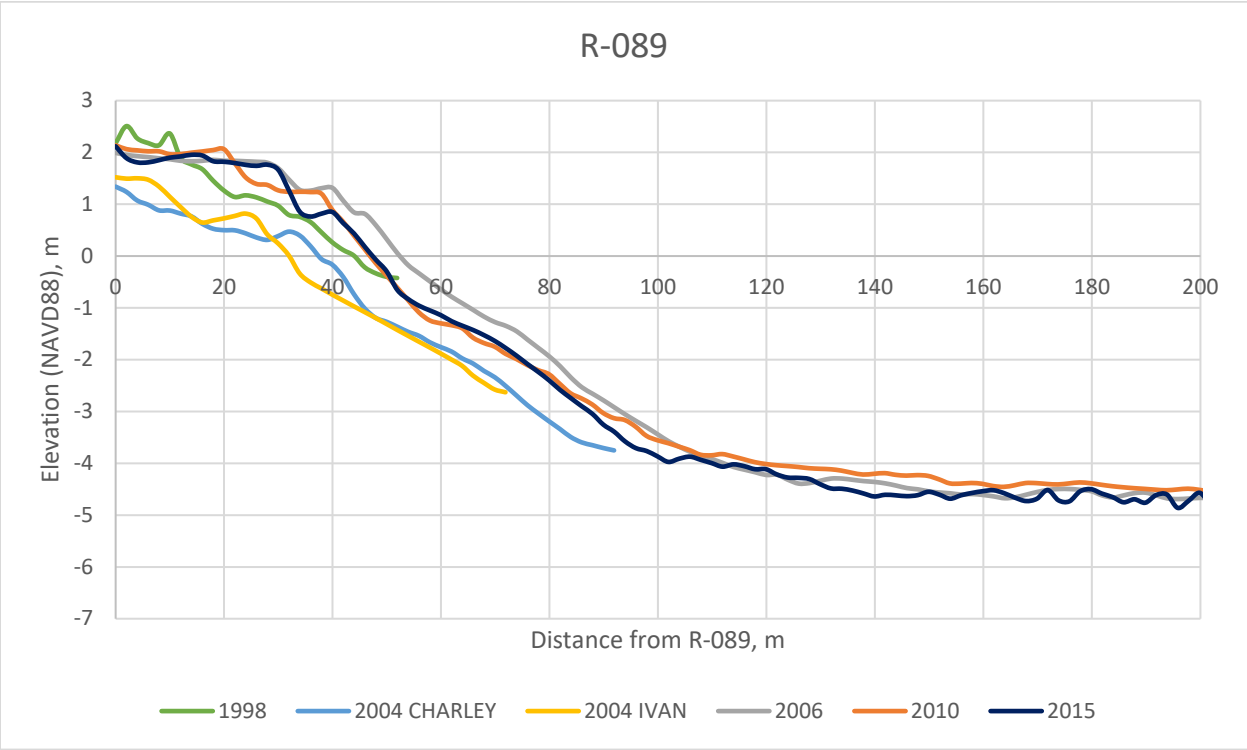


Figure A1.6. Beach profiles from LiDAR surveys with respect to NAVD88 at R-089.

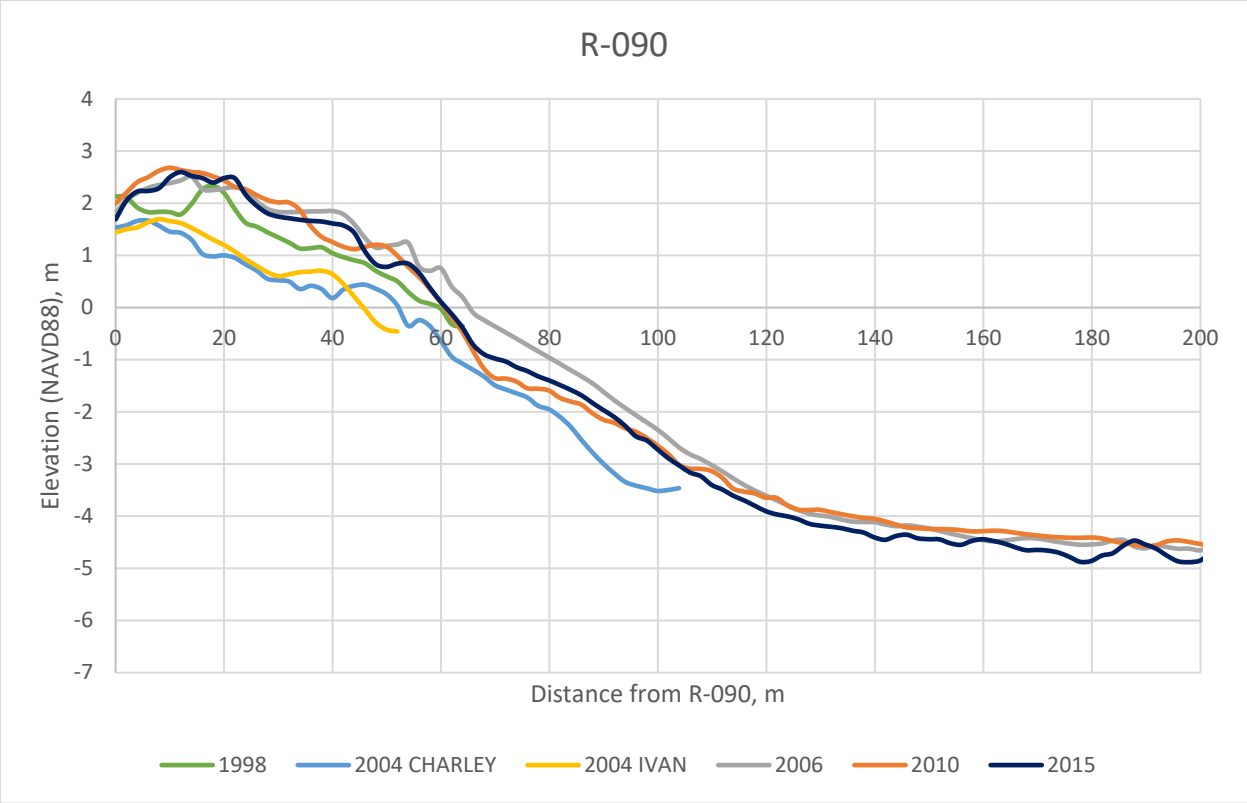


Figure A1.7. Beach profiles from LiDAR surveys with respect to NAVD88 at R-090.

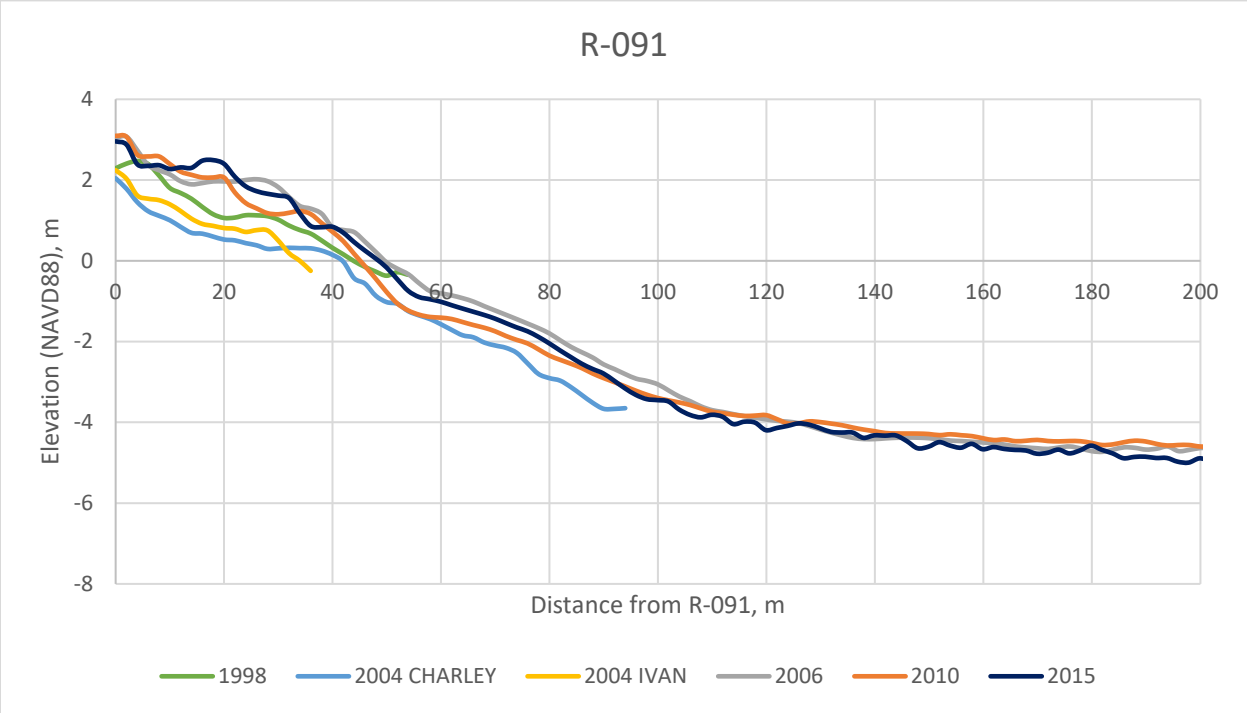


Figure A1.8. Beach profiles from LiDAR surveys with respect to NAVD88 at R-091.

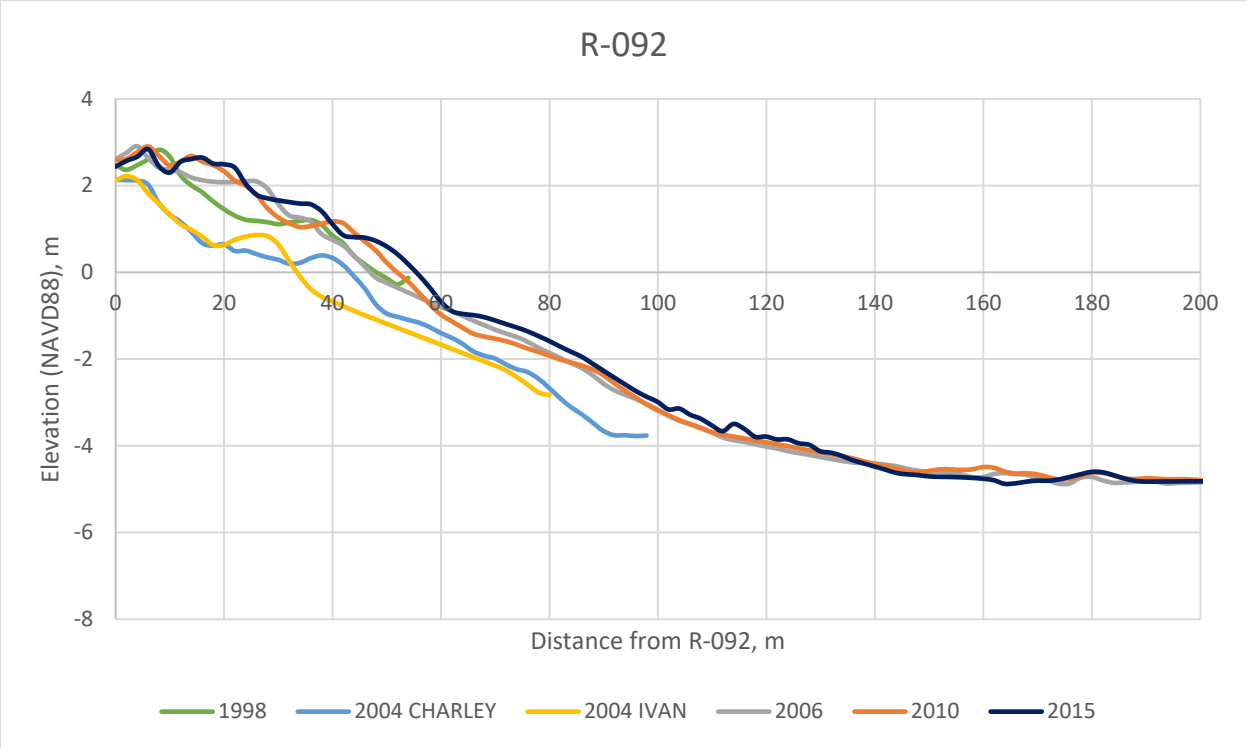


Figure A1.9. Beach profiles from LiDAR surveys with respect to NAVD88 at R-092.

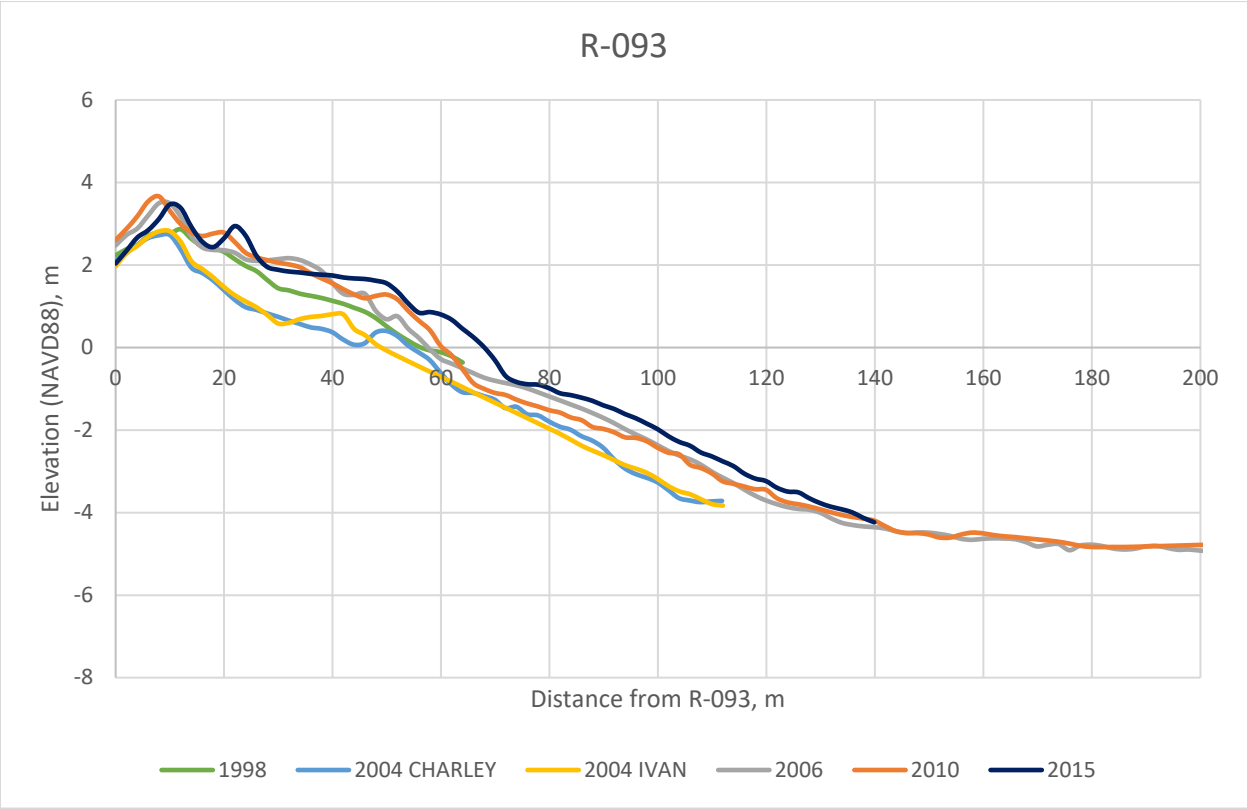


Figure A1.10. Beach profiles from LiDAR surveys with respect to NAVD88 at R-093.

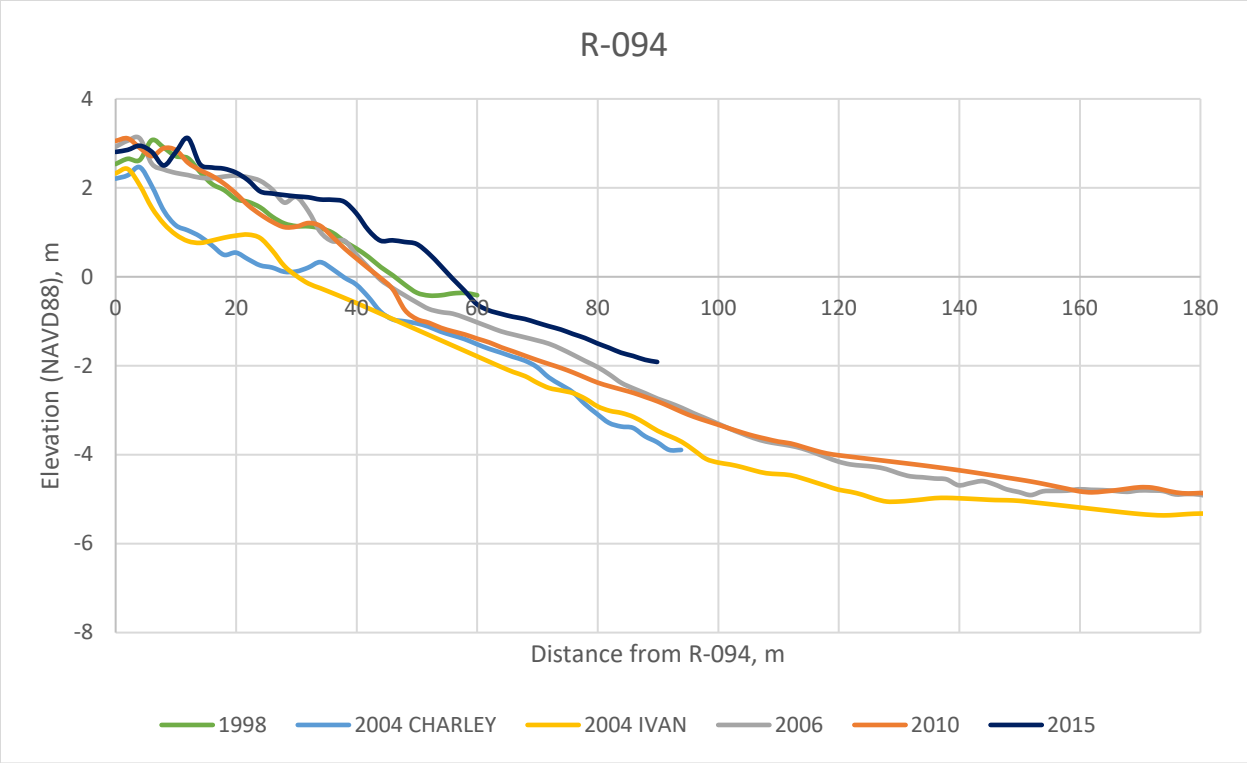


Figure A1.11. Beach profiles from LiDAR surveys with respect to NAVD88 at R-094.

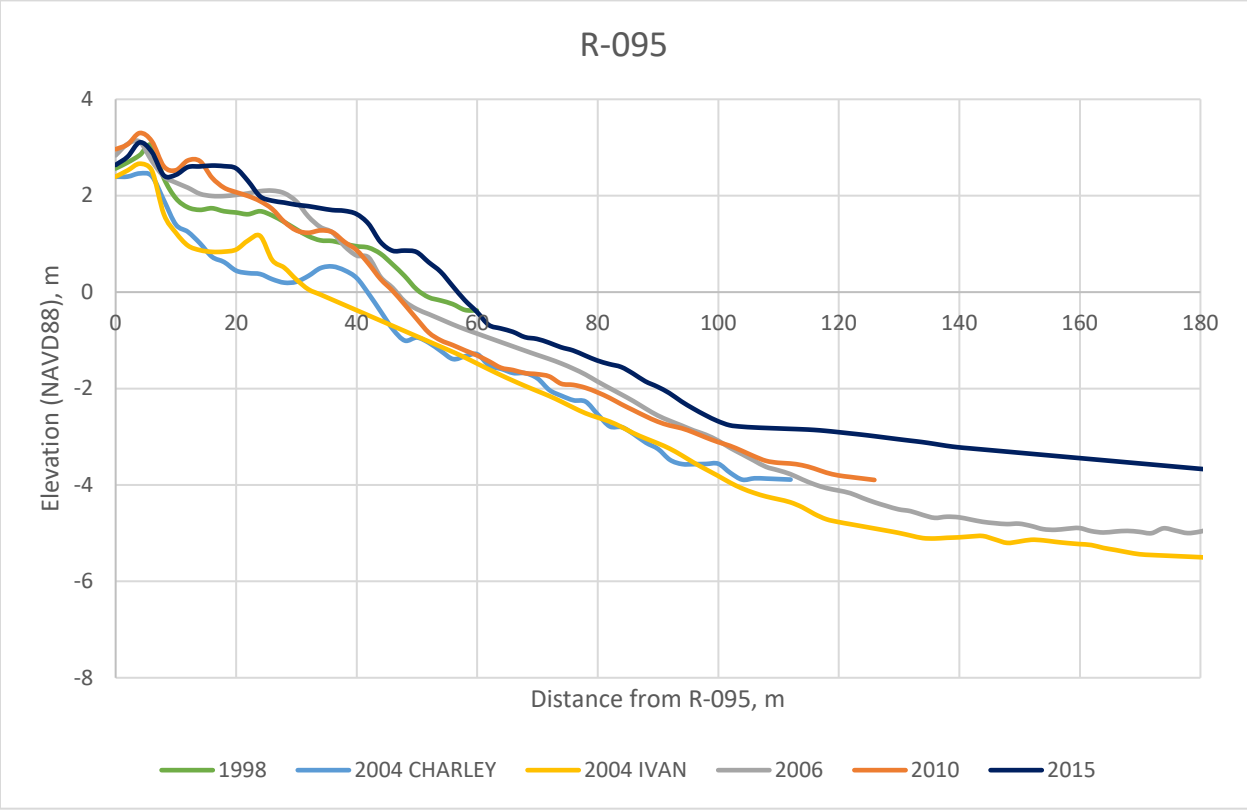


Figure A1.12. Beach profiles from LiDAR surveys with respect to NAVD88 at R-095.

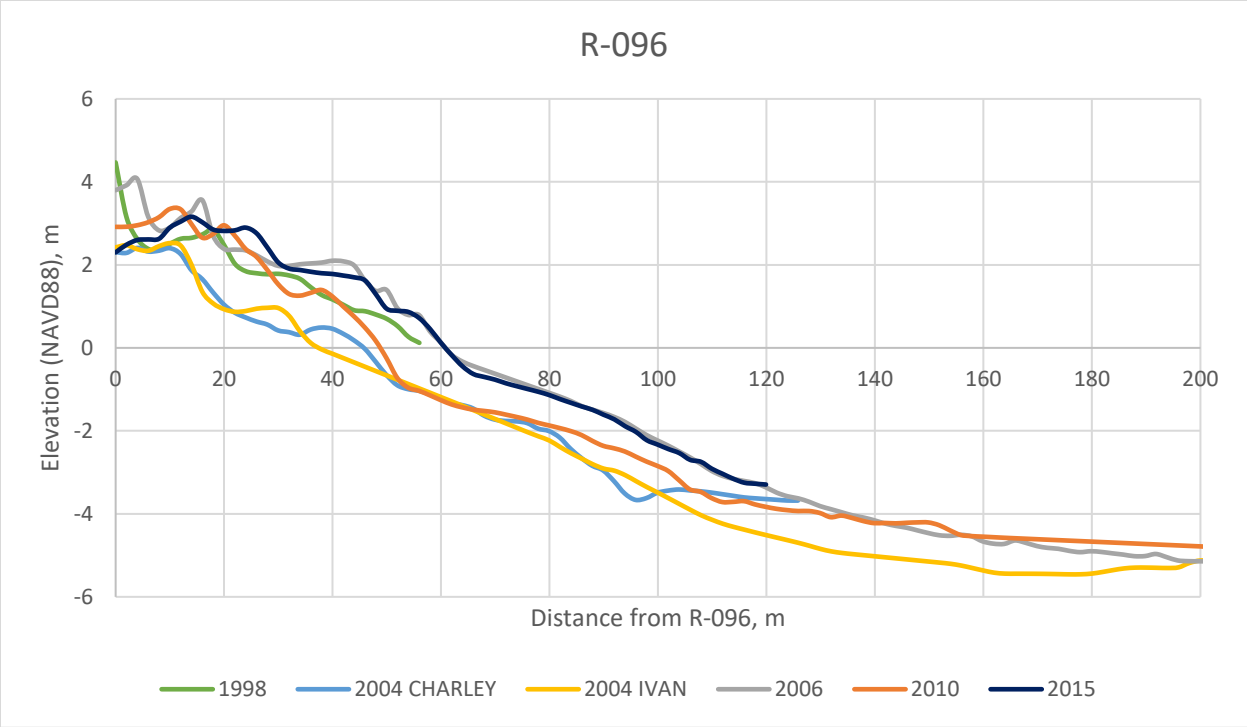


Figure A1.13. Beach profiles from LiDAR surveys with respect to NAVD88 at R-096.

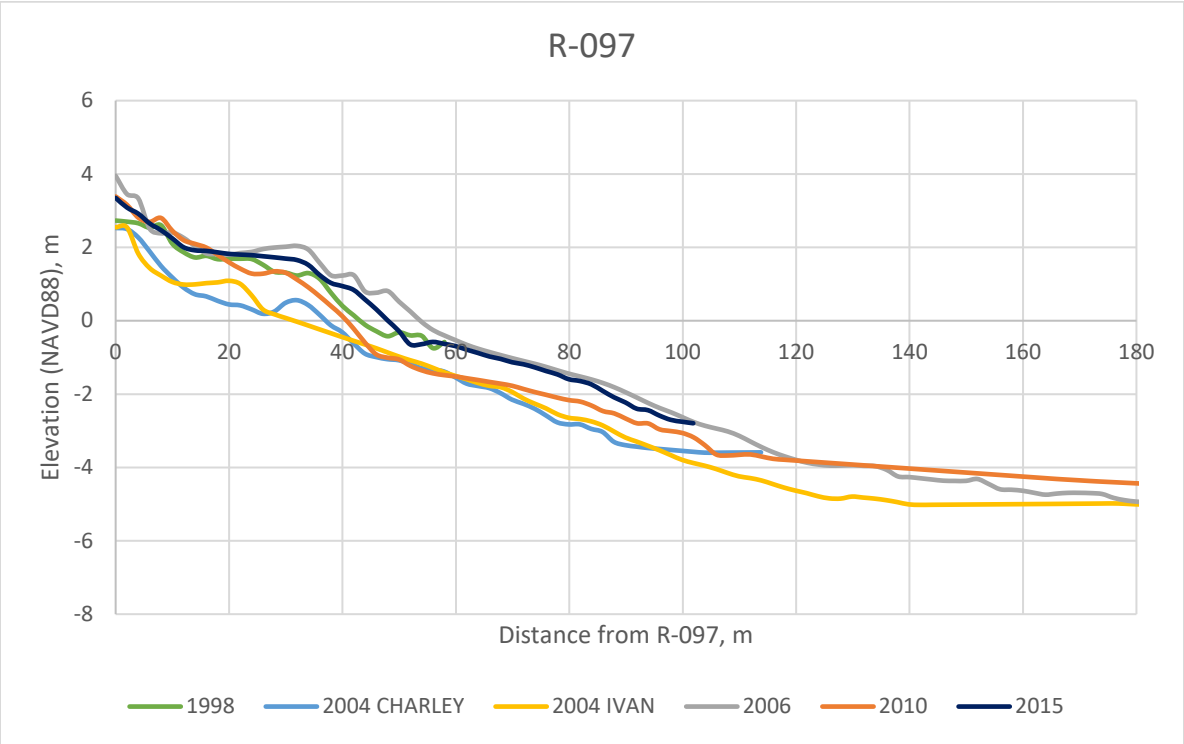


Figure A1.14. Beach profiles from LiDAR surveys with respect to NAVD88 at R-097.

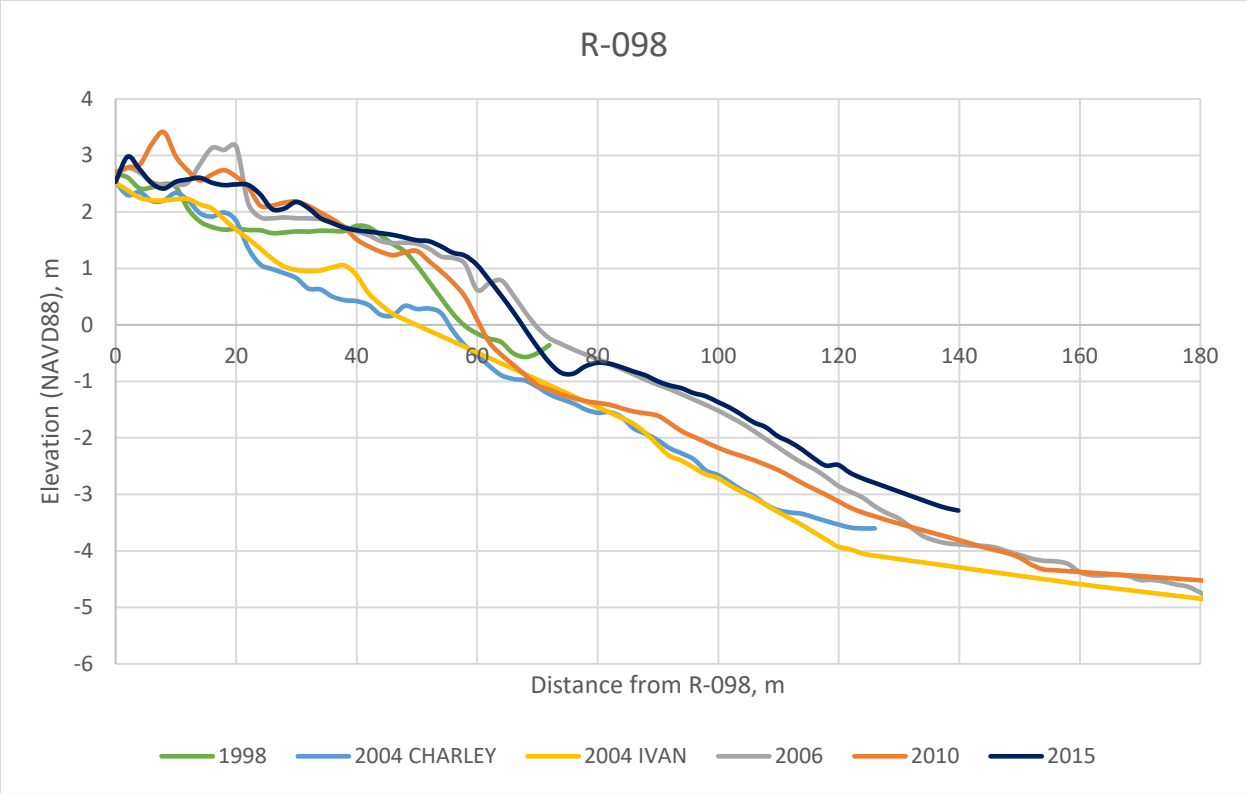


Figure A1.15. Beach profiles from LiDAR surveys with respect to NAVD88 at R-098.

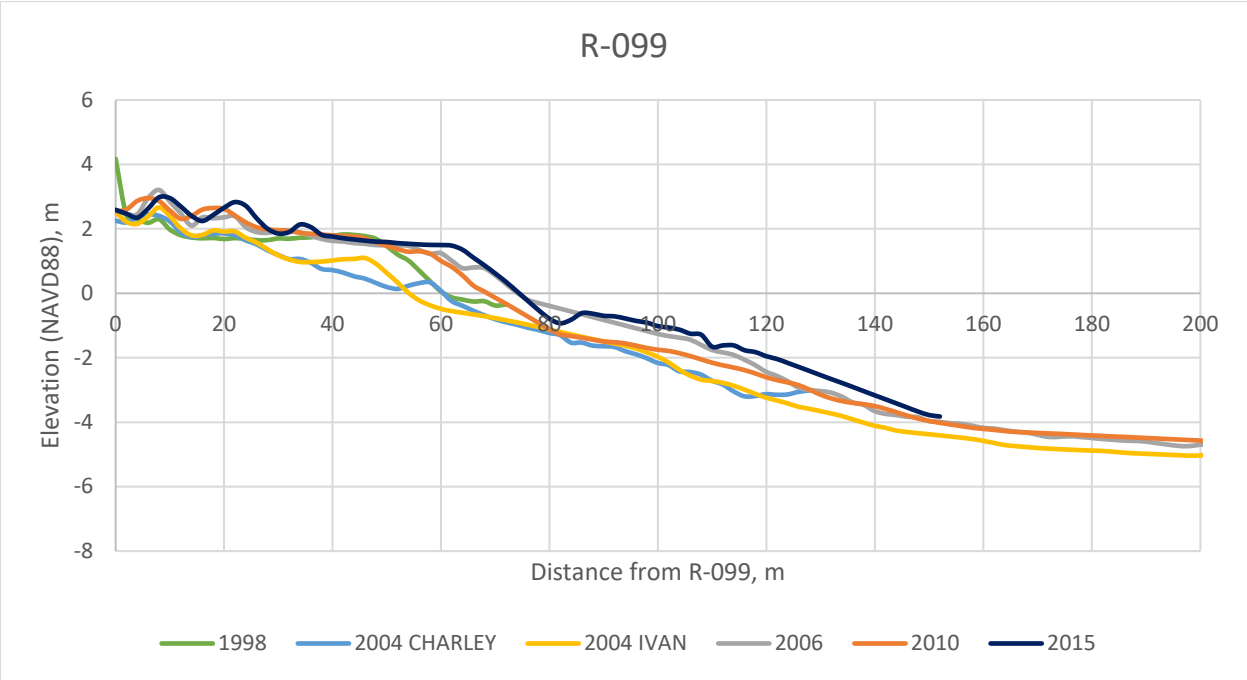


Figure A1.16. Beach profiles from LiDAR surveys with respect to NAVD88 at R-099.

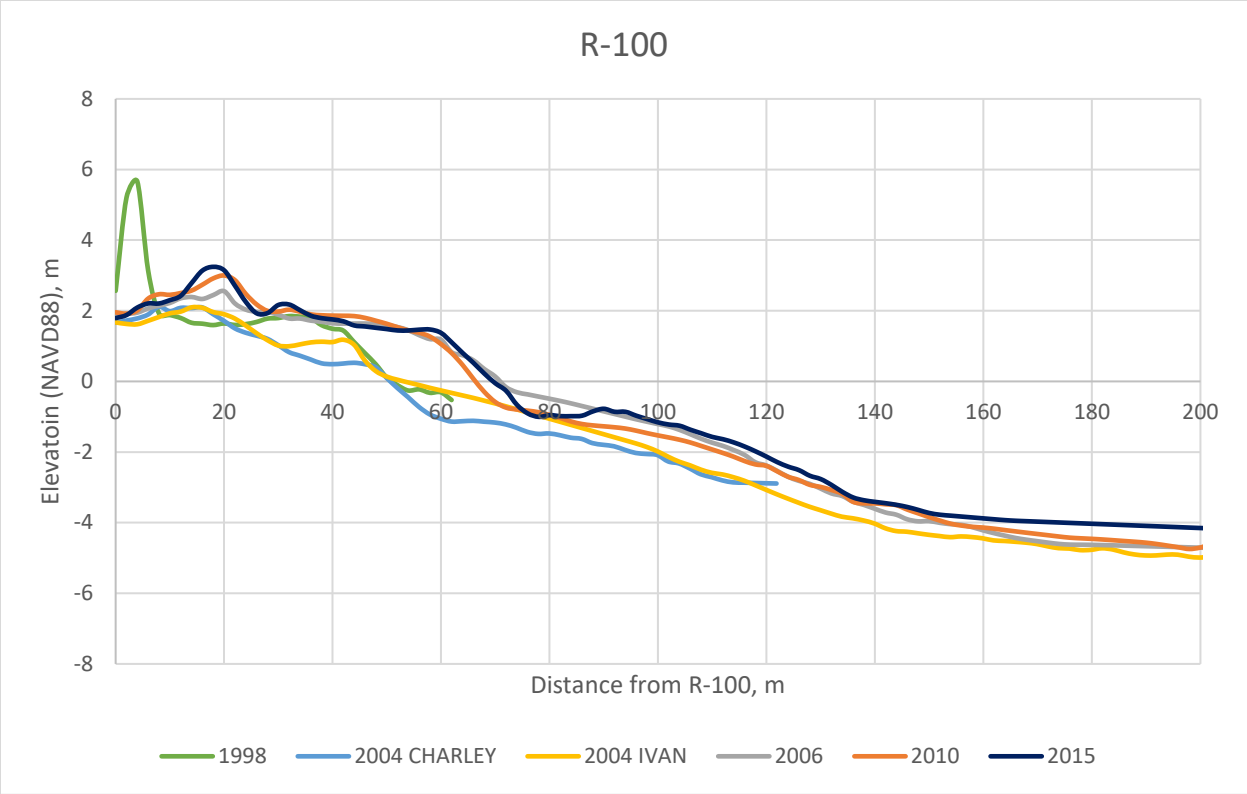


Figure A1.17. Beach profiles from LiDAR surveys with respect to NAVD88 at R-100.

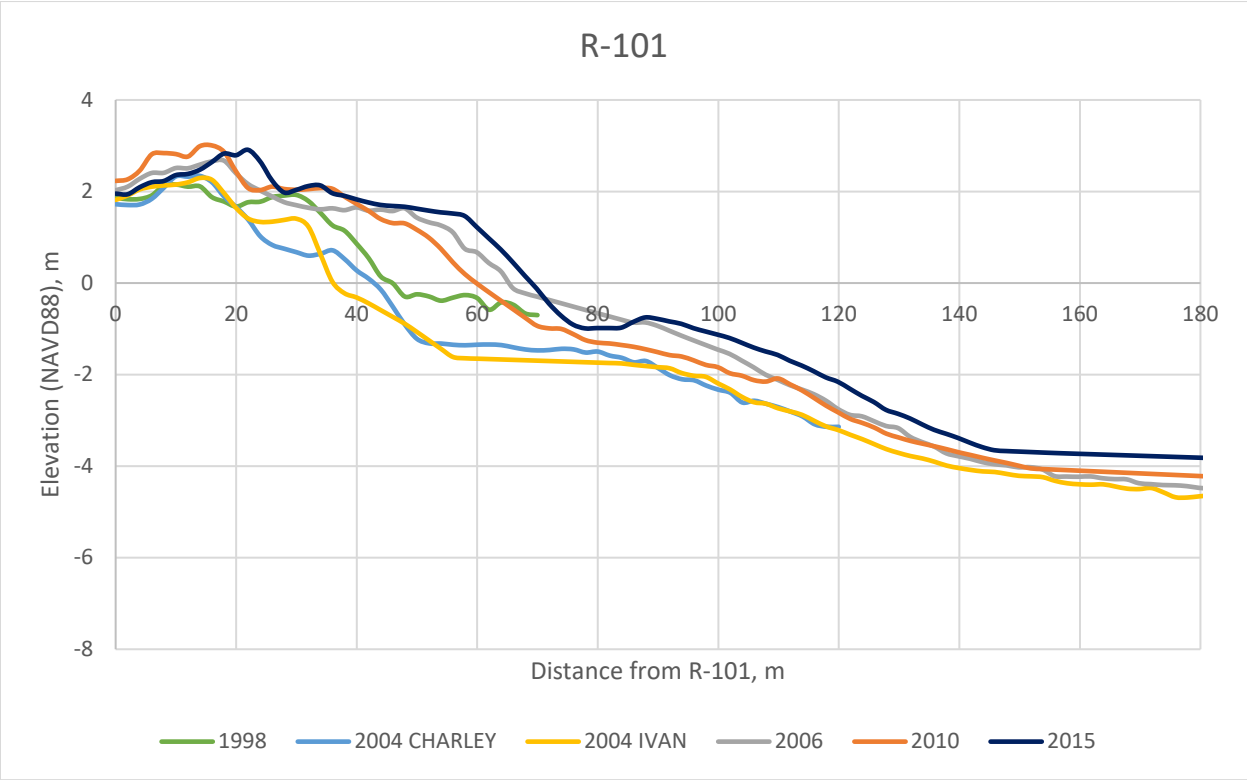


Figure A1.18. Beach profiles from LiDAR surveys with respect to NAVD88 at R-101.

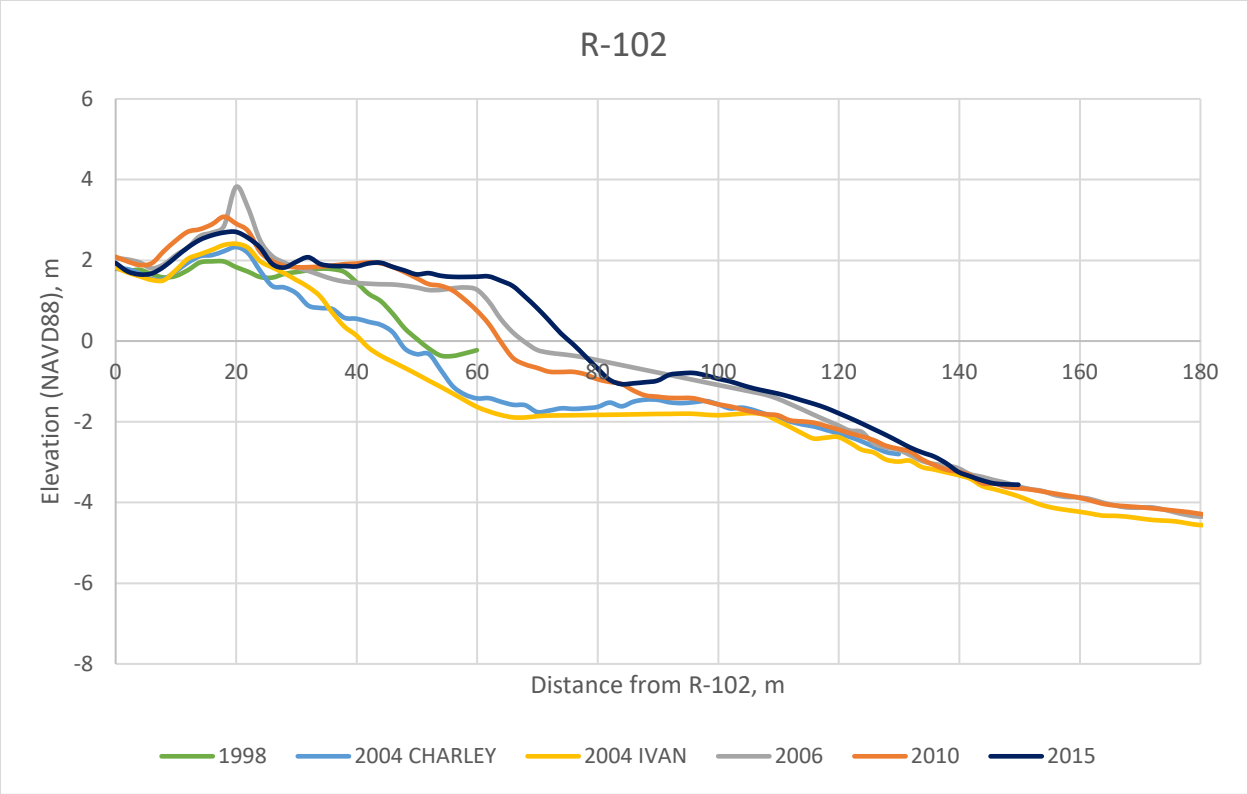


Figure A1.19. Beach profiles from LiDAR surveys with respect to NAVD88 at R-102.

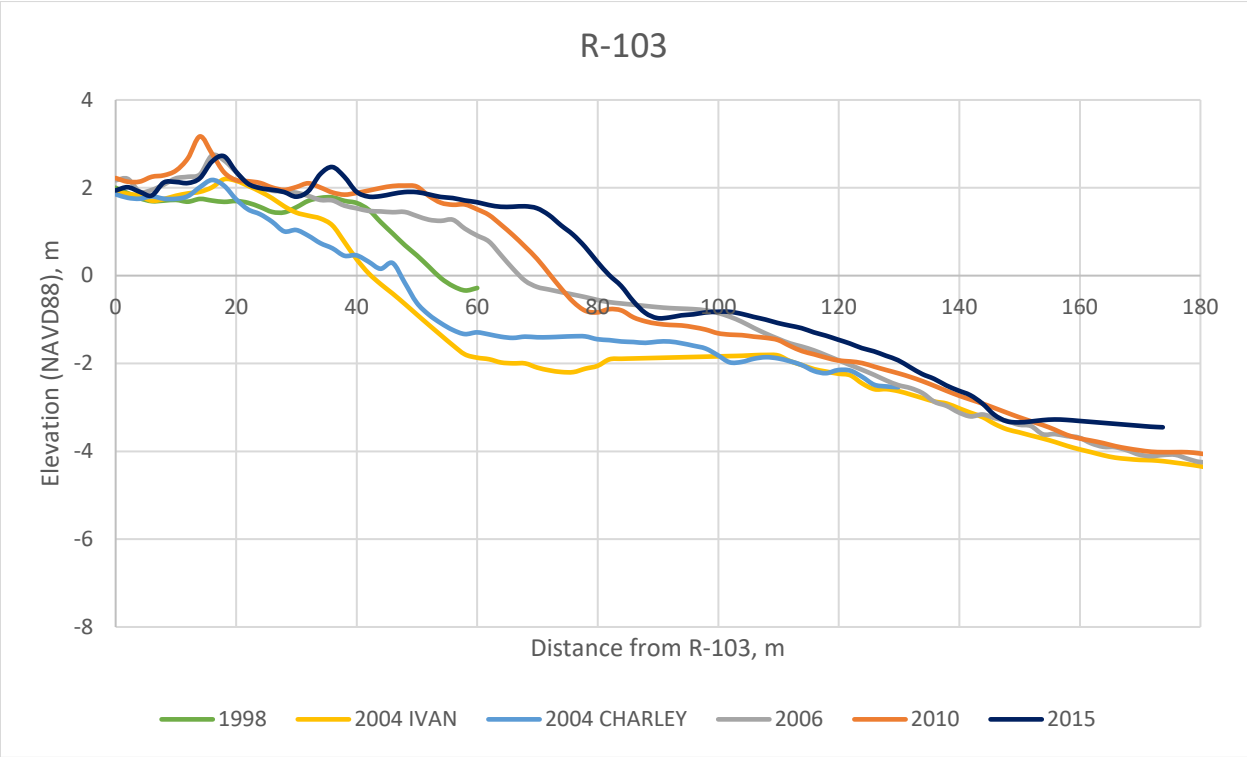


Figure A1.20. Beach profiles from LiDAR surveys with respect to NAVD88 at R-103.

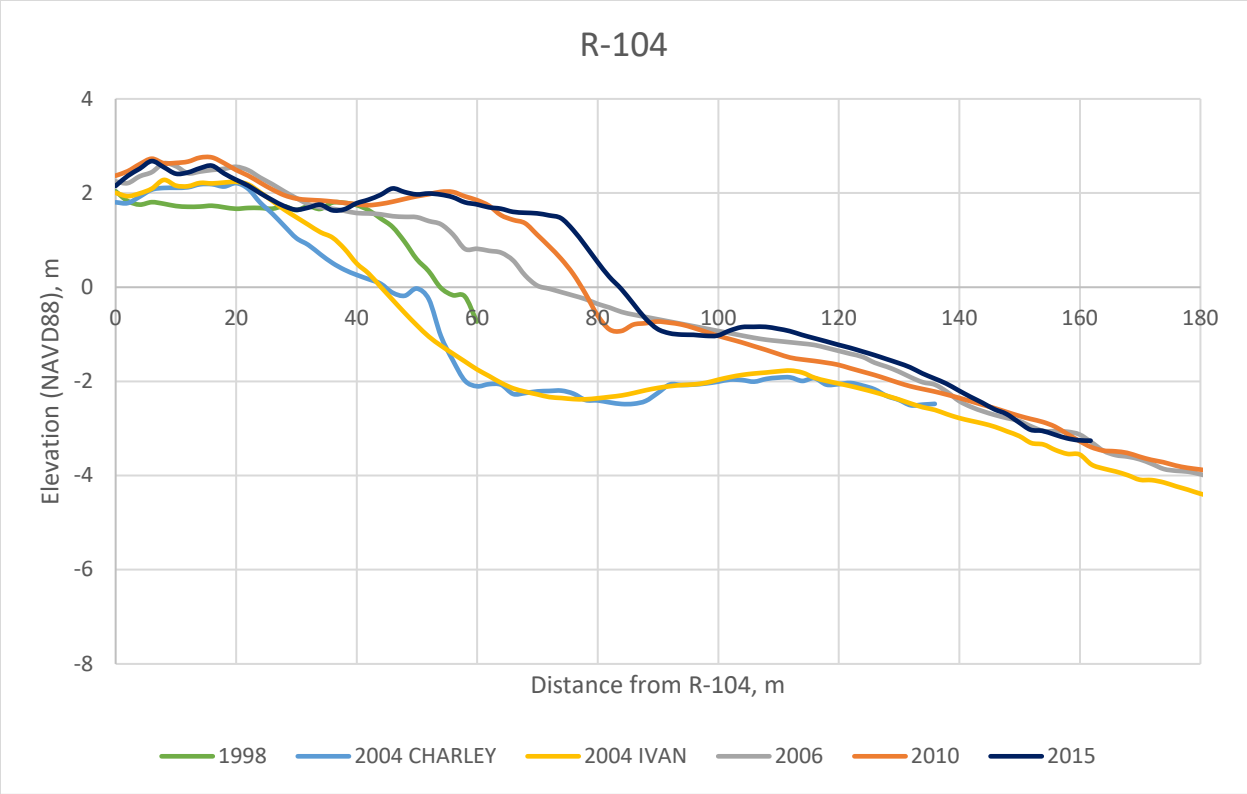


Figure A1.21. Beach profiles from LiDAR surveys with respect to NAVD88 at R-104.

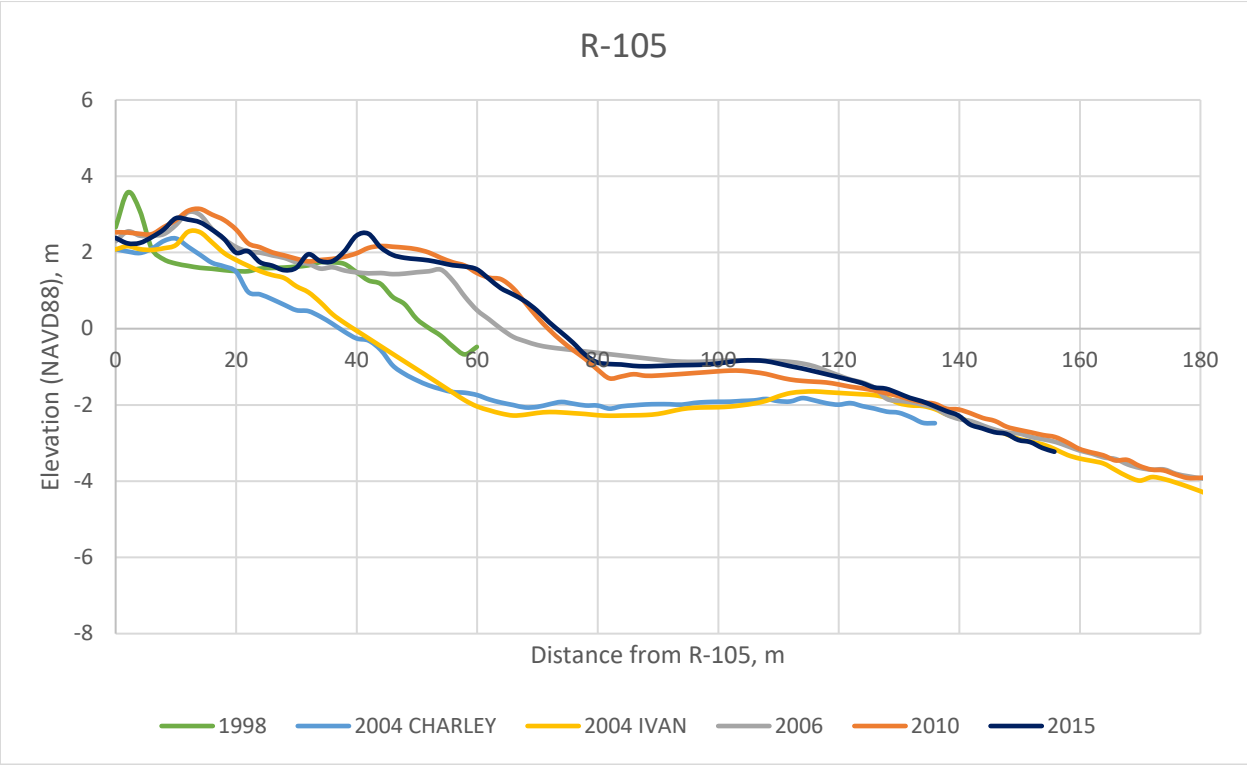


Figure A1.22. Beach profiles from LiDAR surveys with respect to NAVD88 at R-105.

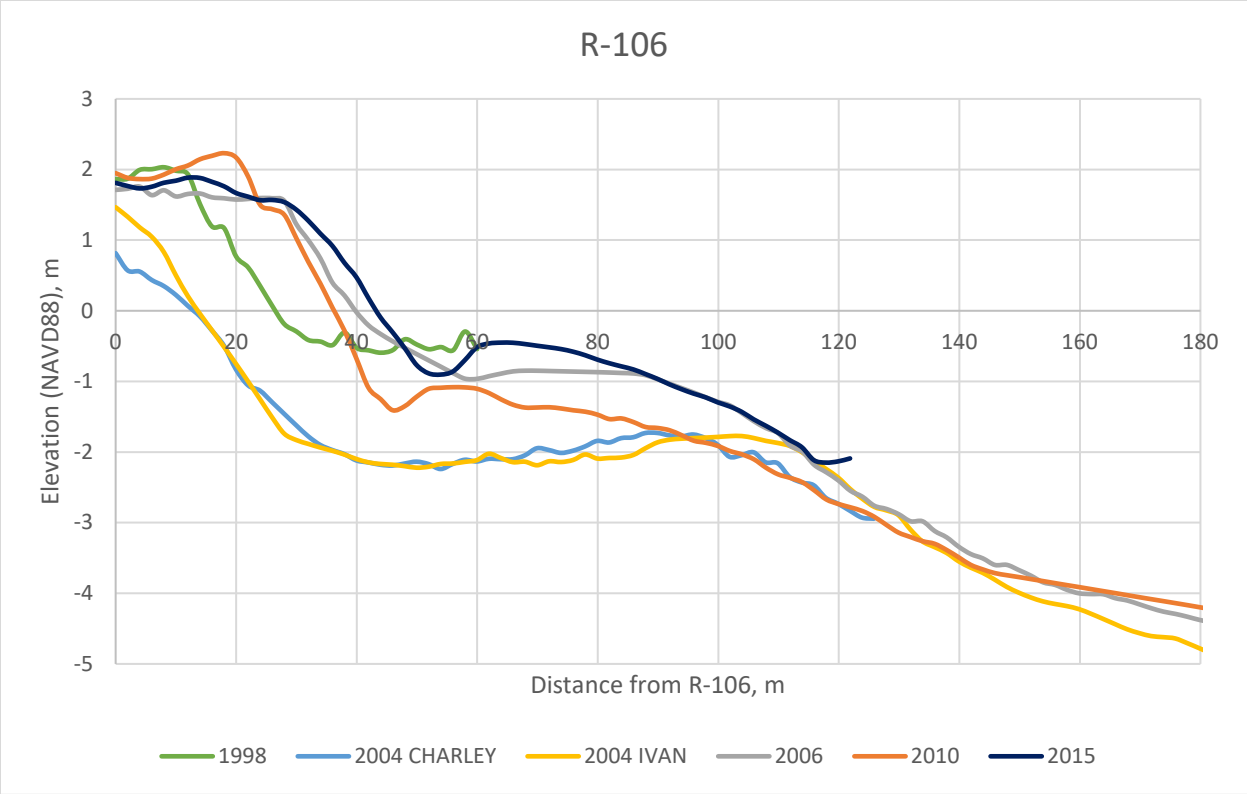


Figure A1.23. Beach profiles from LiDAR surveys with respect to NAVD88 at R-106.

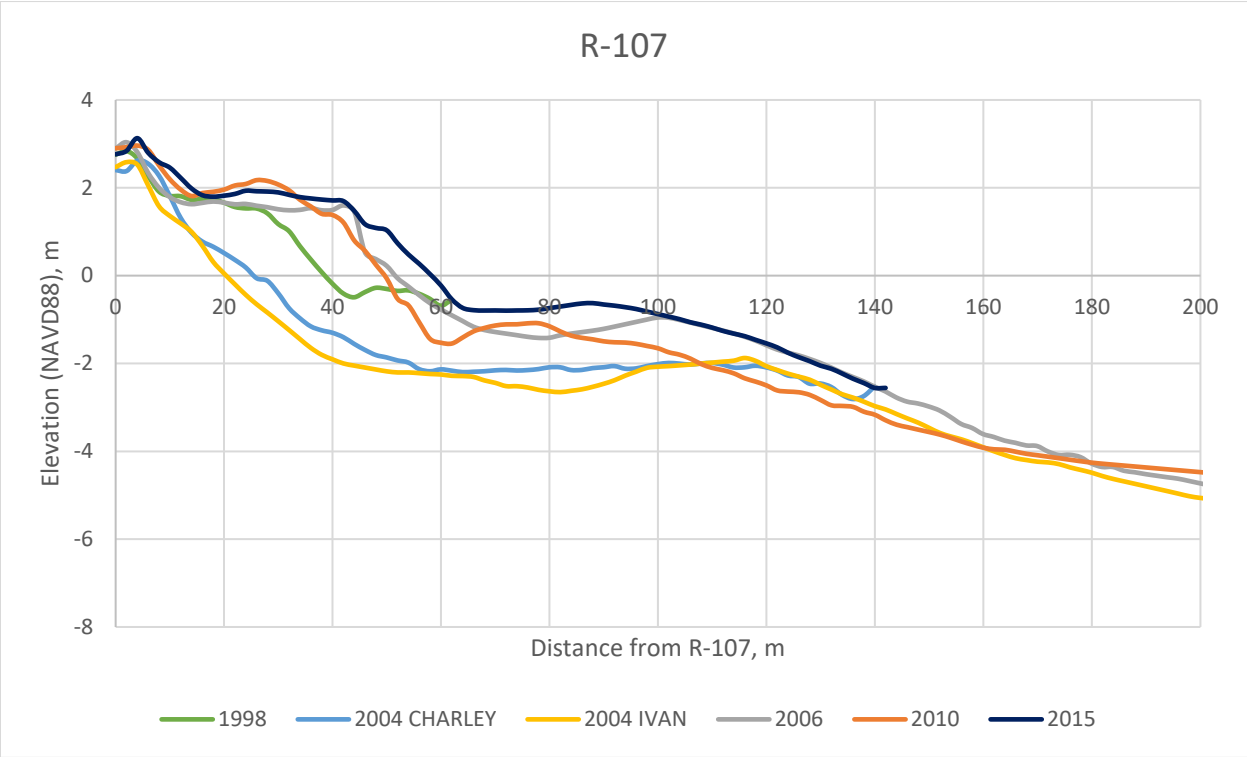


Figure A1.24. Beach profiles from LiDAR surveys with respect to NAVD88 at R-107.

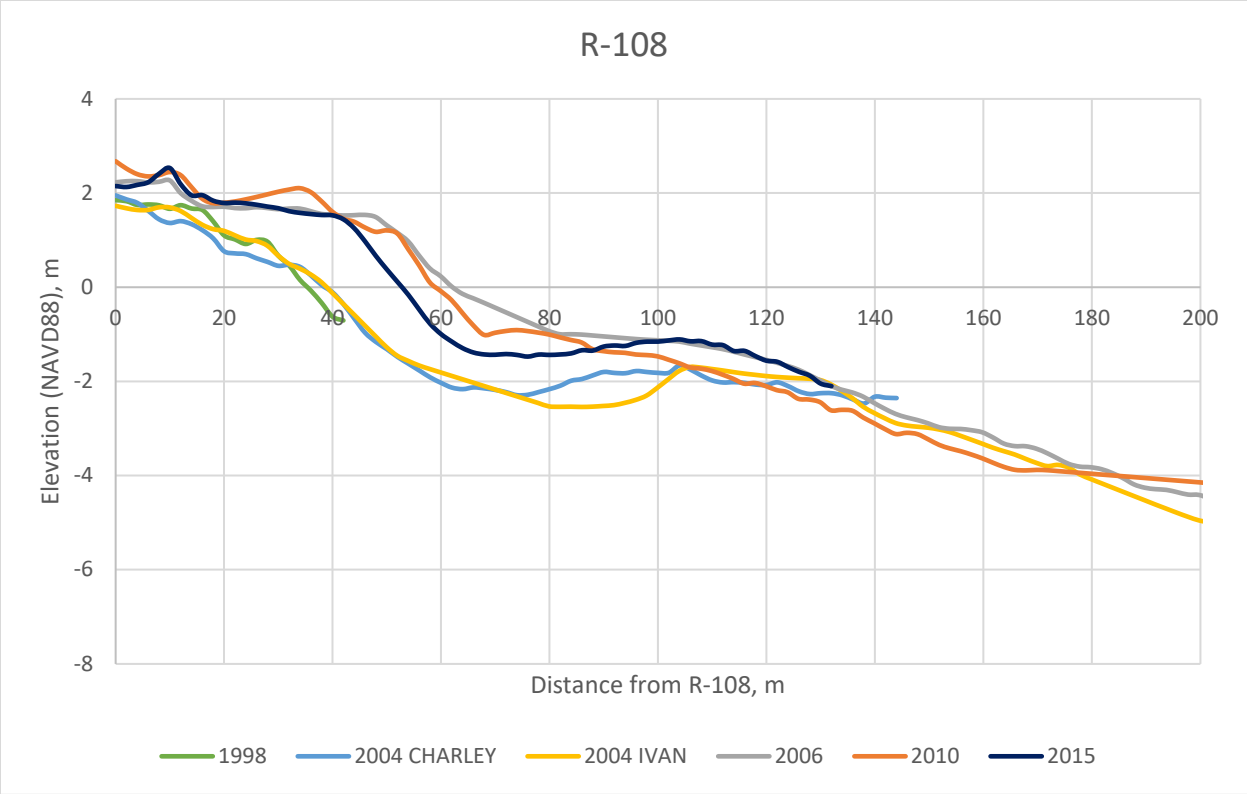


Figure A1.25. Beach profiles from LiDAR surveys with respect to NAVD88 at R-108.

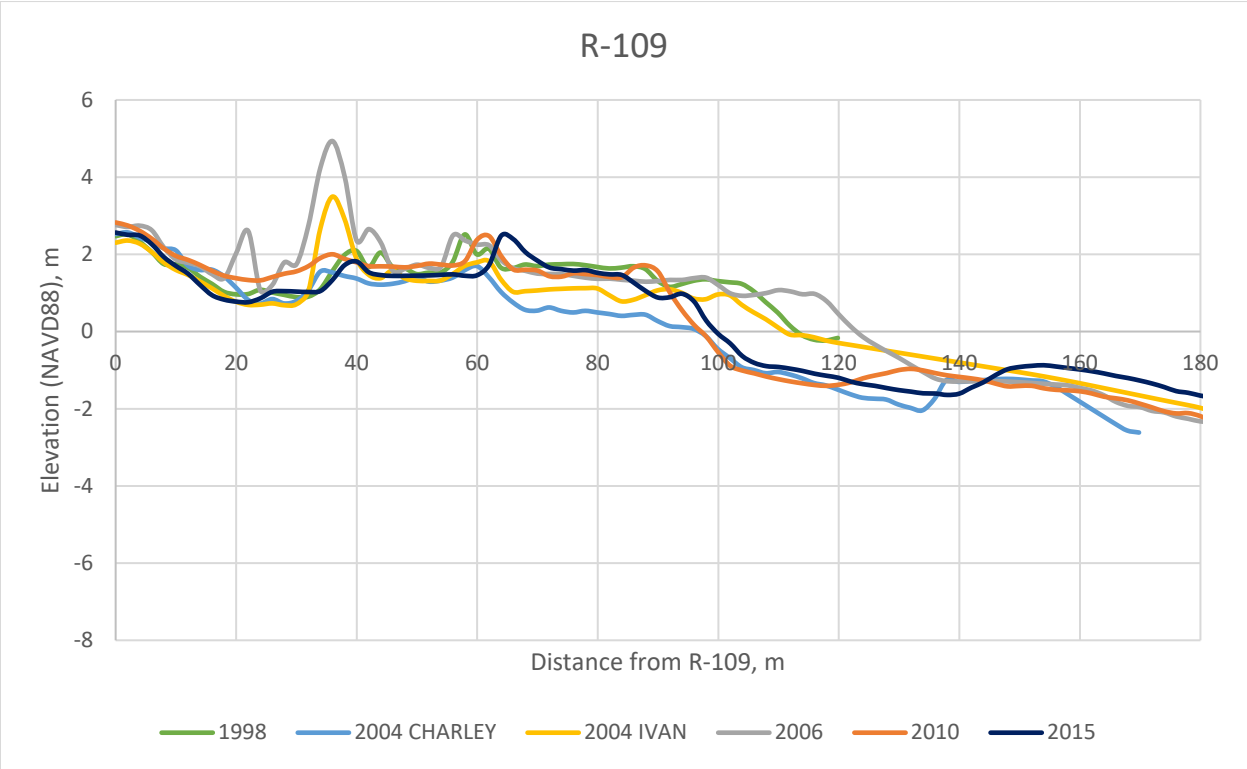


Figure A1.26. Beach profiles from LiDAR surveys with respect to NAVD88 at R-109.

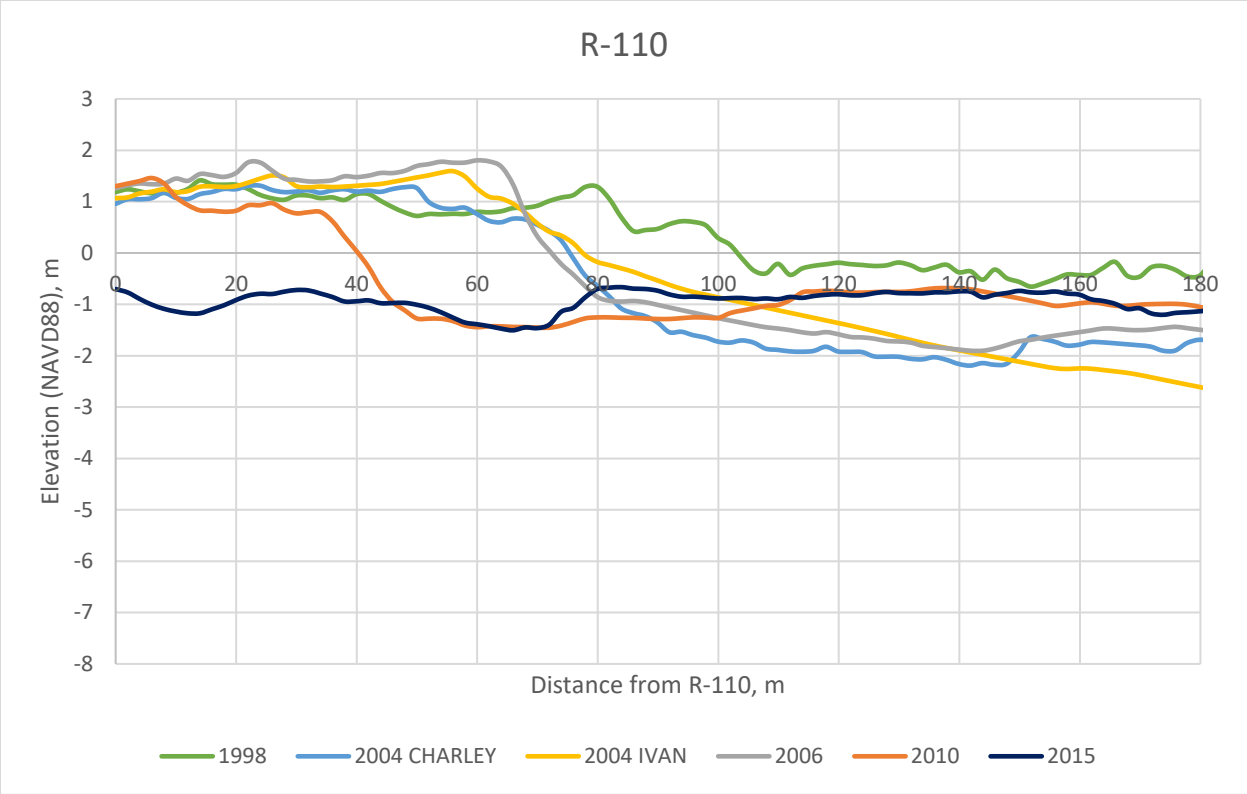


Figure A1.27. Beach profiles from LiDAR surveys with respect to NAVD88 at R-110.

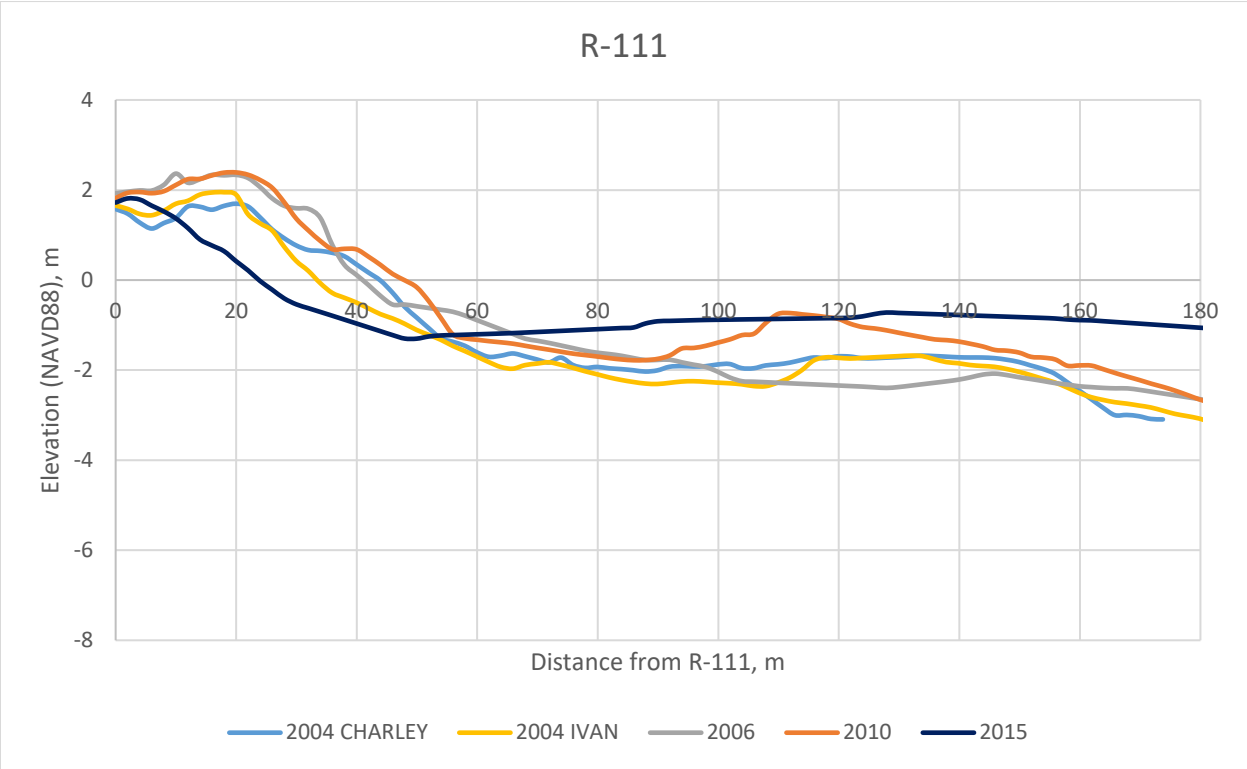


Figure A1.28. Beach profiles from LiDAR surveys with respect to NAVD88 at R-111.

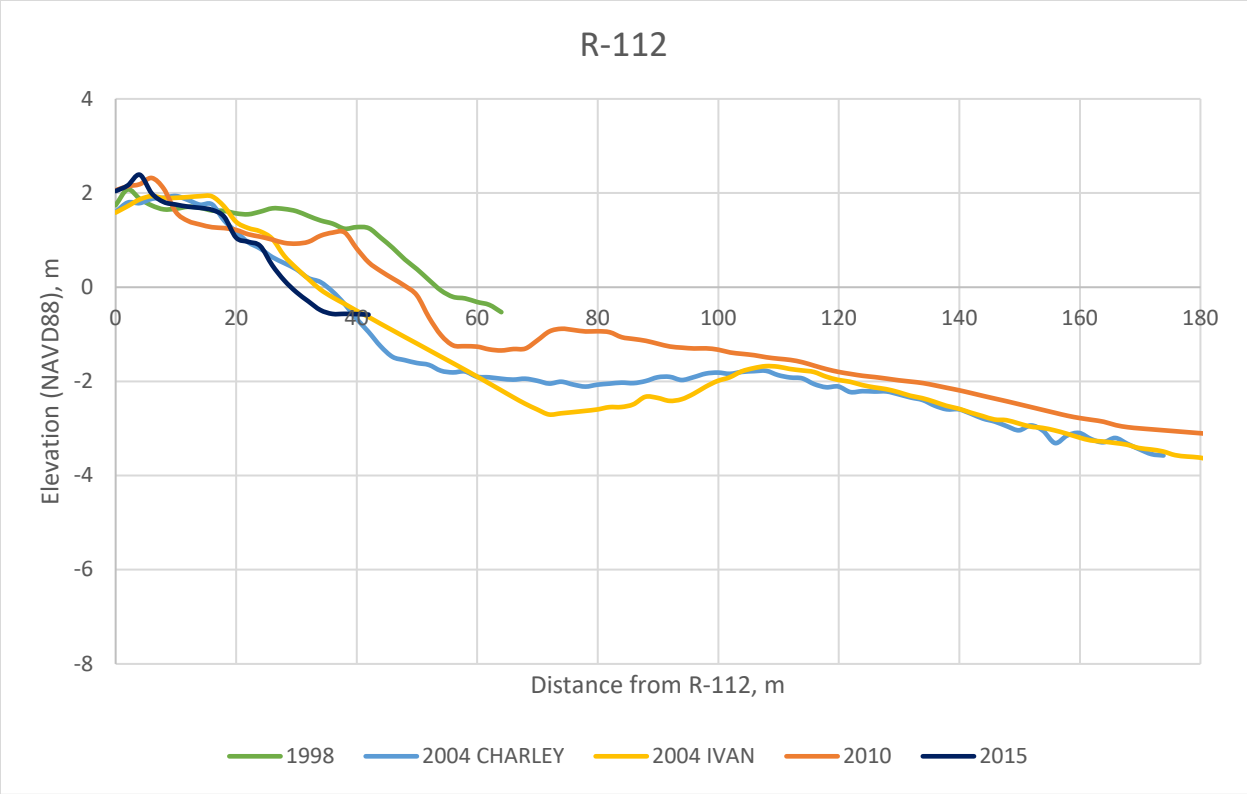


Figure A1.29. Beach profiles from LiDAR surveys with respect to NAVD88 at R-112.

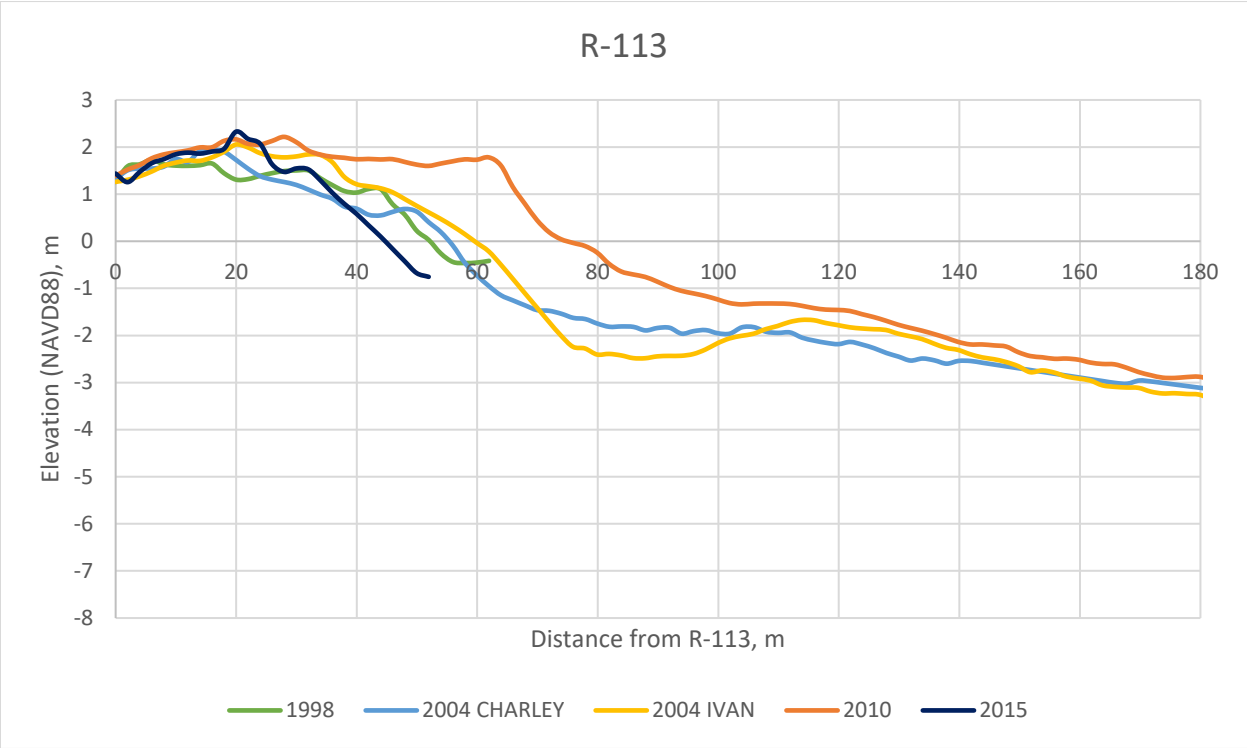


Figure A1.30. Beach profiles from LiDAR surveys with respect to NAVD88 at R-113.

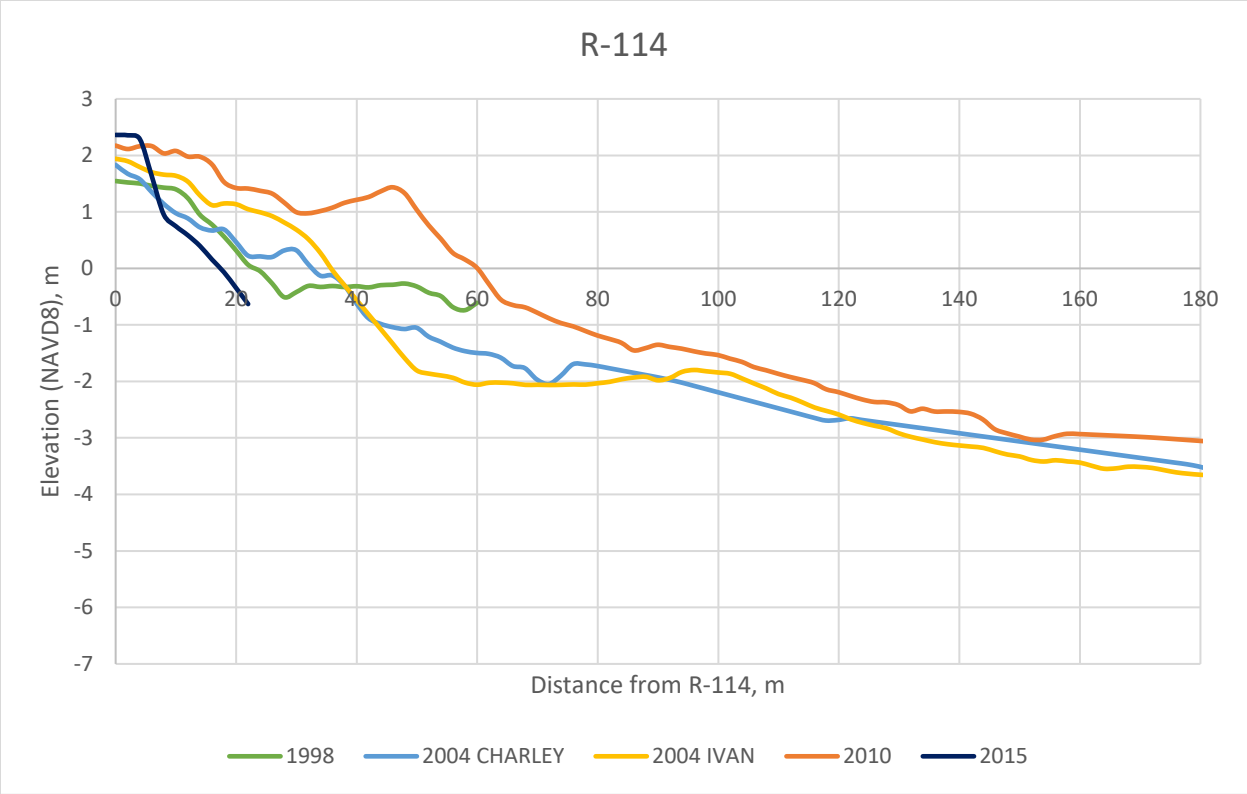


Figure A1.31. Beach profiles from LiDAR surveys with respect to NAVD88 at R-114.

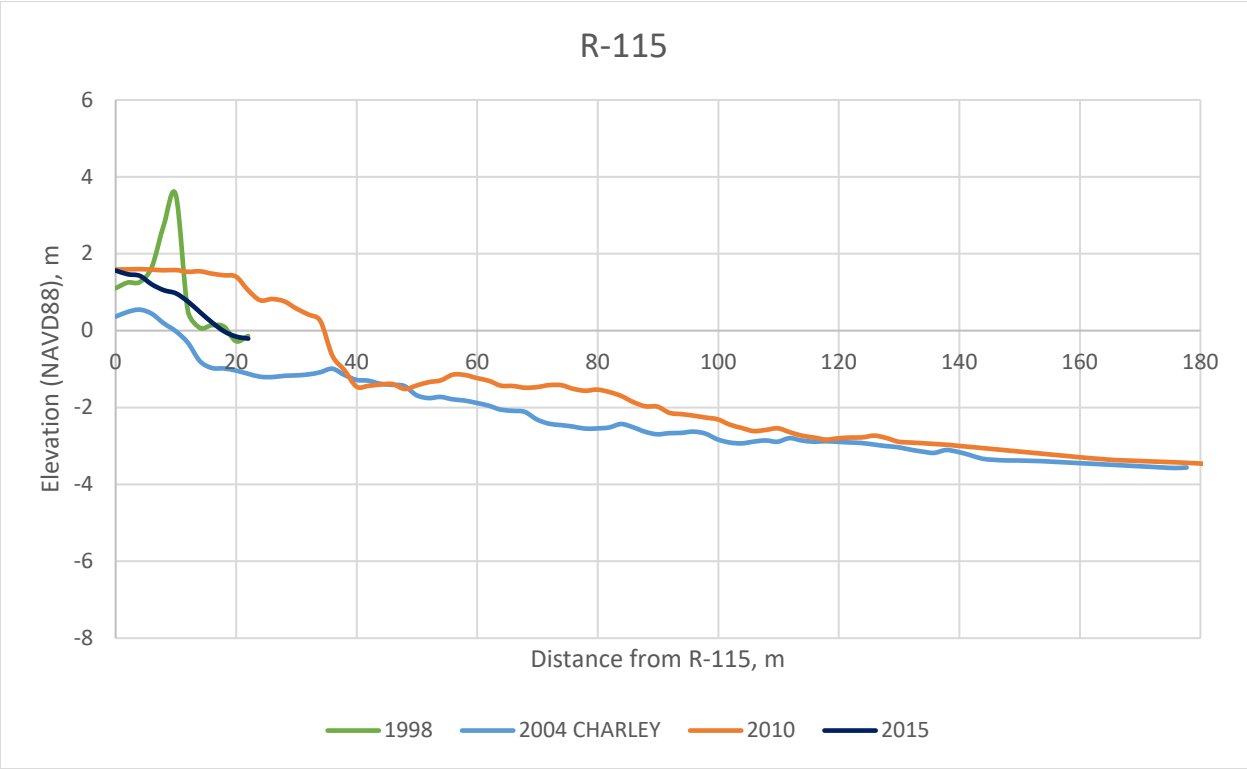


Figure A1.32. Beach profiles from LiDAR surveys with respect to NAVD88 at R-115.

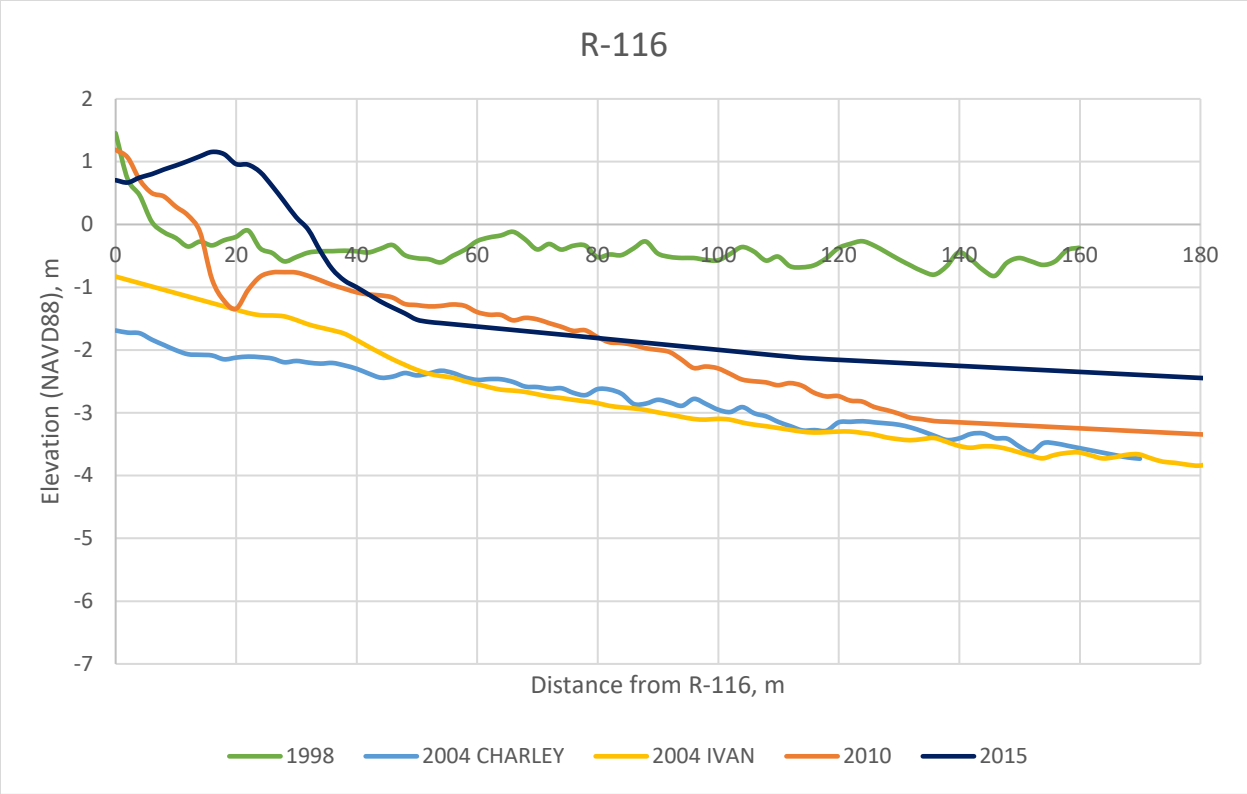


Figure A1.33. Beach profiles from LiDAR surveys with respect to NAVD88 at R-116.

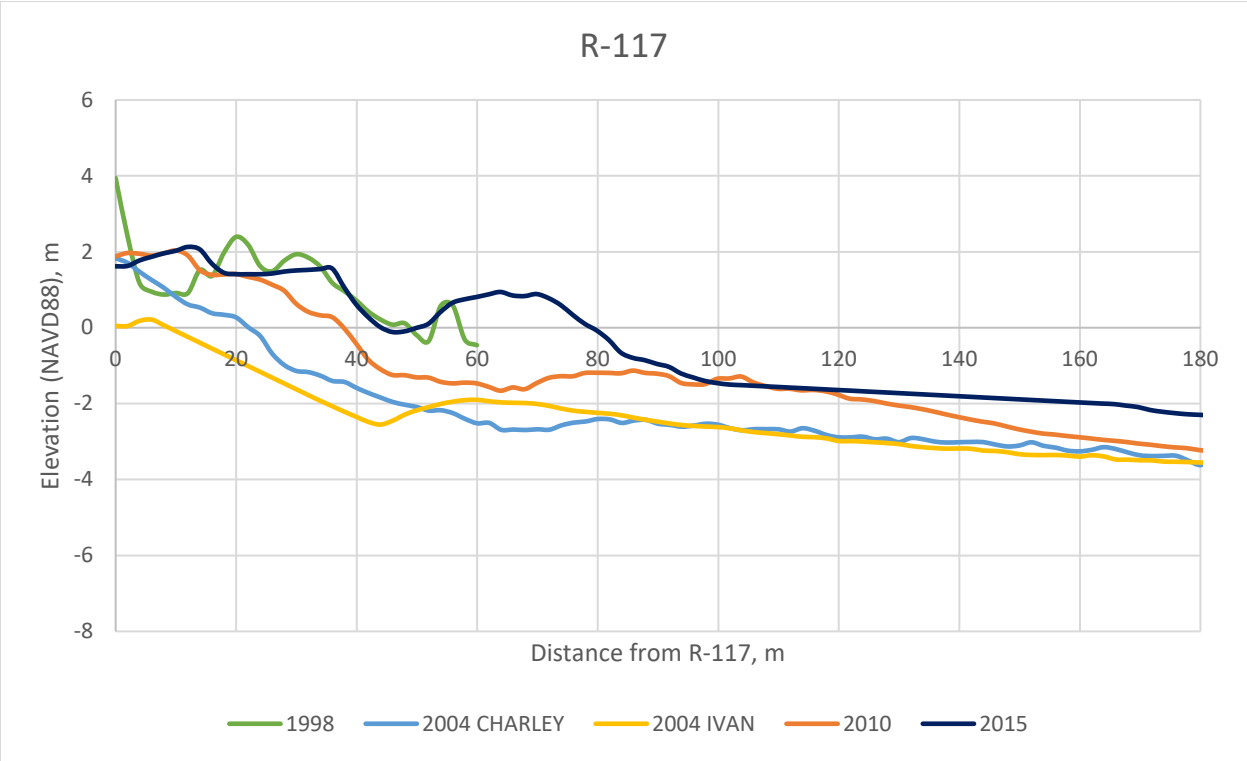


Figure A1.34. Beach profiles from LiDAR surveys with respect to NAVD88 at R-117.

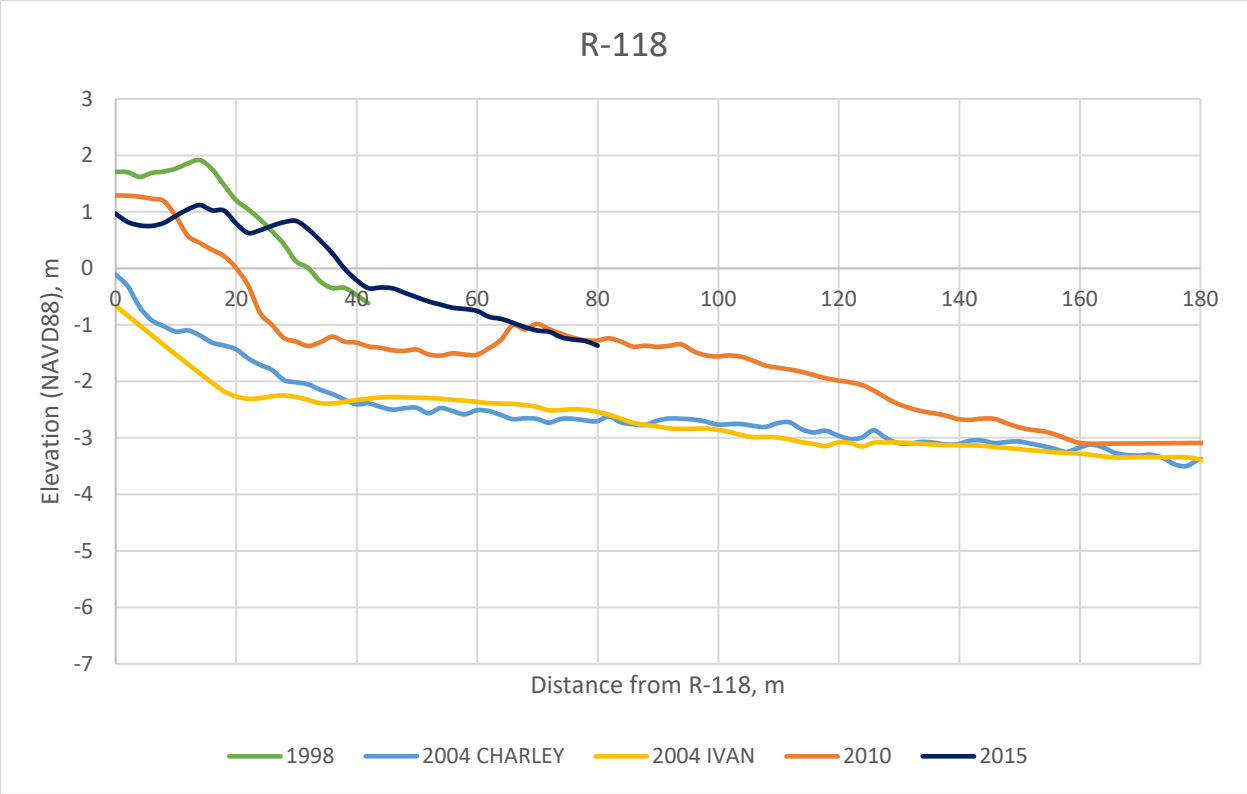


Figure A1.35. Beach profiles from LiDAR surveys with respect to NAVD88 at R-118.

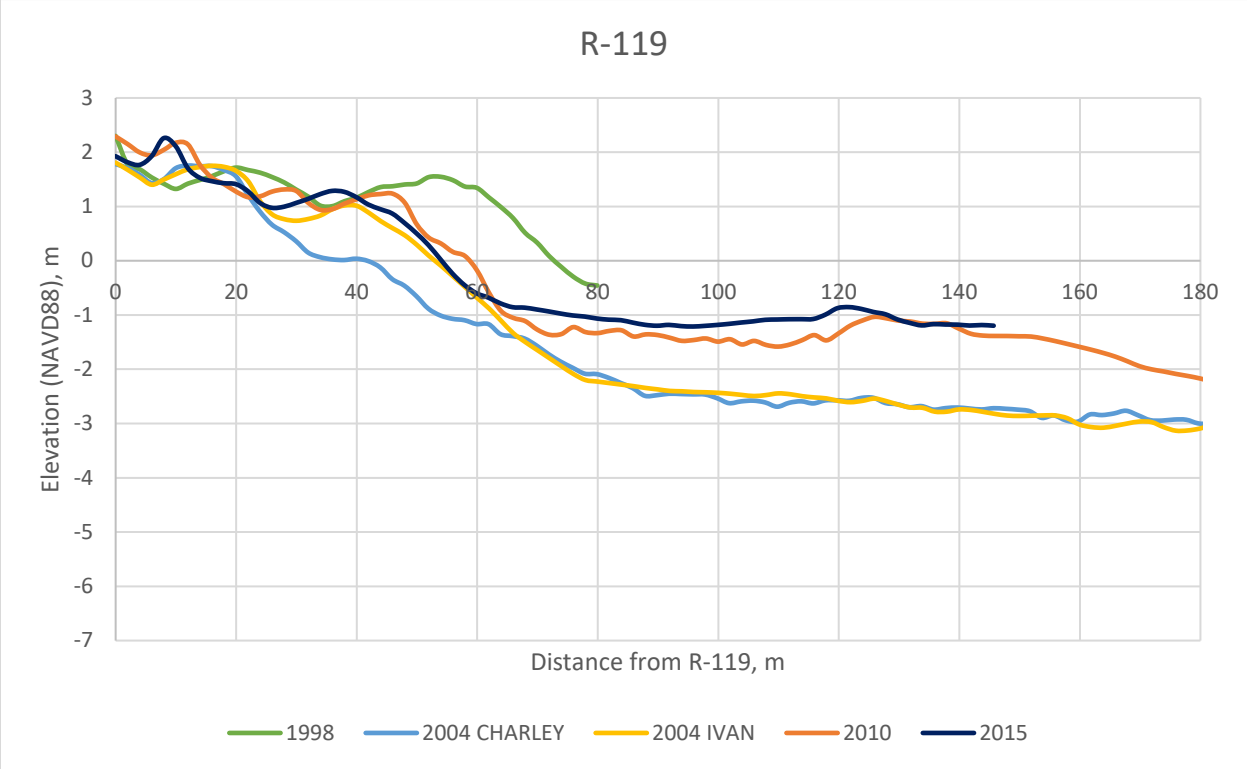


Figure A1.36. Beach profiles from LiDAR surveys with respect to NAVD88 at R-119.

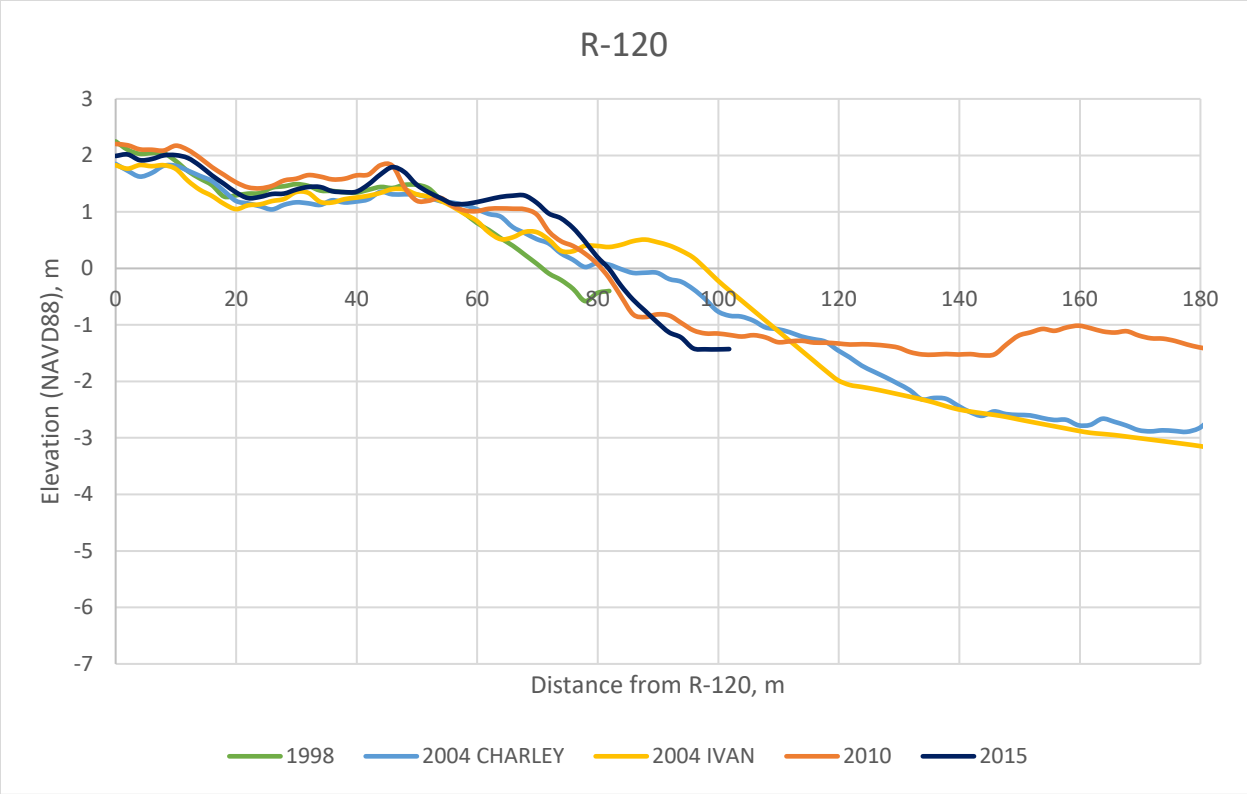


Figure A1.37. Beach profiles from LiDAR surveys with respect to NAVD88 at R-120.

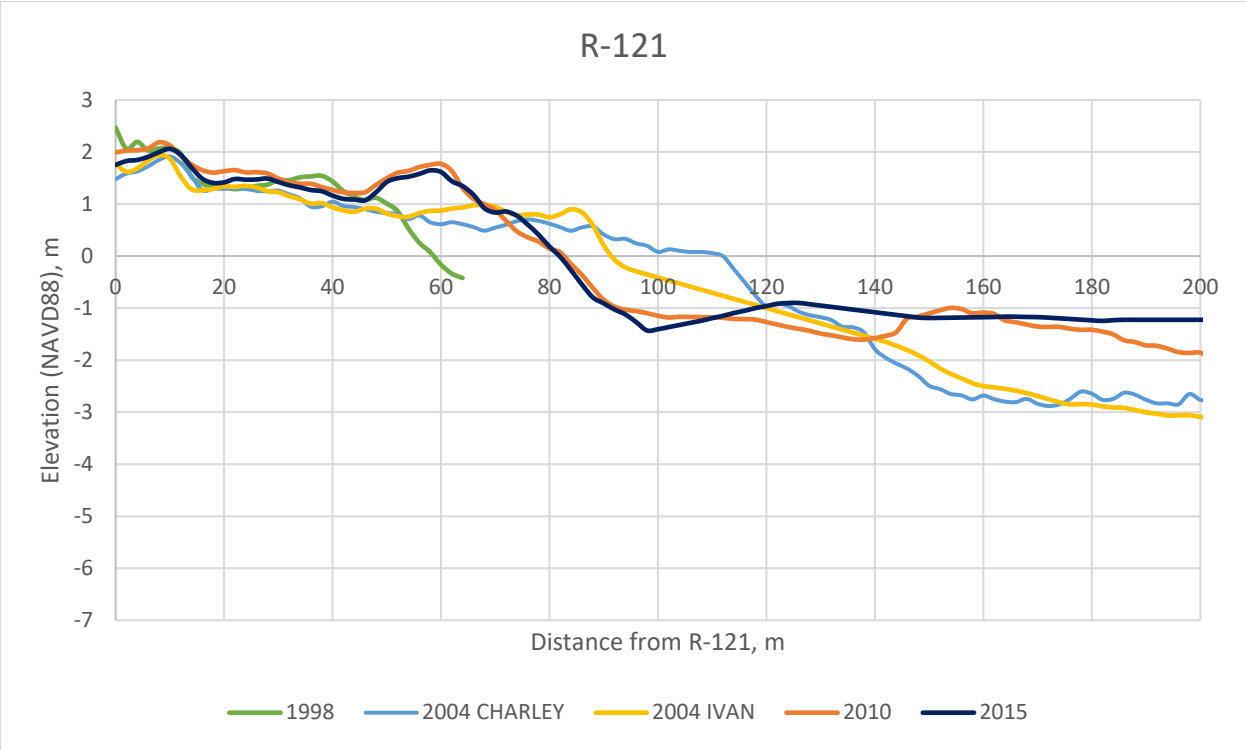


Figure A1.38. Beach profiles from LiDAR surveys with respect to NAVD88 at R-121.

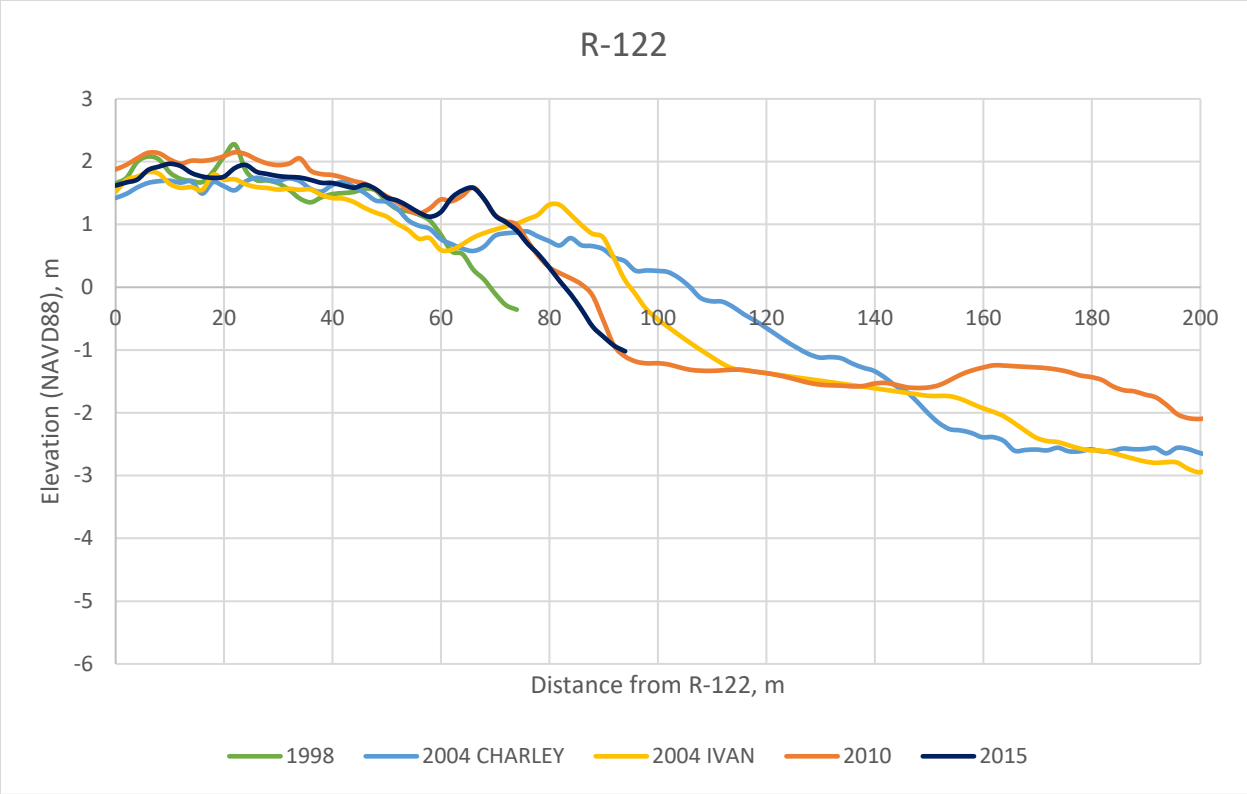


Figure A1.39. Beach profiles from LiDAR surveys with respect to NAVD88 at R-122.

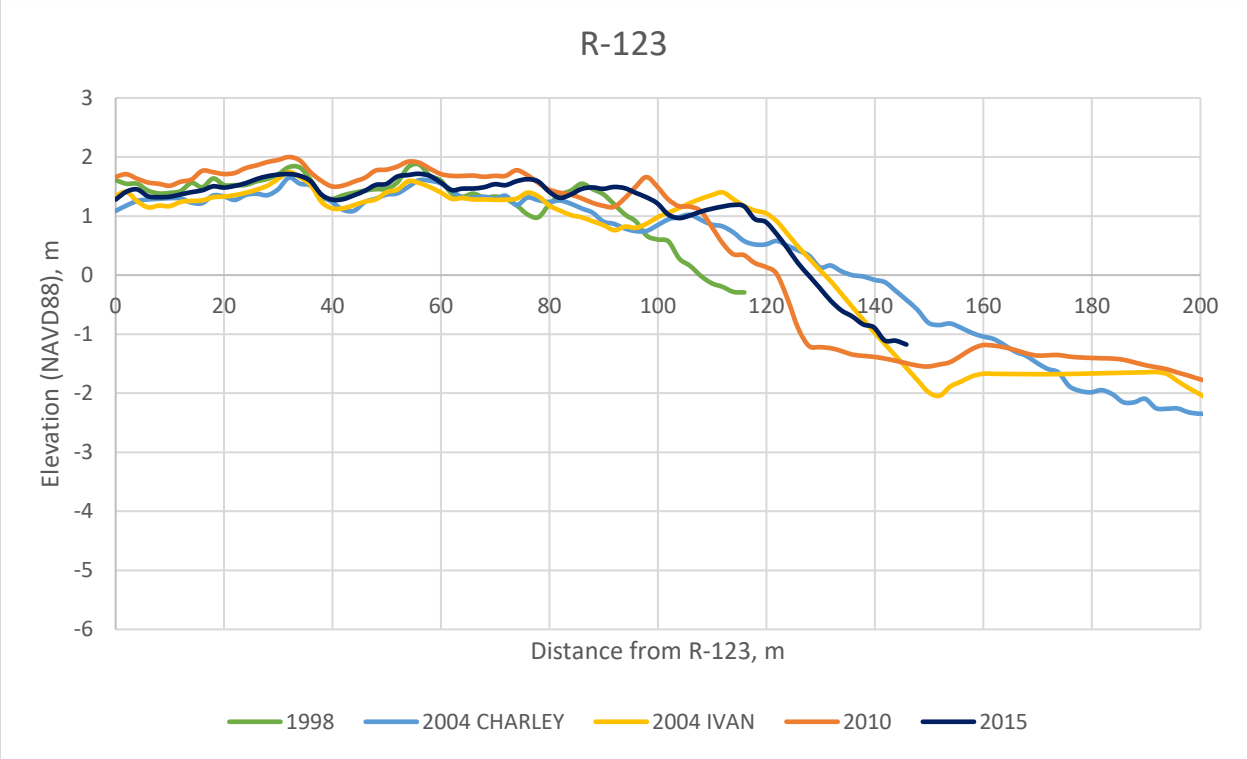


Figure A1.40. Beach profiles from LiDAR surveys with respect to NAVD88 at R-123.

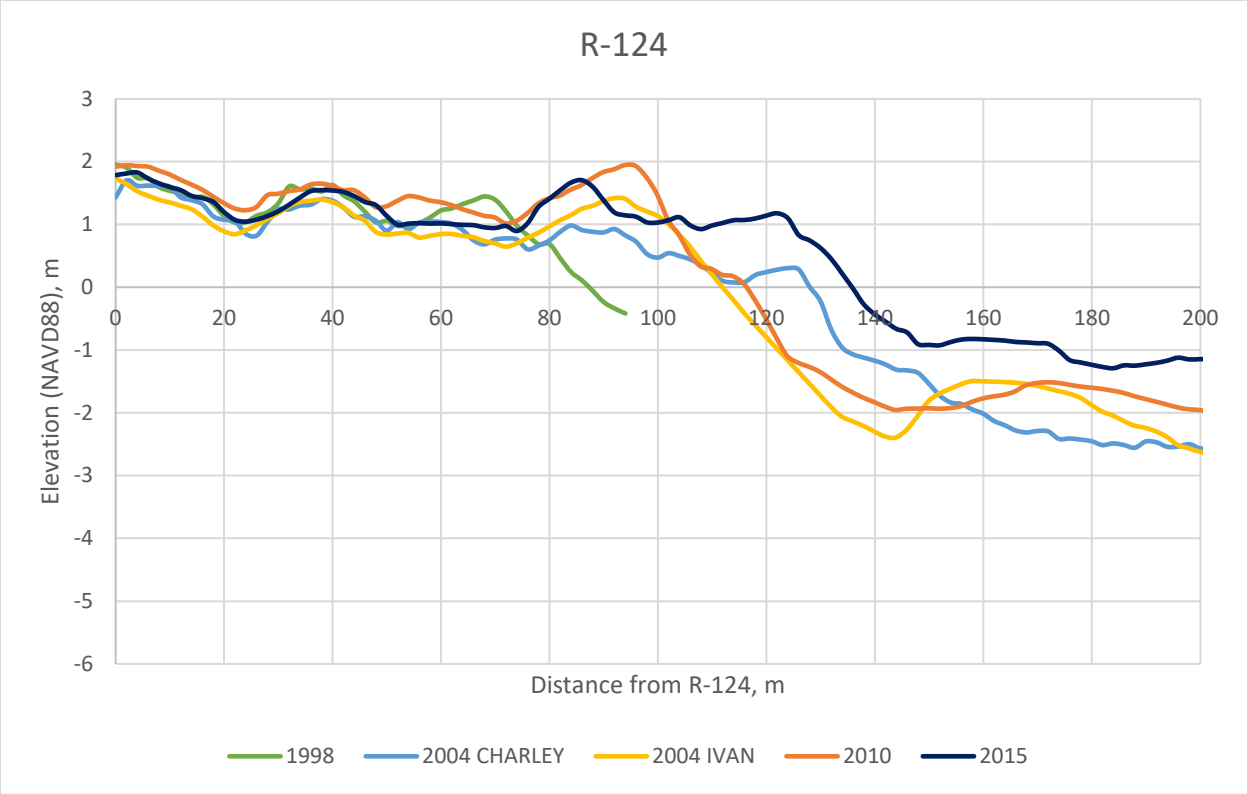


Figure A1.41. Beach profiles from LiDAR surveys with respect to NAVD88 at R-124.

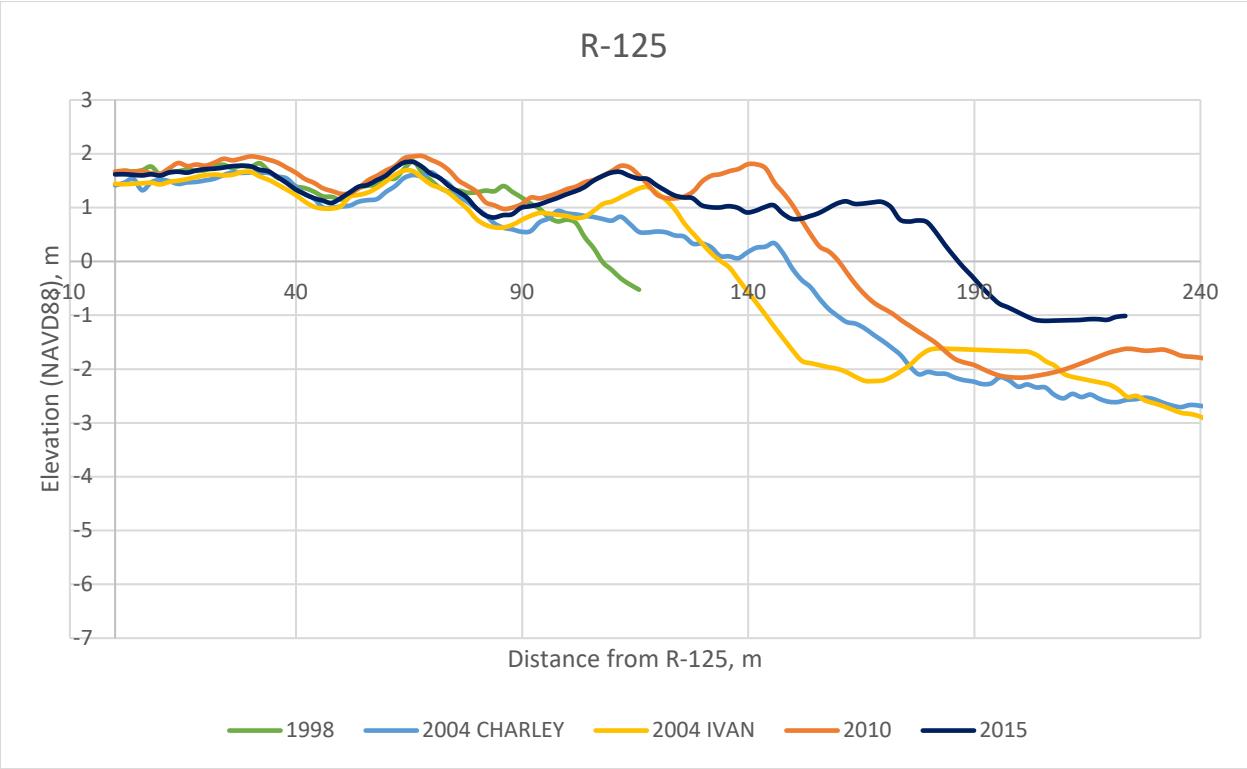


Figure A1.42. Beach profiles from LiDAR surveys with respect to NAVD88 at R-125.

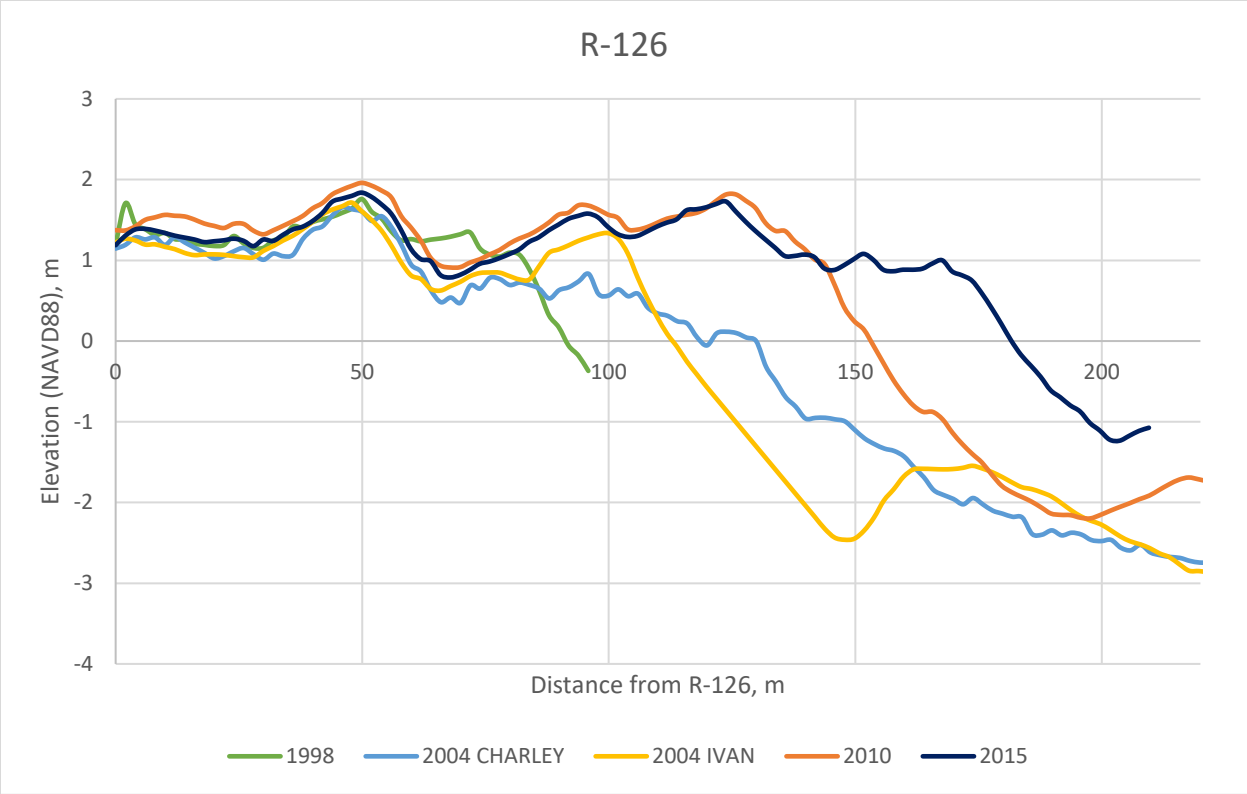


Figure A1.43. Beach profiles from LiDAR surveys with respect to NAVD88 at R-126.

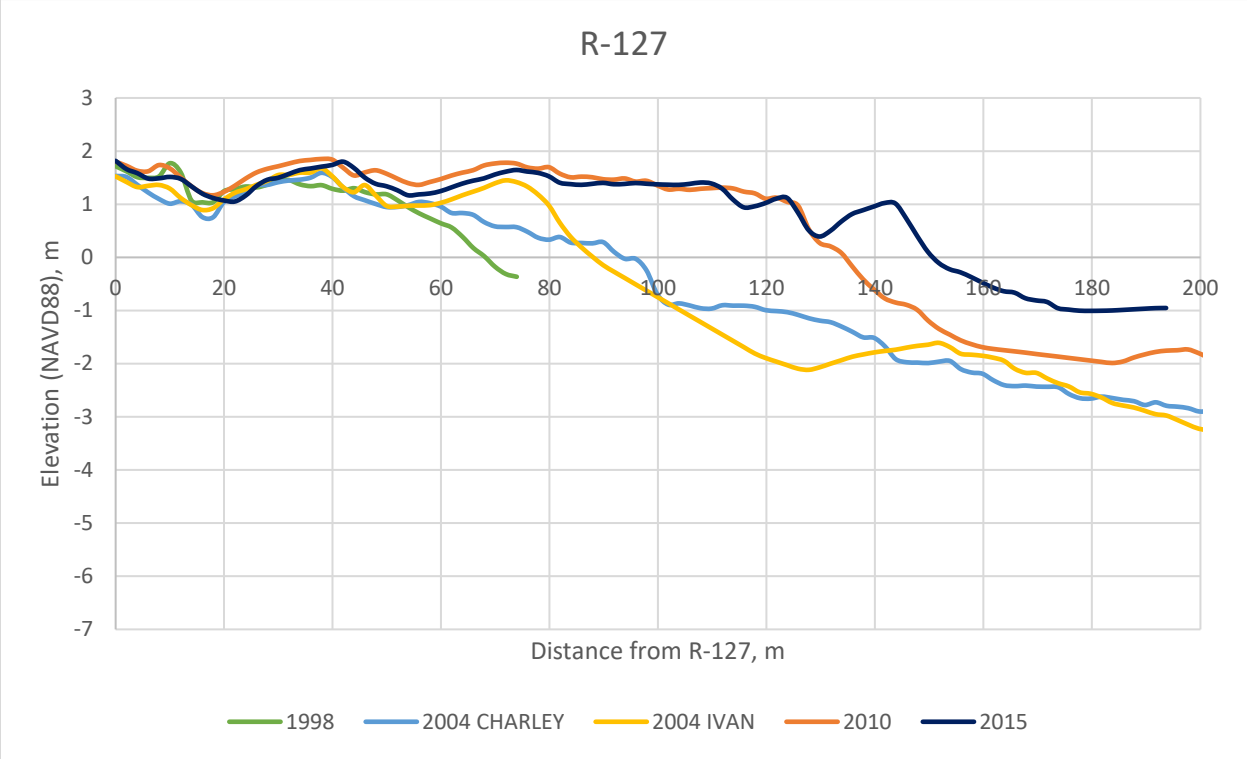


Figure A1.44. Beach profiles from LiDAR surveys with respect to NAVD88 at R-127.

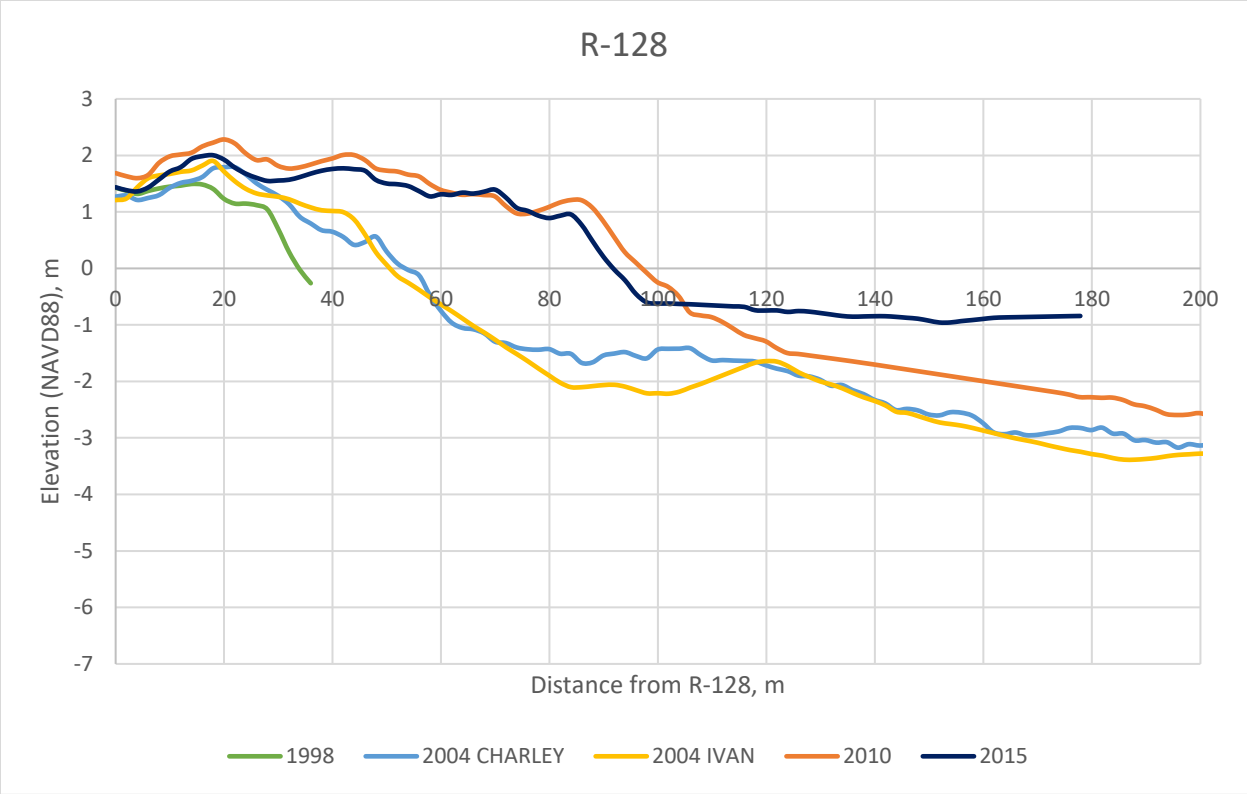


Figure A1.45. Beach profiles from LiDAR surveys with respect to NAVD88 at R-128.

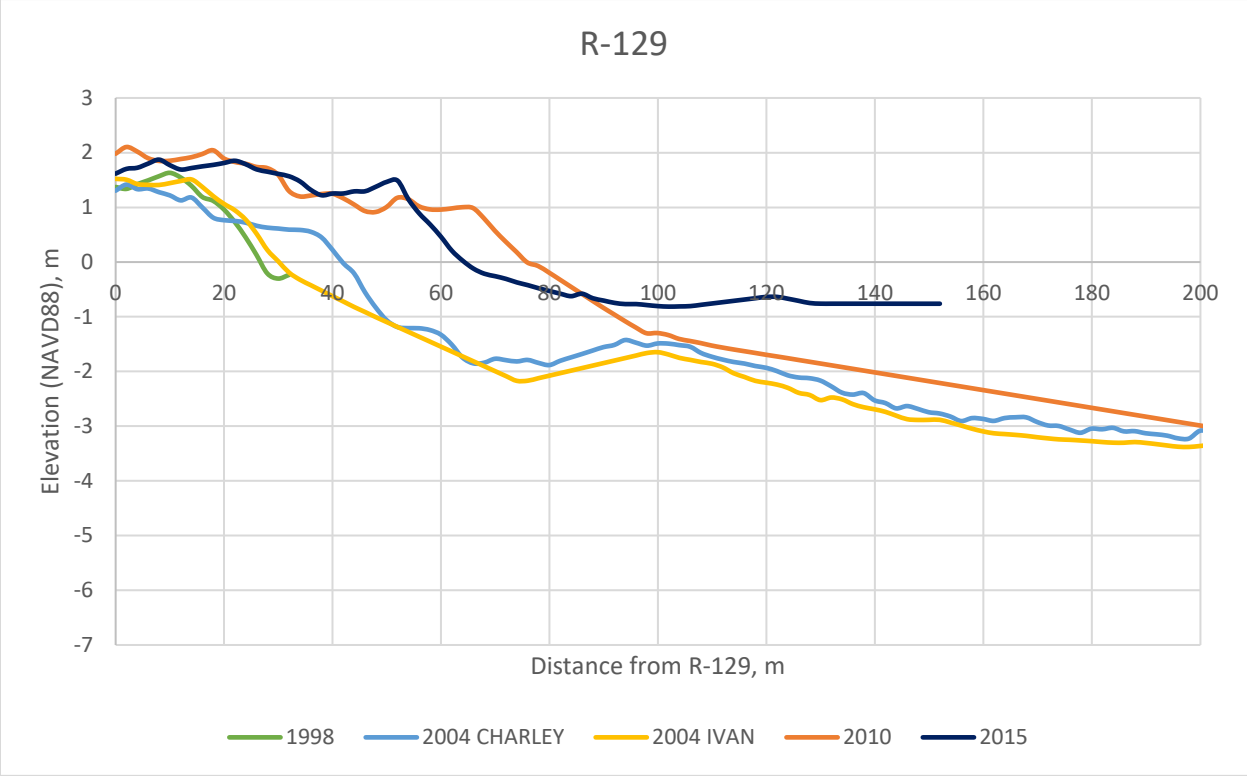


Figure A1.46. Beach profiles from LiDAR surveys with respect to NAVD88 at R-129.

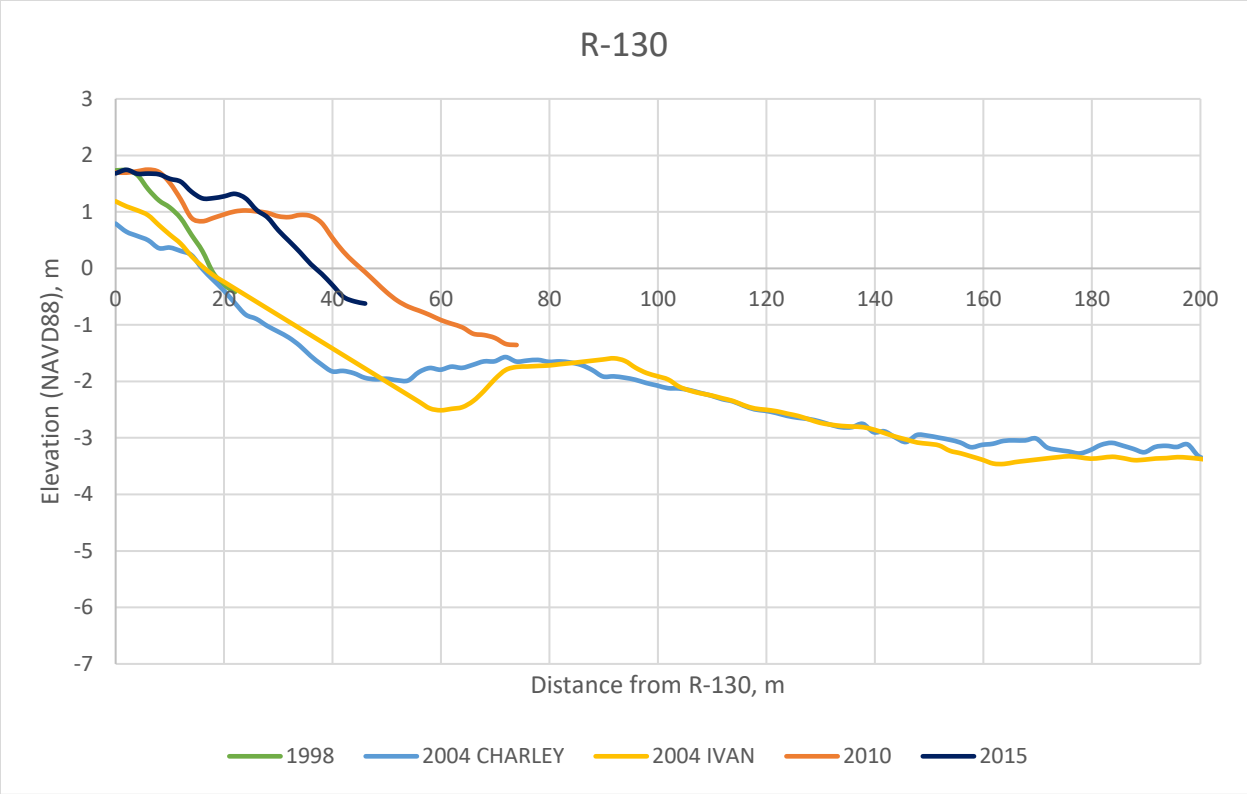


Figure A1.47. Beach profiles from LiDAR surveys with respect to NAVD88 at R-130.

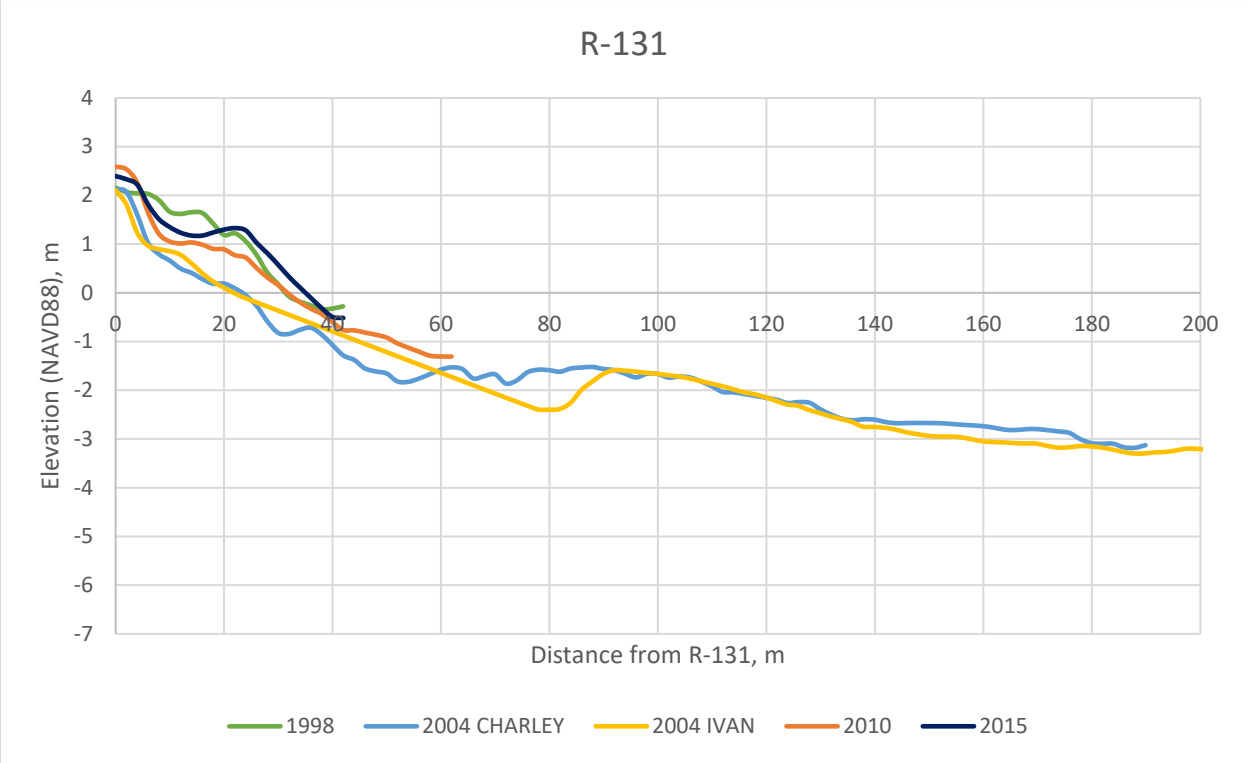


Figure A1.48. Beach profiles from LiDAR surveys with respect to NAVD88 at R-131.

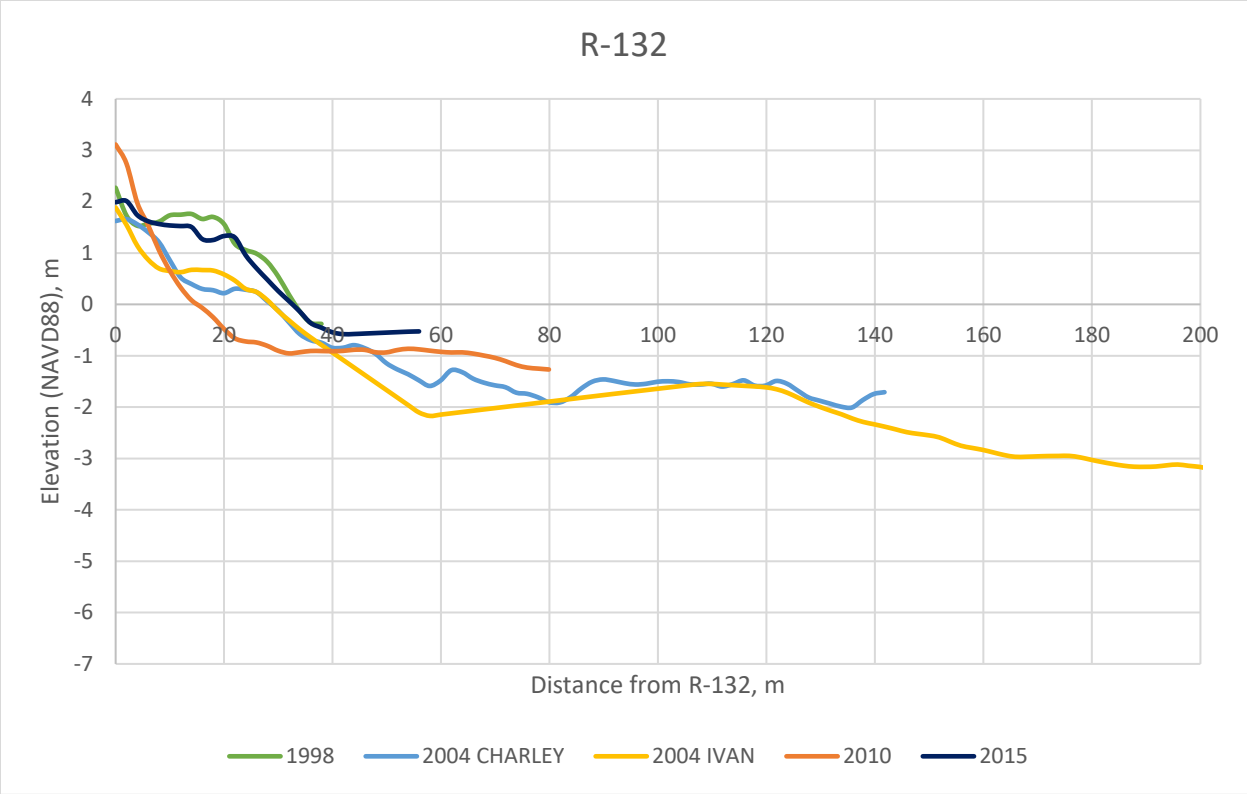


Figure A1.49. Beach profiles from LiDAR surveys with respect to NAVD88 at R-132.

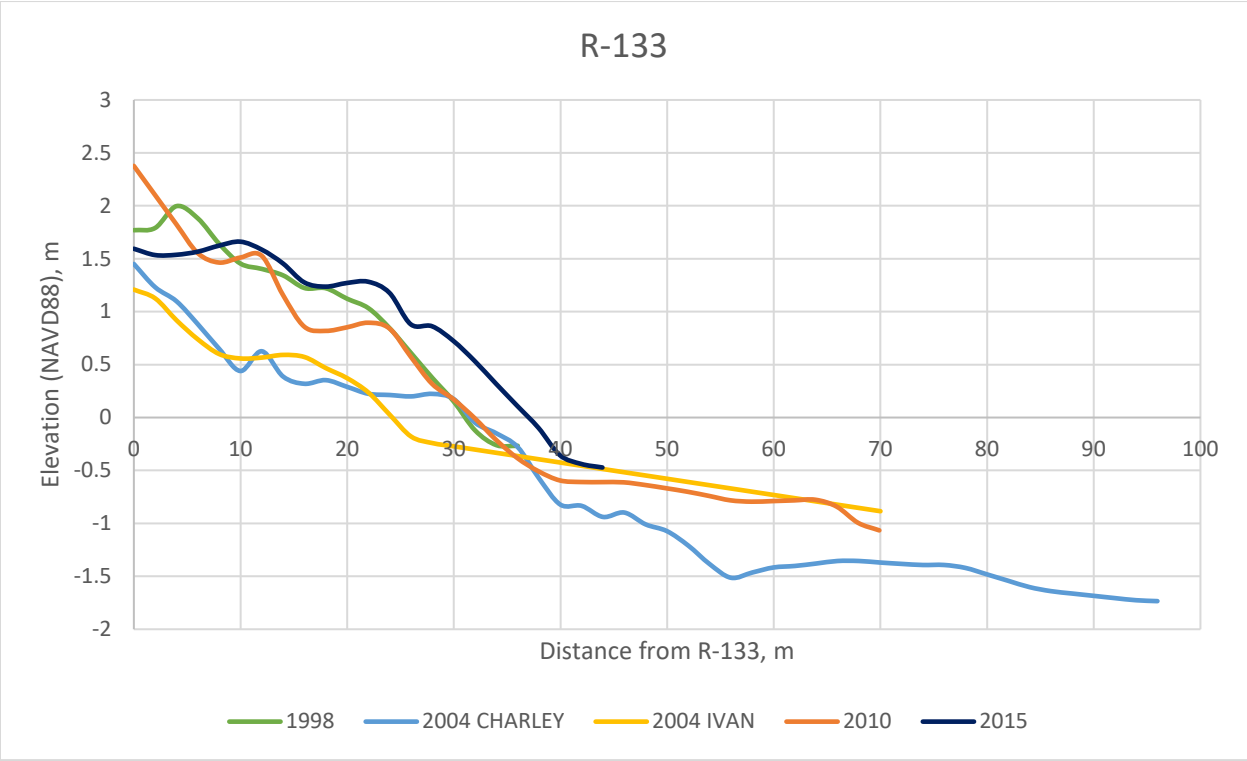


Figure A1.50. Beach profiles from LiDAR surveys with respect to NAVD88 at R-133.

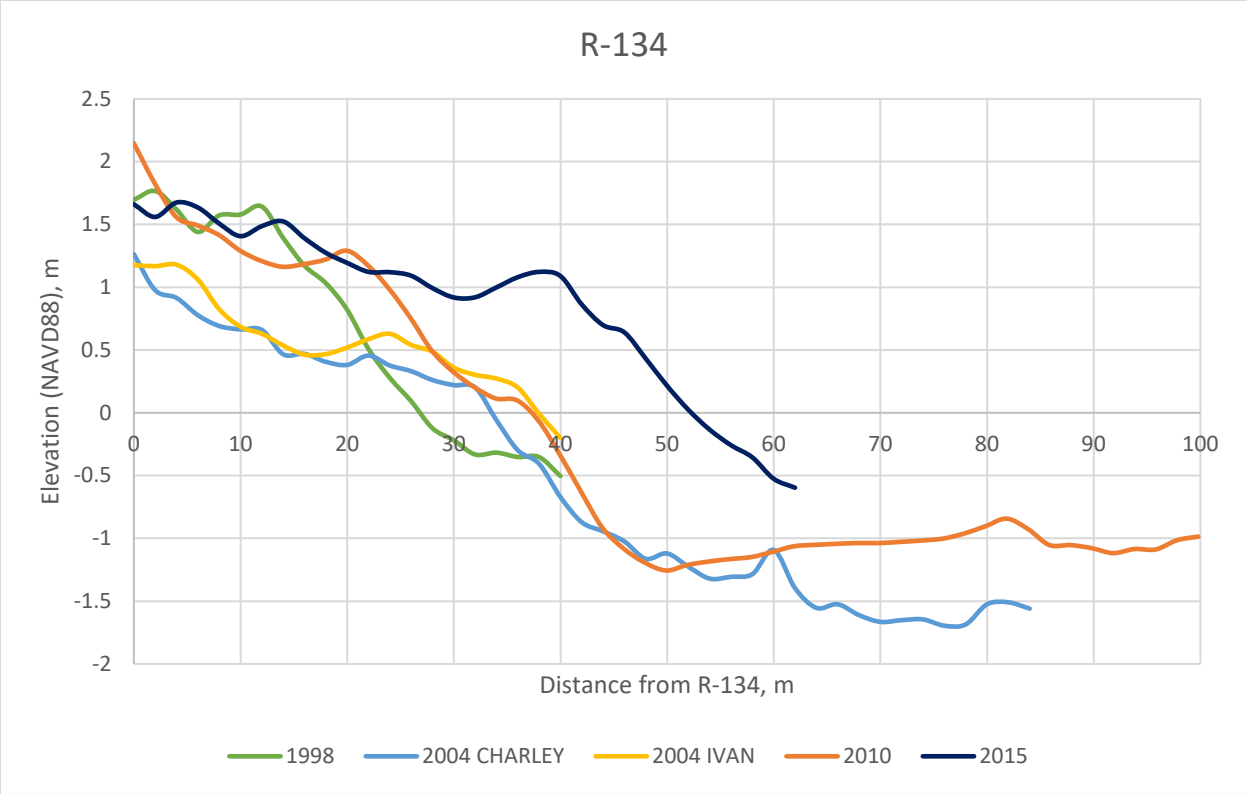


Figure A1.51. Beach profiles from LiDAR surveys with respect to NAVD88 at R-134.

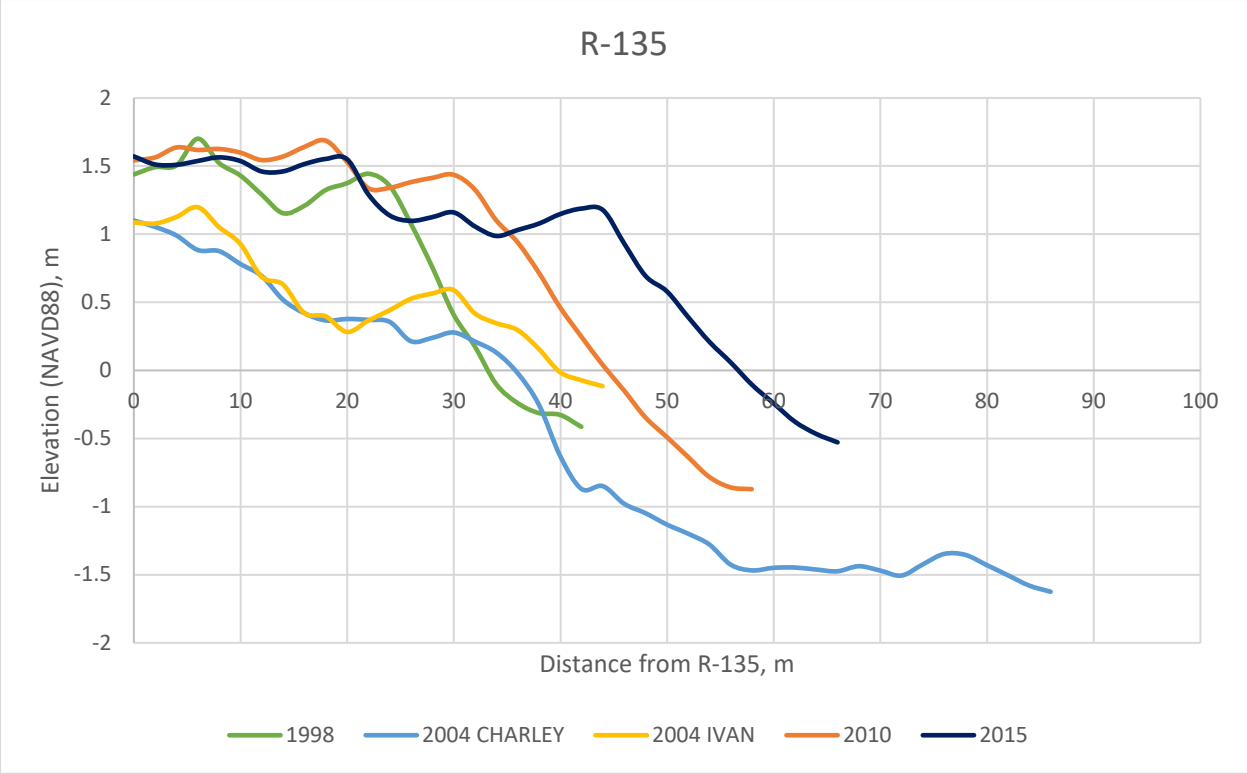


Figure A1.52. Beach profiles from LiDAR surveys with respect to NAVD88 at R-135.

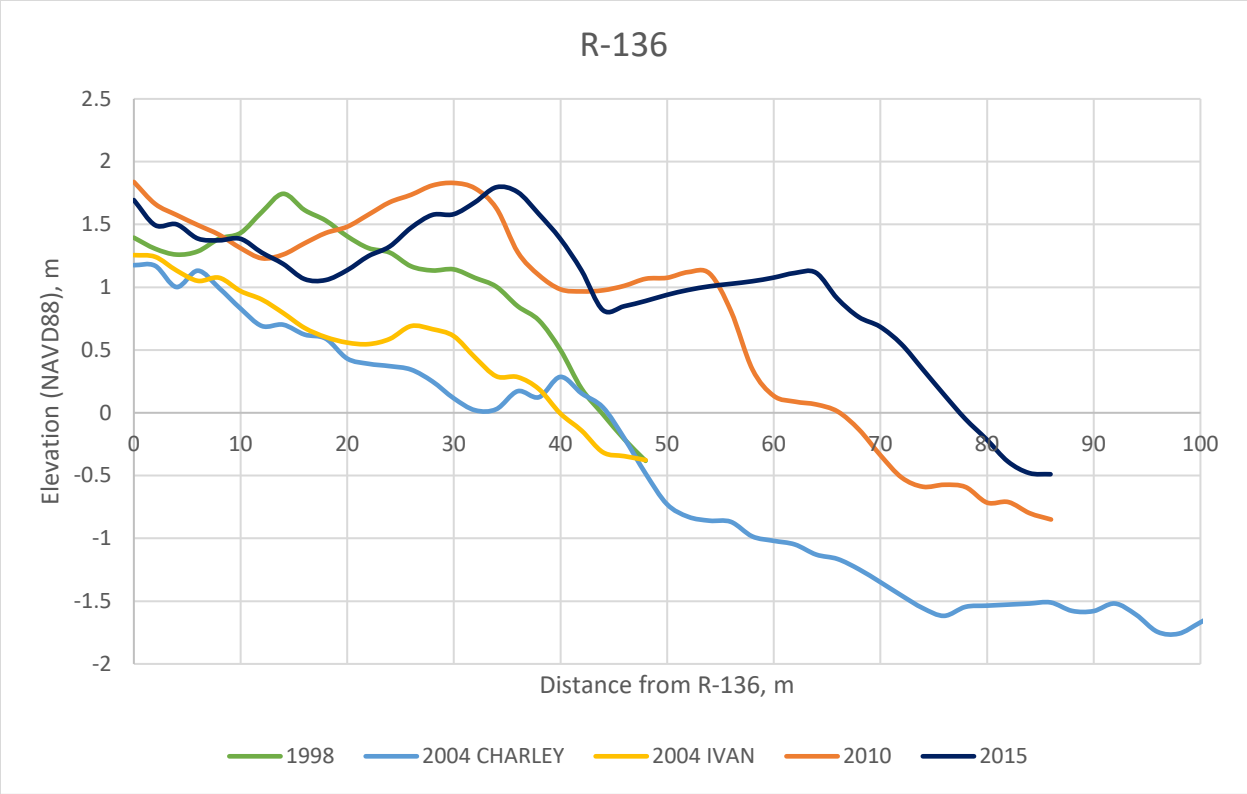


Figure A1.53. Beach profiles from LiDAR surveys with respect to NAVD88 at R-136.

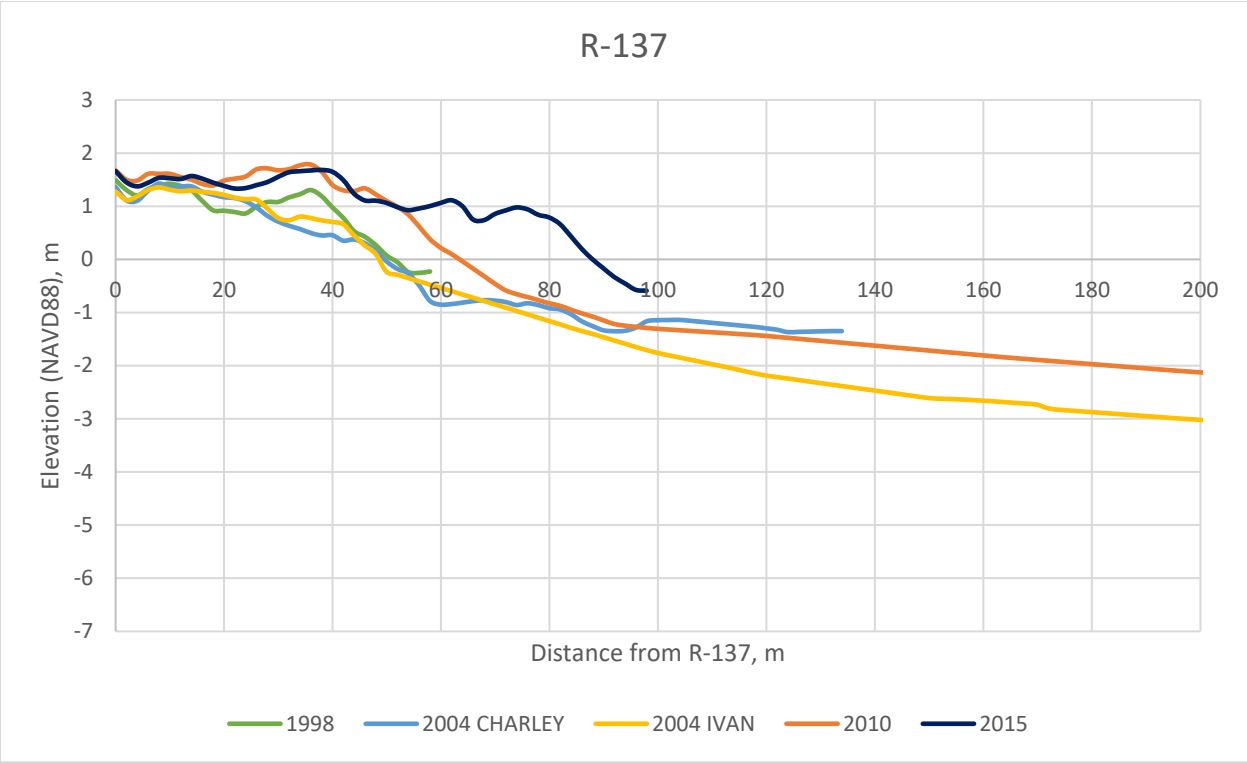


Figure A1.54. Beach profiles from LiDAR surveys with respect to NAVD88 at R-137.

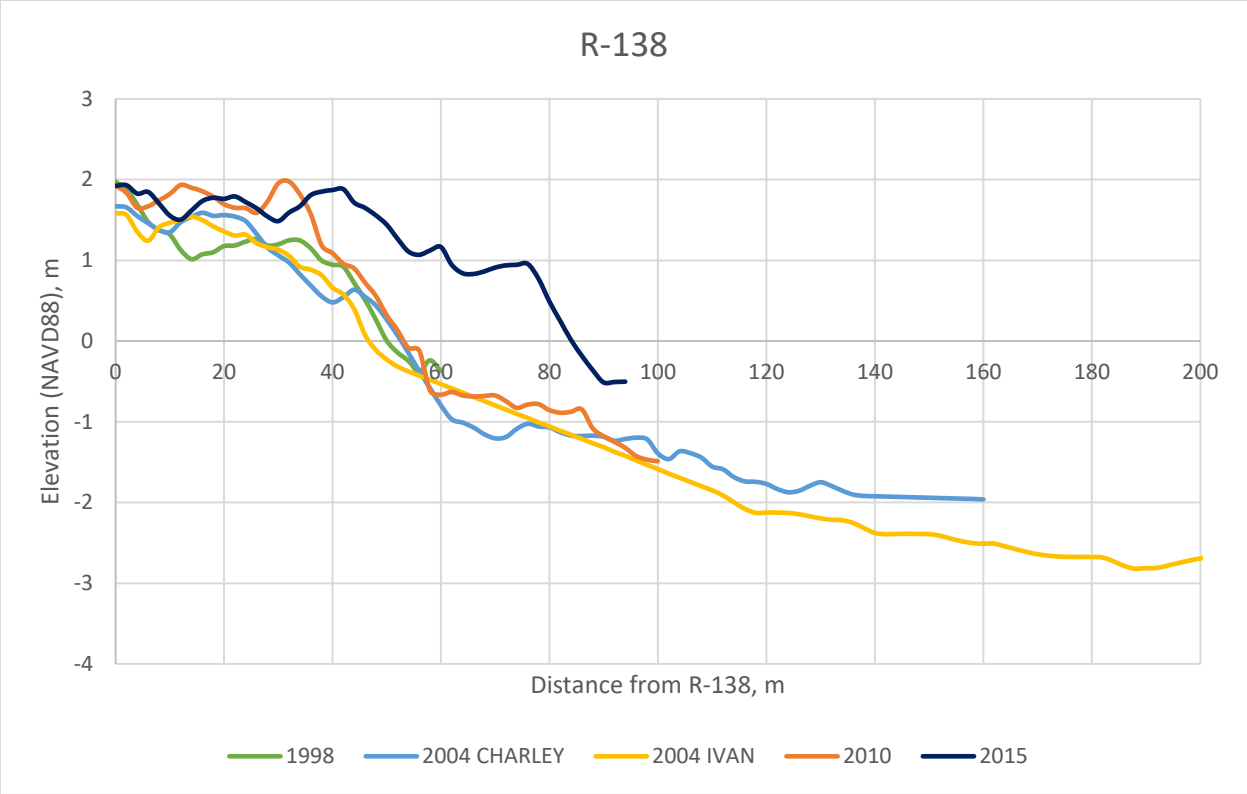


Figure A1.55. Beach profiles from LiDAR surveys with respect to NAVD88 at R-138.

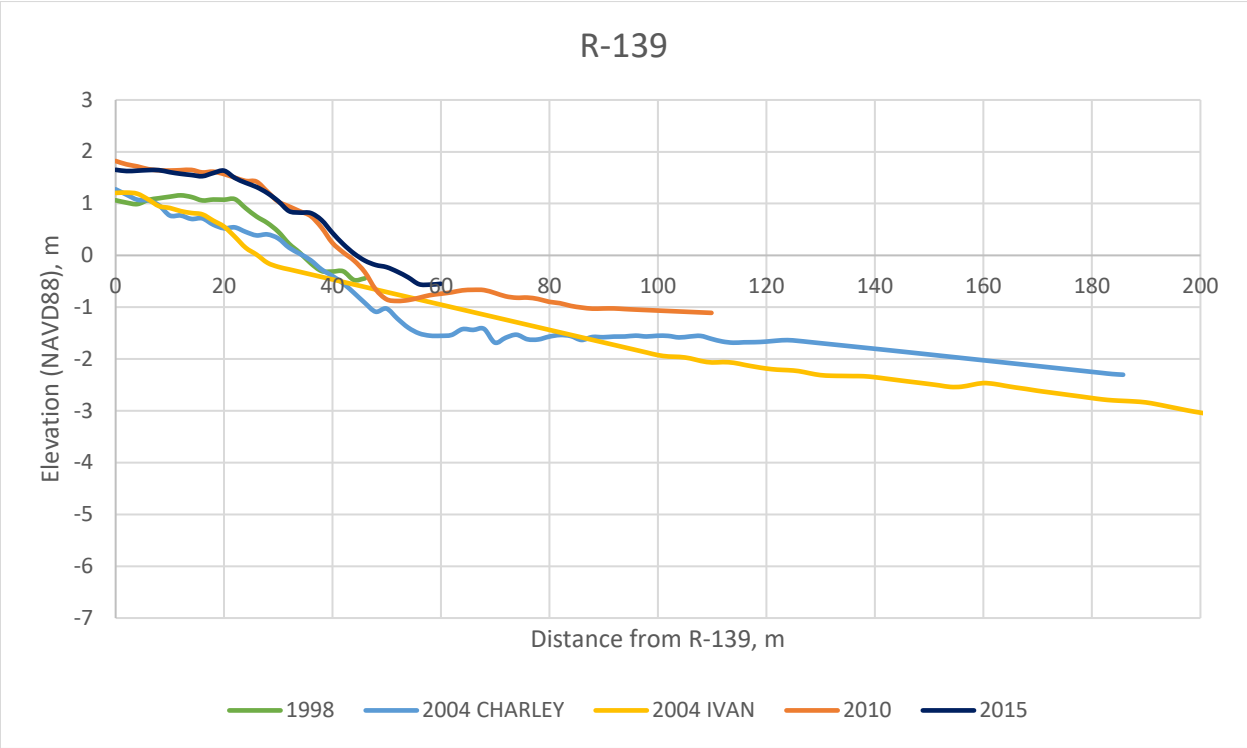


Figure A1.56. Beach profiles from LiDAR surveys with respect to NAVD88 at R-139.

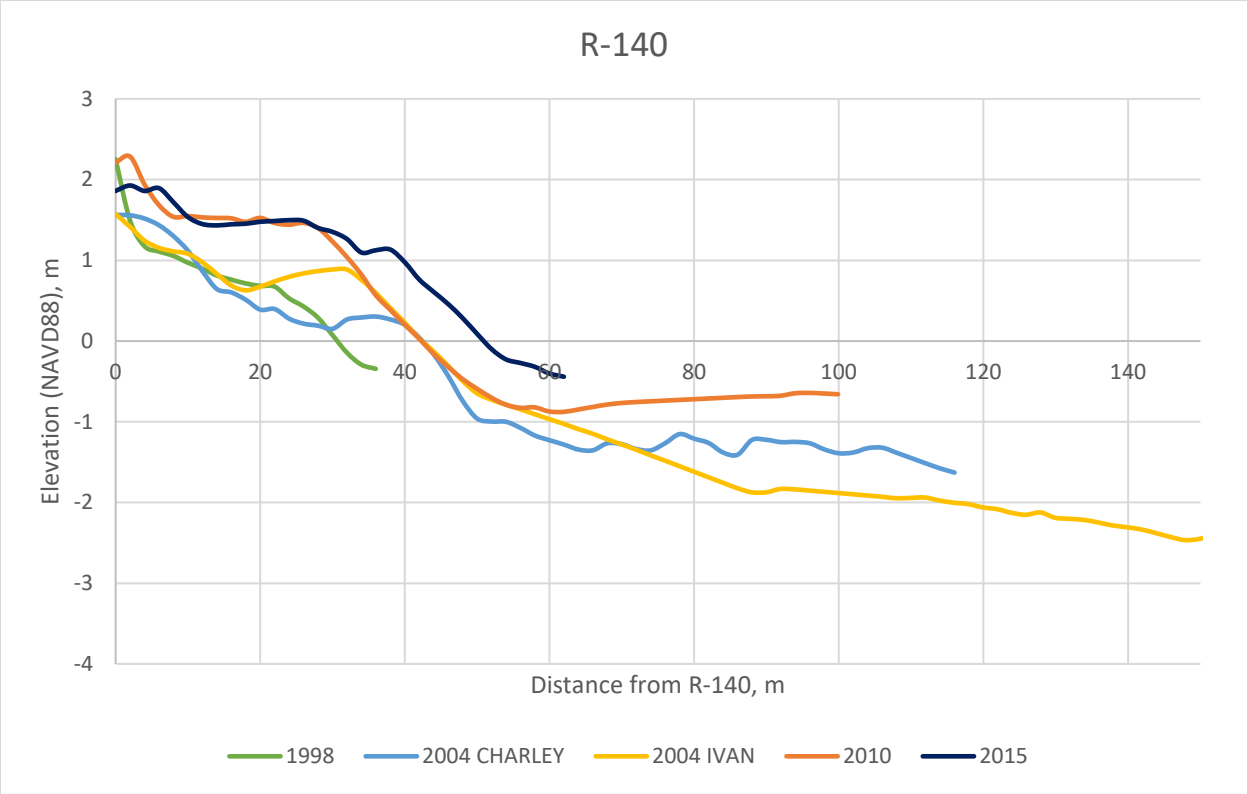


Figure A1.57. Beach profiles from LiDAR surveys with respect to NAVD88 at R-140.

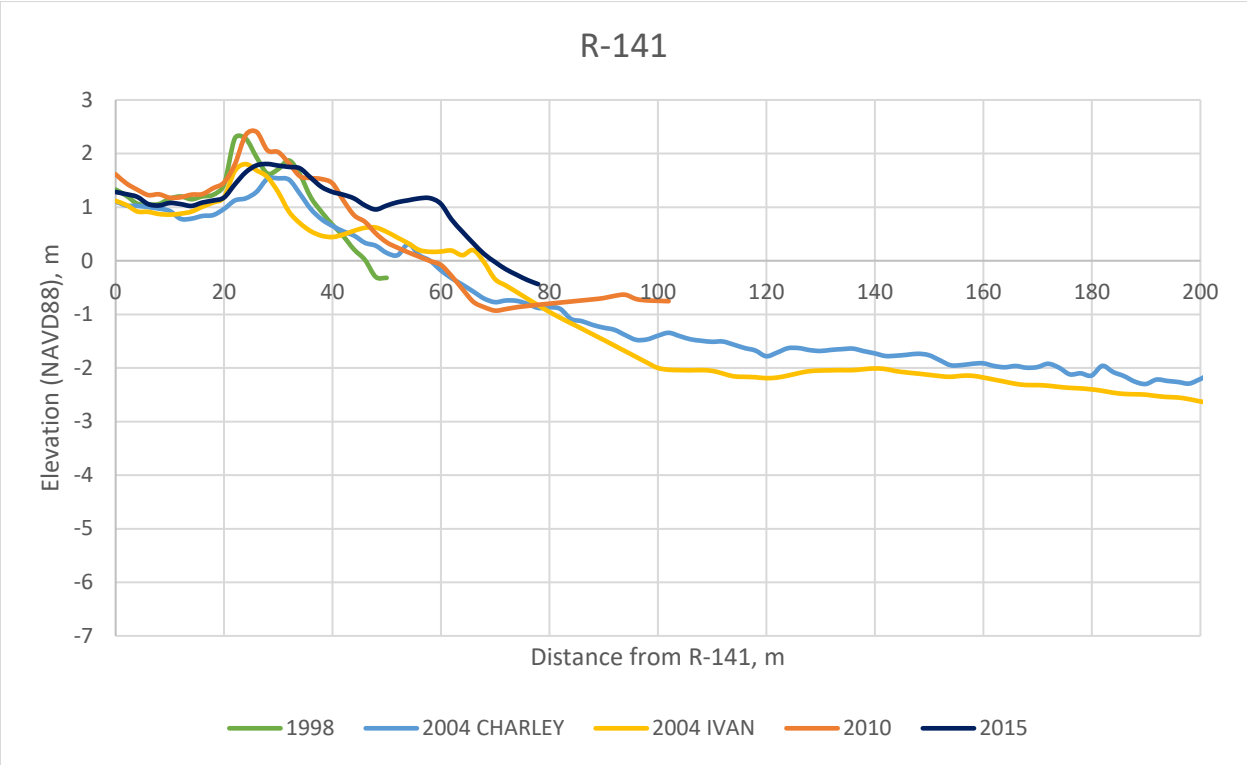


Figure A1.58. Beach profiles from LiDAR surveys with respect to NAVD88 at R-141.

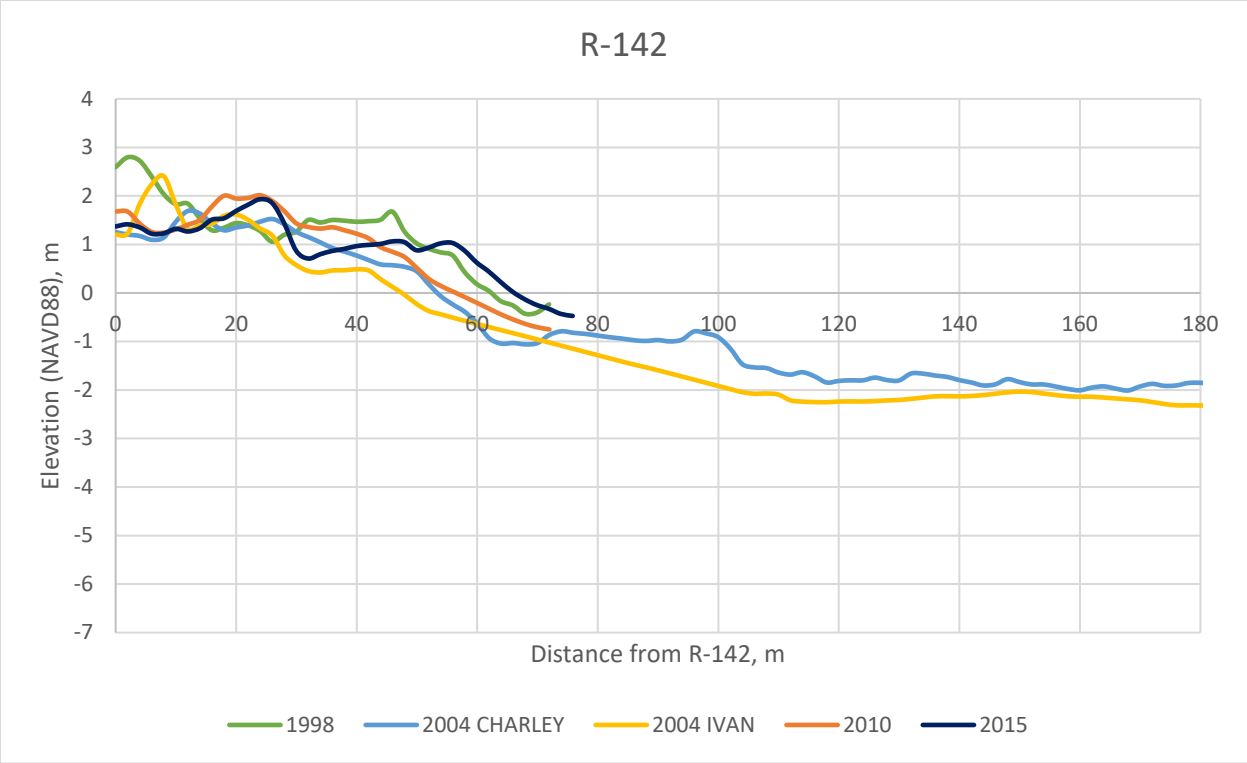


Figure A1.59. Beach profiles from LiDAR surveys with respect to NAVD88 at R-142.

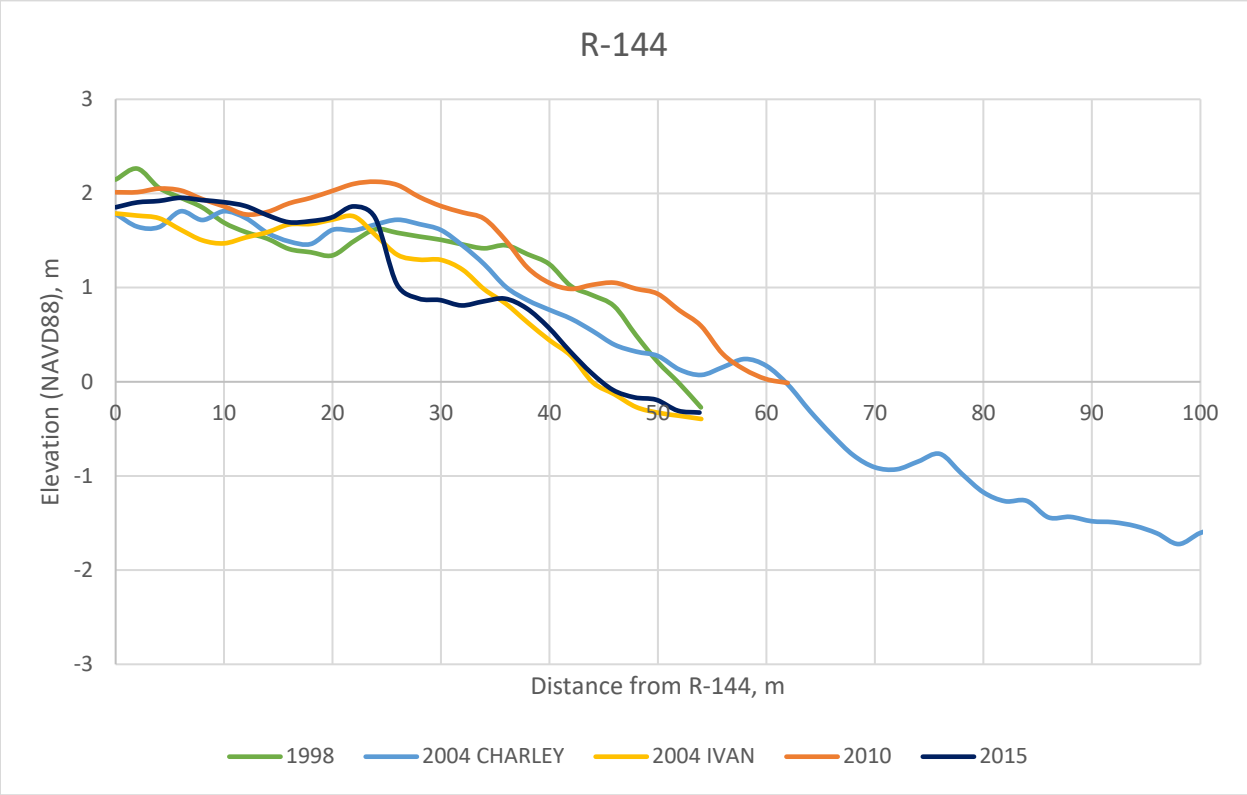


Figure A1.60. Beach profiles from LiDAR surveys with respect to NAVD88 at R-144.

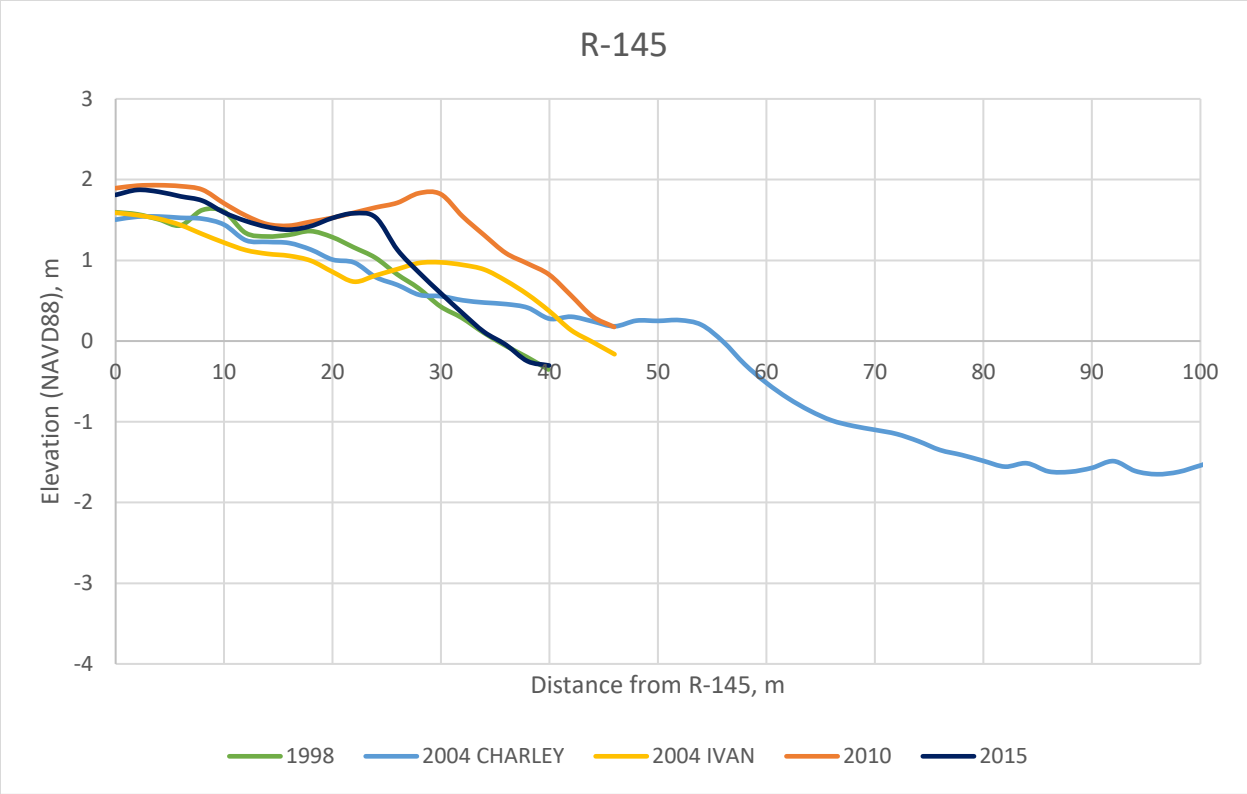


Figure A1.61. Beach profiles from LiDAR surveys with respect to NAVD88 at R-145.

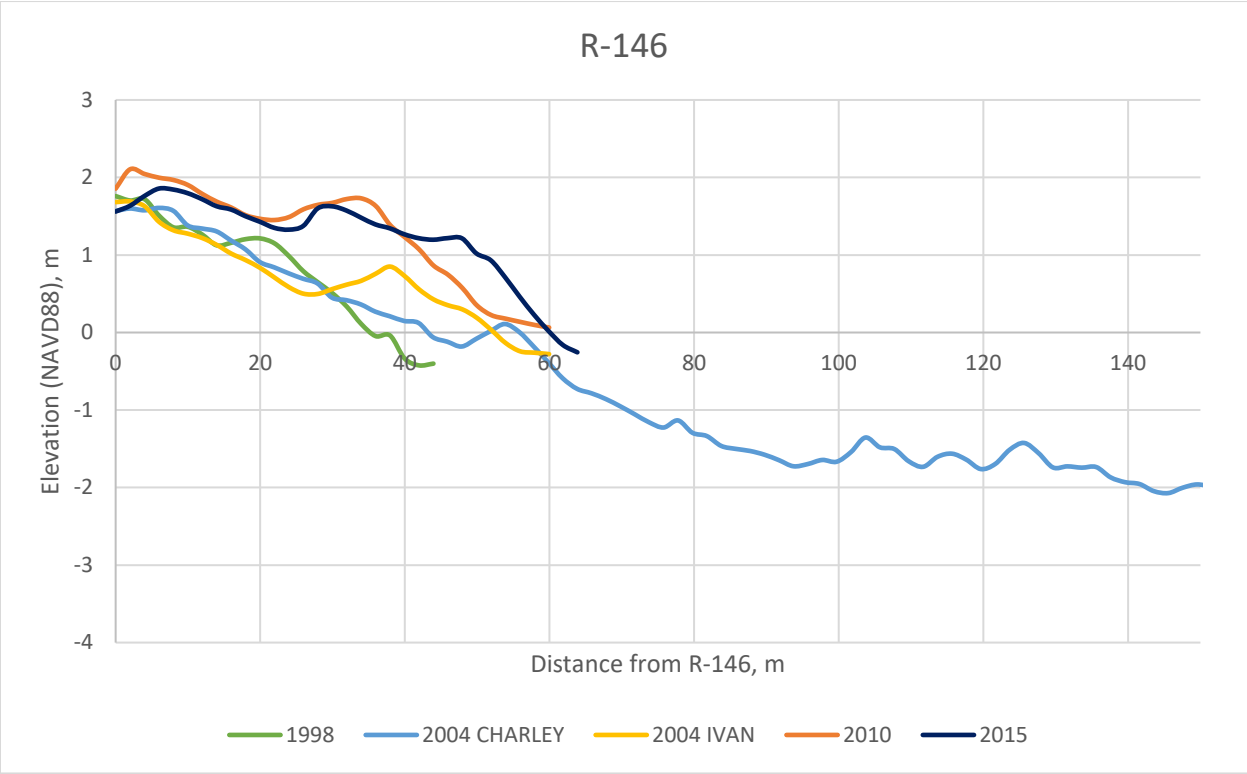


Figure A1.62. Beach profiles from LiDAR surveys with respect to NAVD88 at R-146.

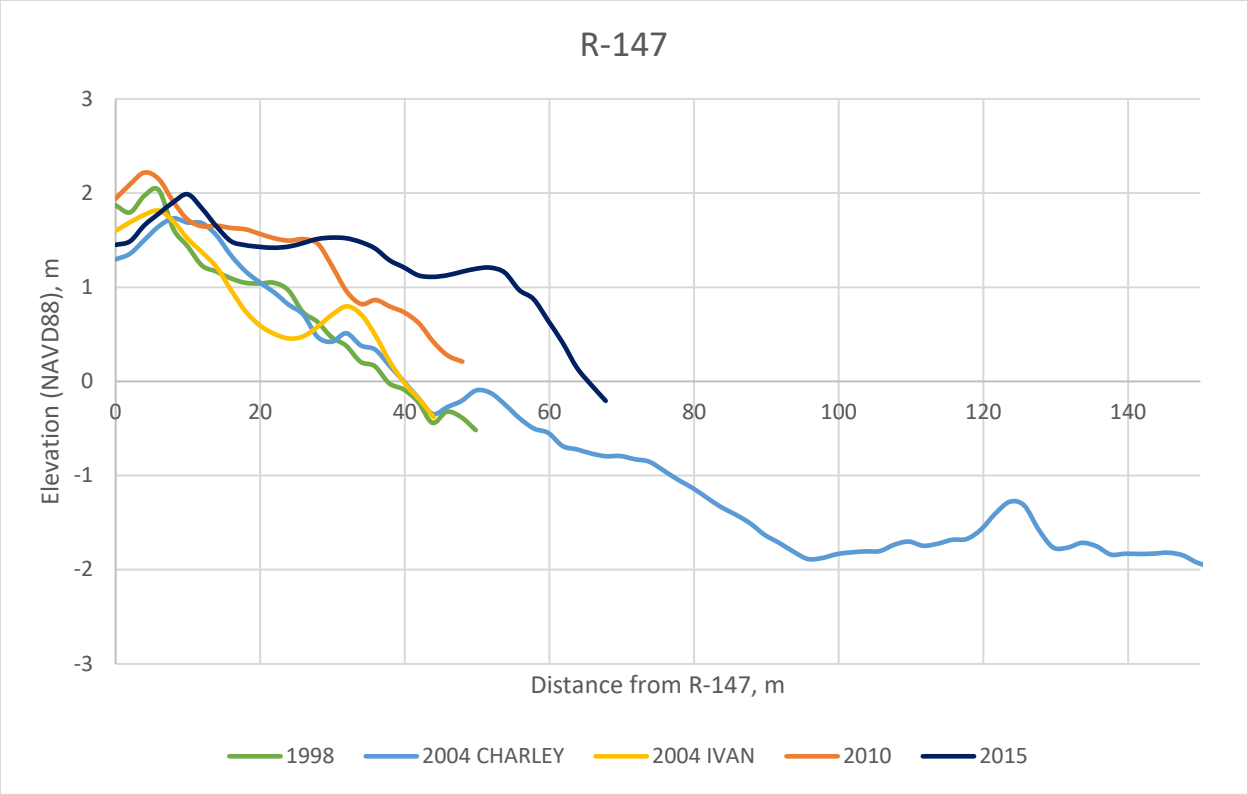


Figure A1.63. Beach profiles from LiDAR surveys with respect to NAVD88 at R-147.

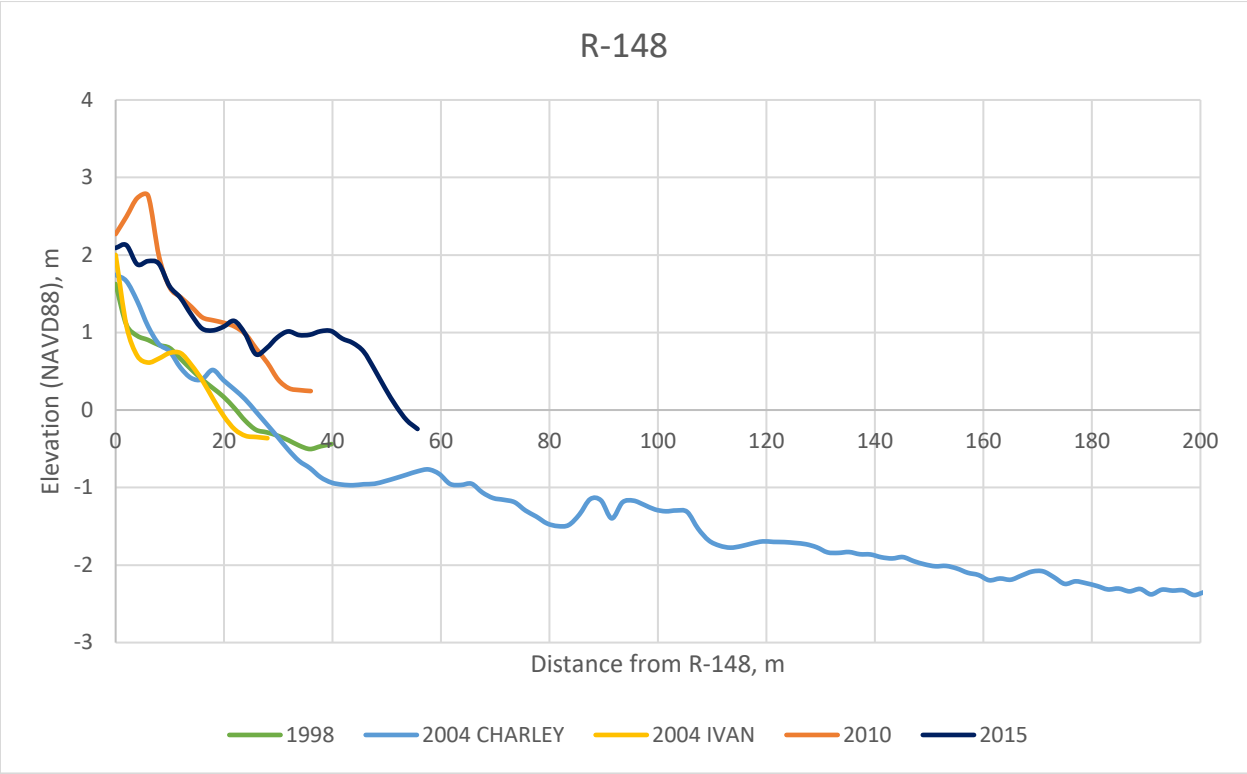


Figure A1.64. Beach profiles from LiDAR surveys with respect to NAVD88 at R-148.

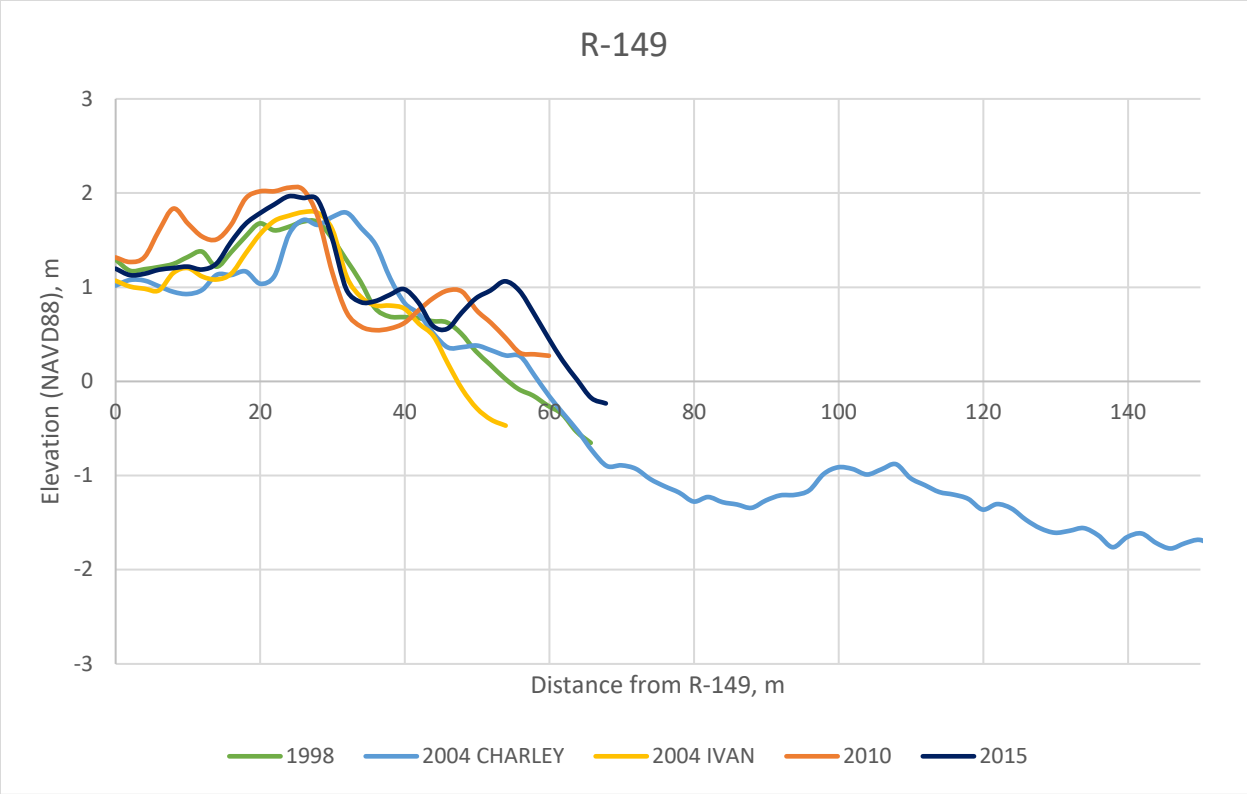


Figure A1.65. Beach profiles from LiDAR surveys with respect to NAVD88 at R-149.

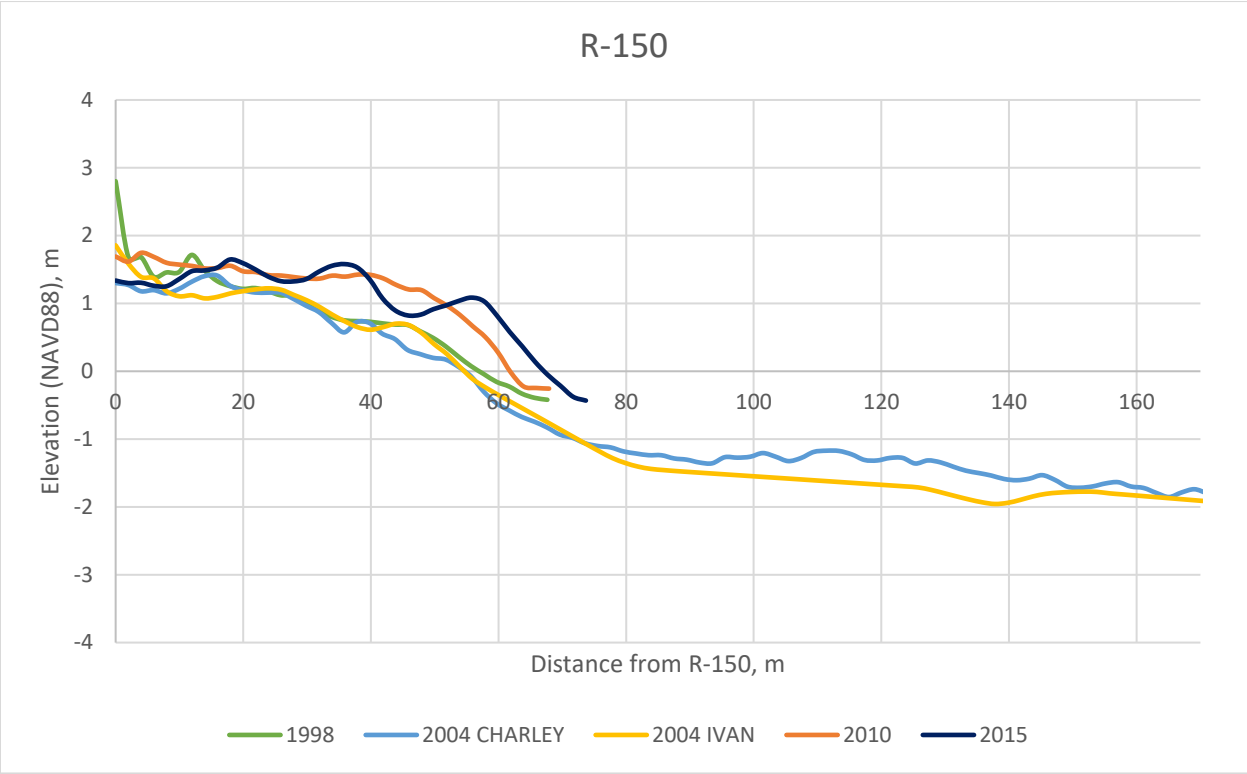


Figure A1.66. Beach profiles from LiDAR surveys with respect to NAVD88 at R-150.

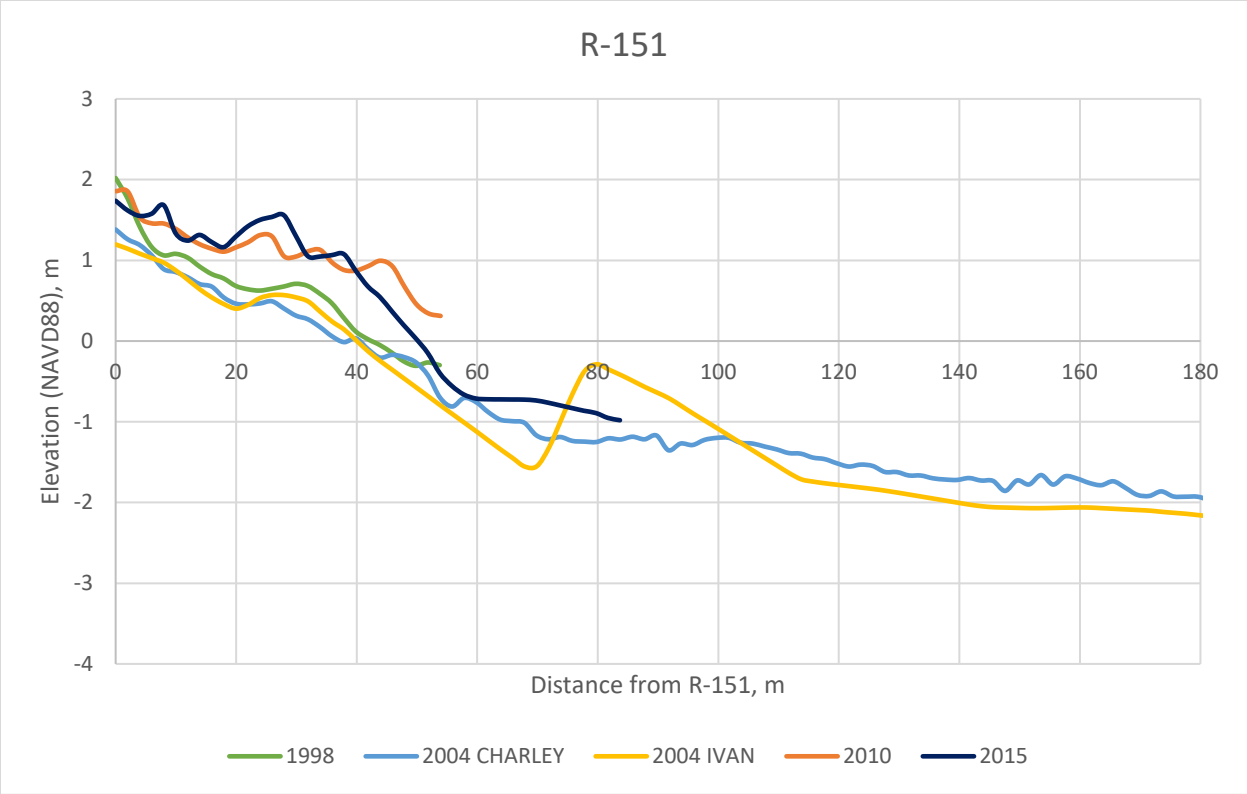


Figure A1.67. Beach profiles from LiDAR surveys with respect to NAVD88 at R-151.

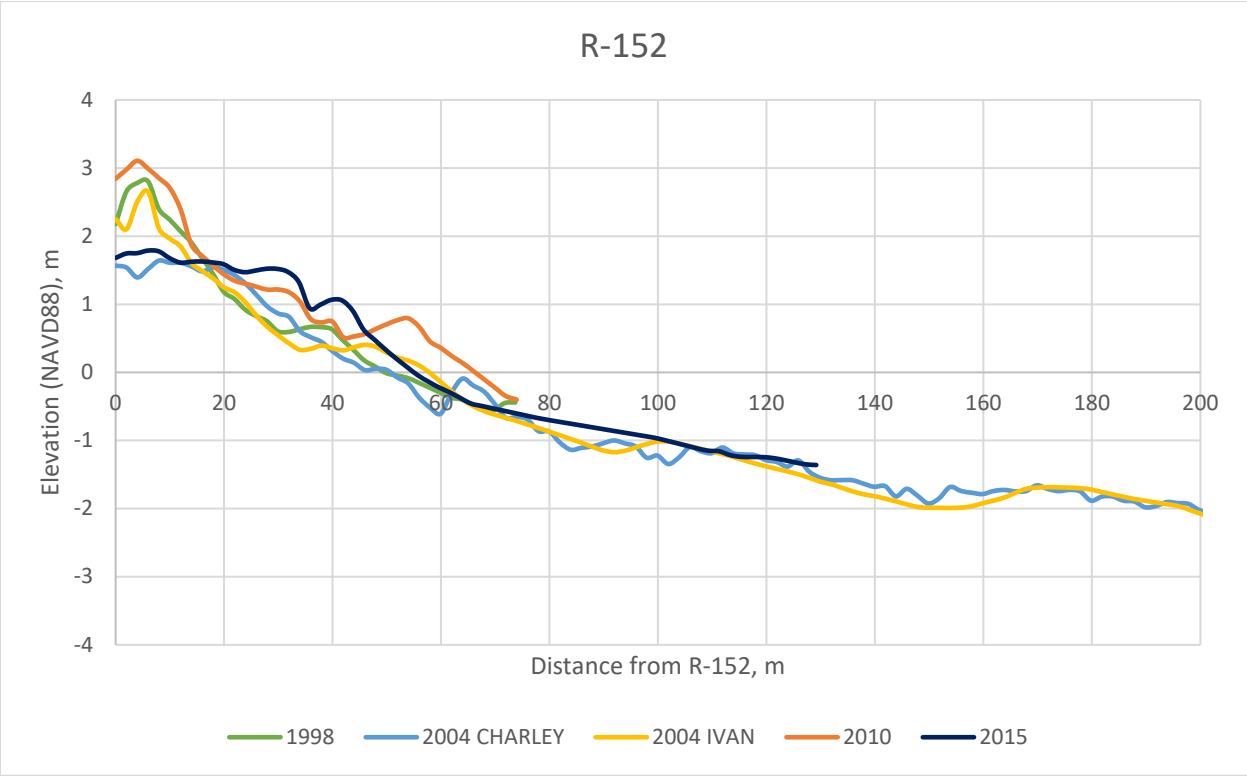


Figure A1.68. Beach profiles from LiDAR surveys with respect to NAVD88 at R-152.

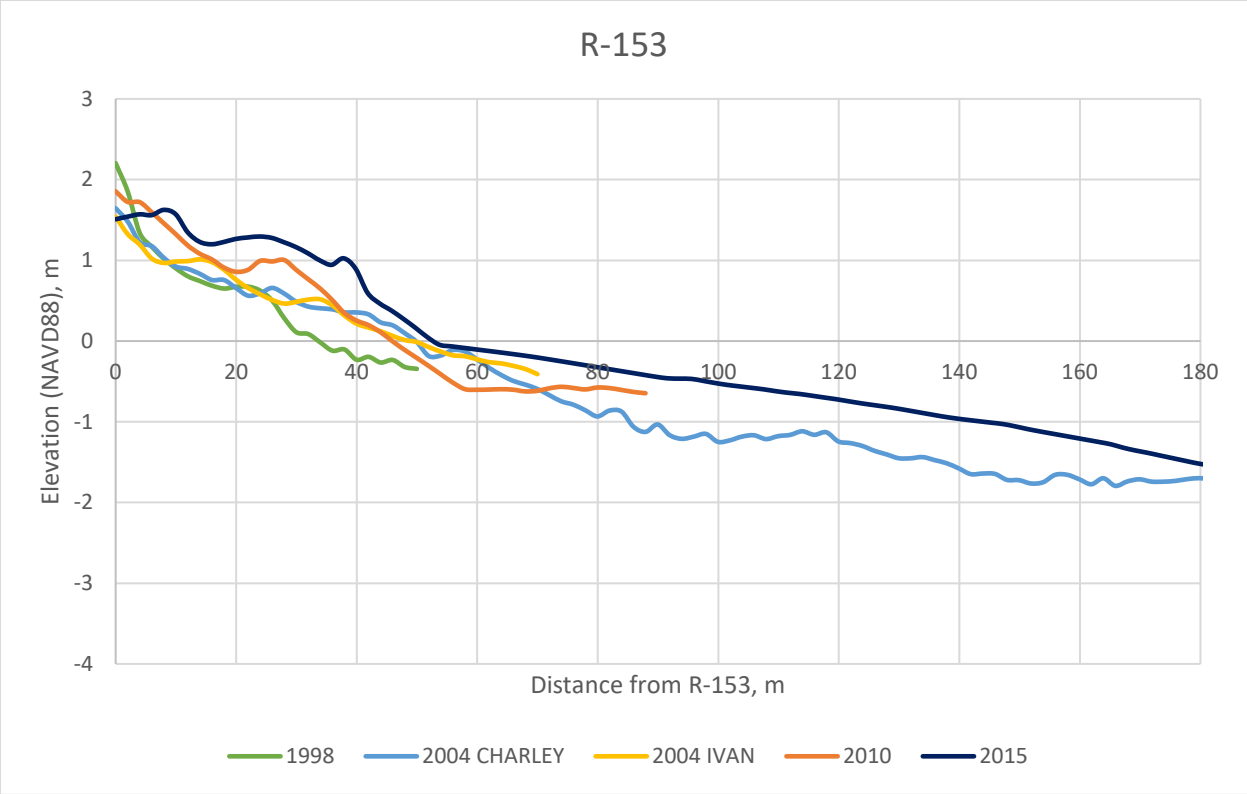


Figure A1.69. Beach profiles from LiDAR surveys with respect to NAVD88 at R-153.

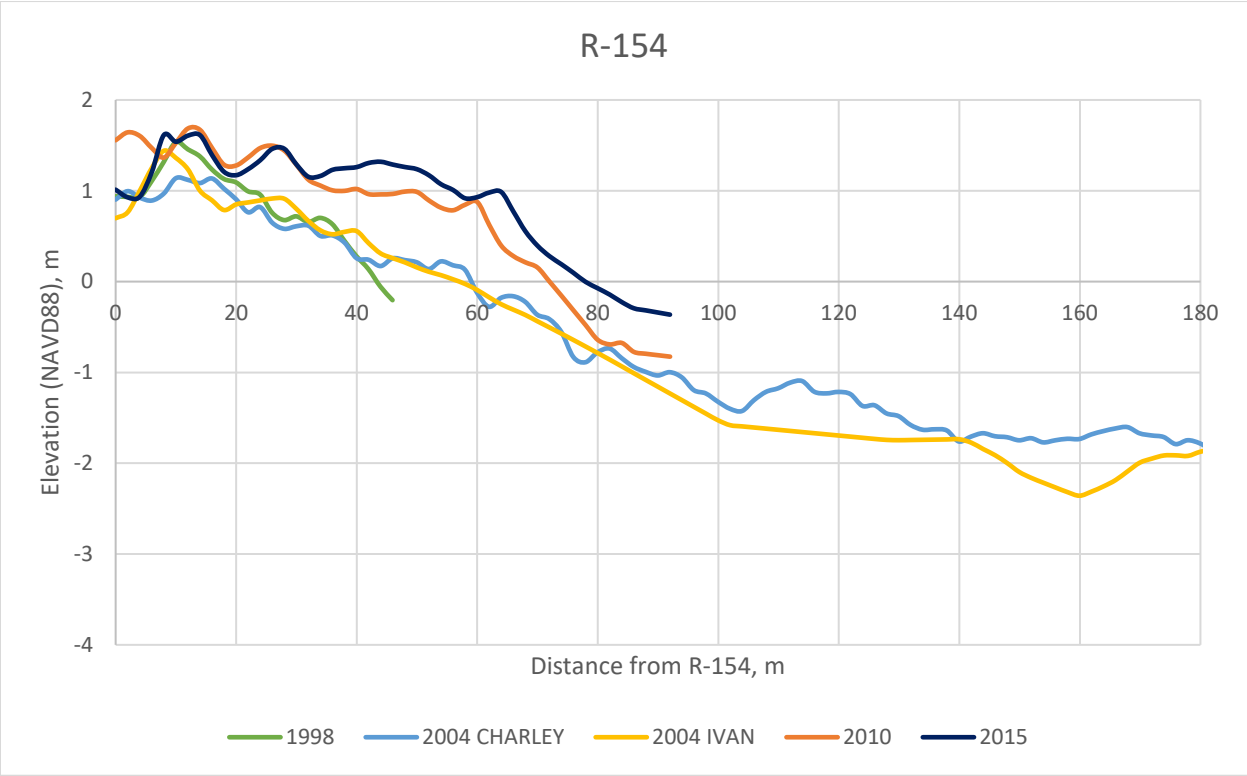


Figure A1.70. Beach profiles from LiDAR surveys with respect to NAVD88 at R-154.

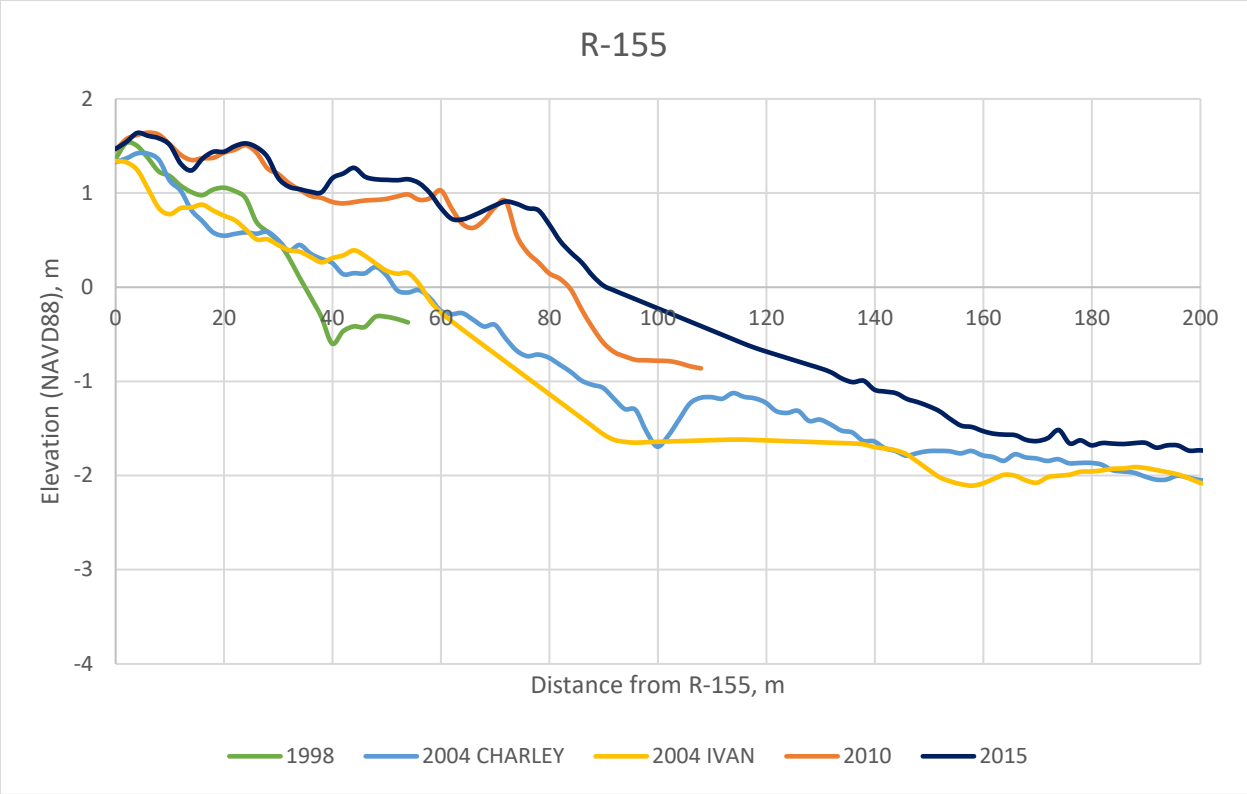


Figure A1.71. Beach profiles from LiDAR surveys with respect to NAVD88 at R-155.

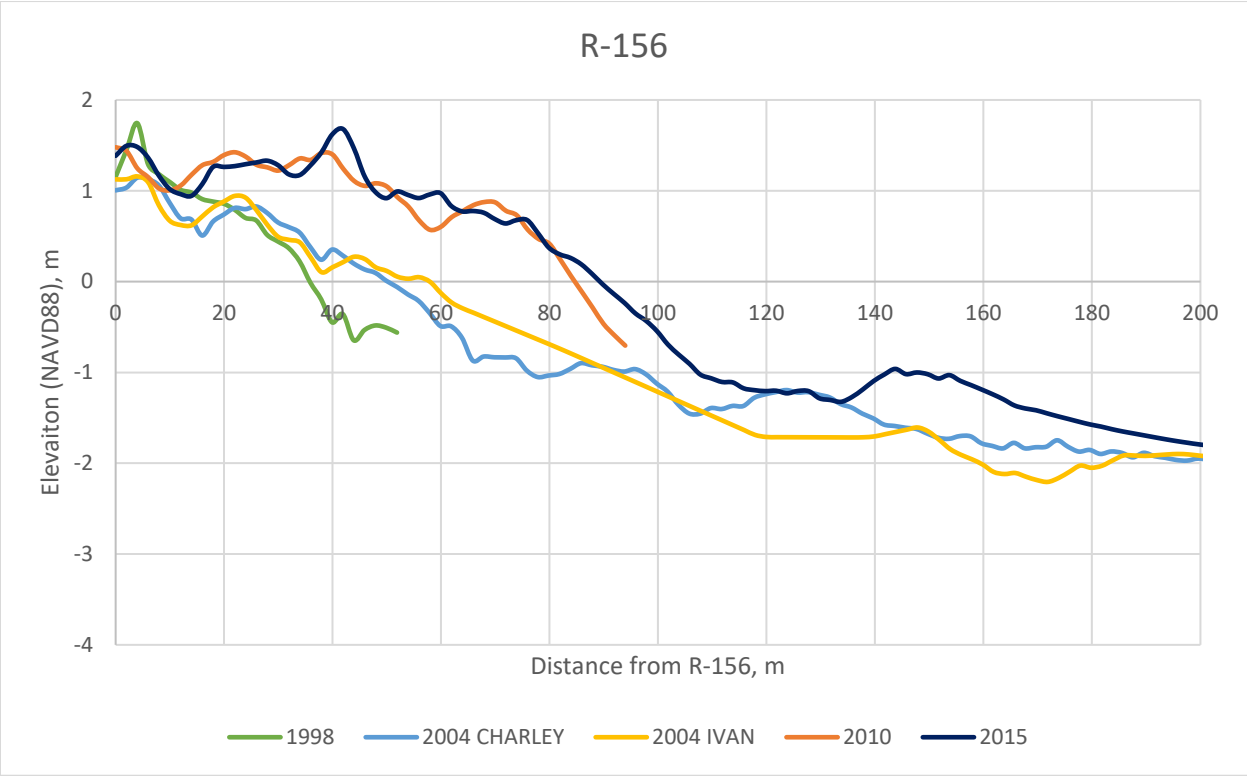


Figure A1.72. Beach profiles from LiDAR surveys with respect to NAVD88 at R-156.

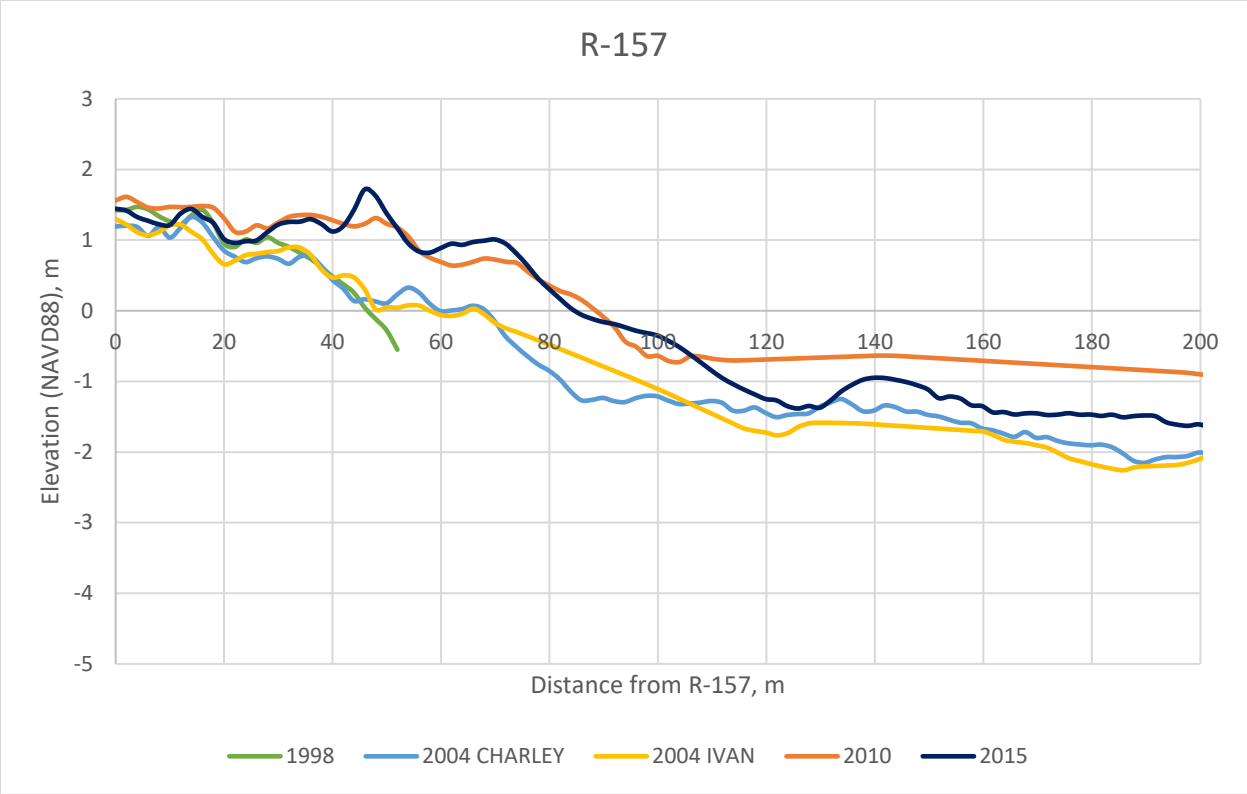


Figure A1.73. Beach profiles from LiDAR surveys with respect to NAVD88 at R-157.

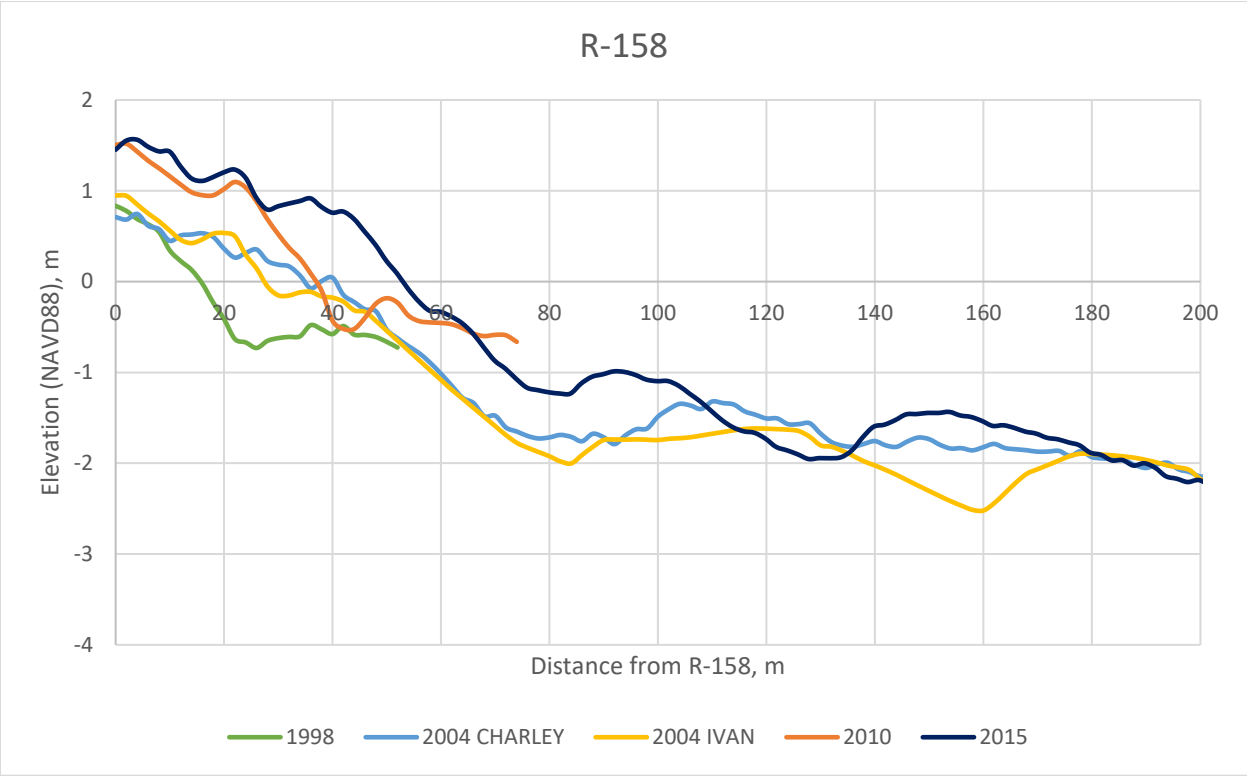


Figure A1.74. Beach profiles from LiDAR surveys with respect to NAVD88 at R-158.

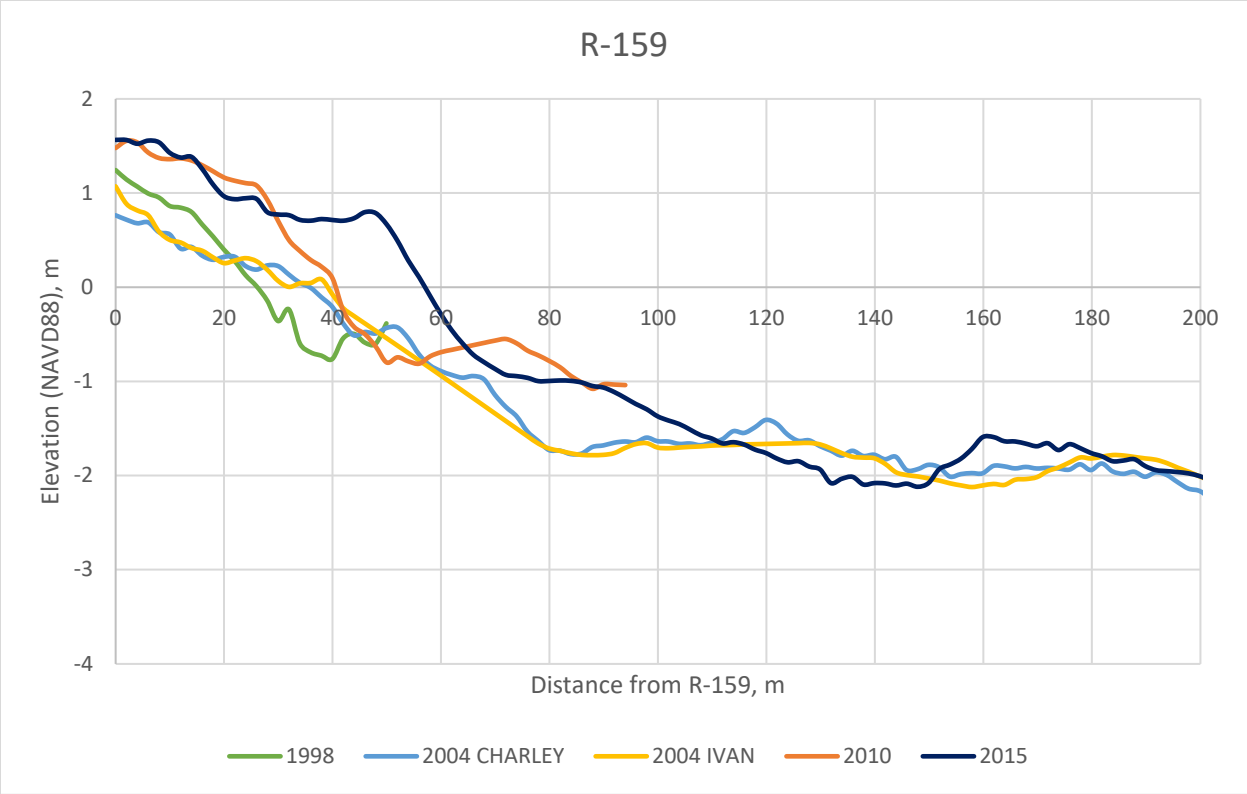


Figure A1.75. Beach profiles from LiDAR surveys with respect to NAVD88 at R-159.

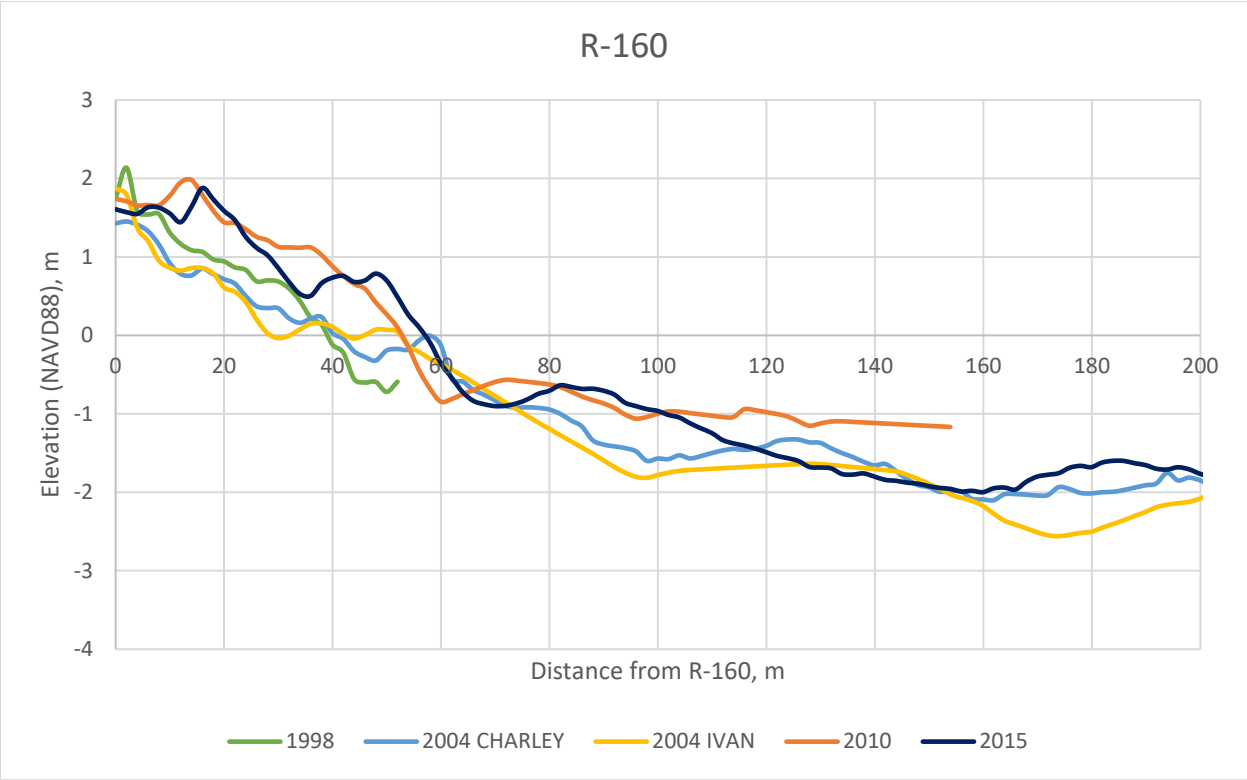


Figure A1.76. Beach profiles from LiDAR surveys with respect to NAVD88 at R-160.

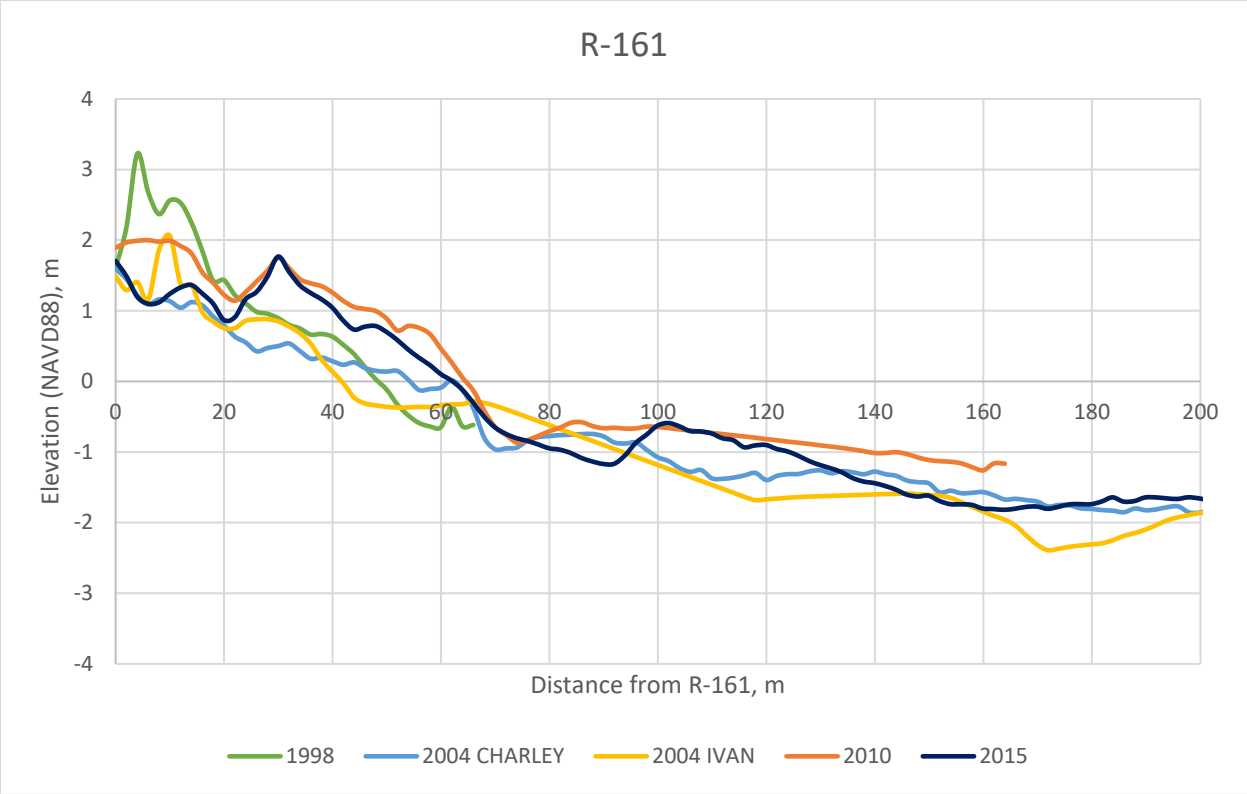


Figure A1.77. Beach profiles from LiDAR surveys with respect to NAVD88 at R-161.

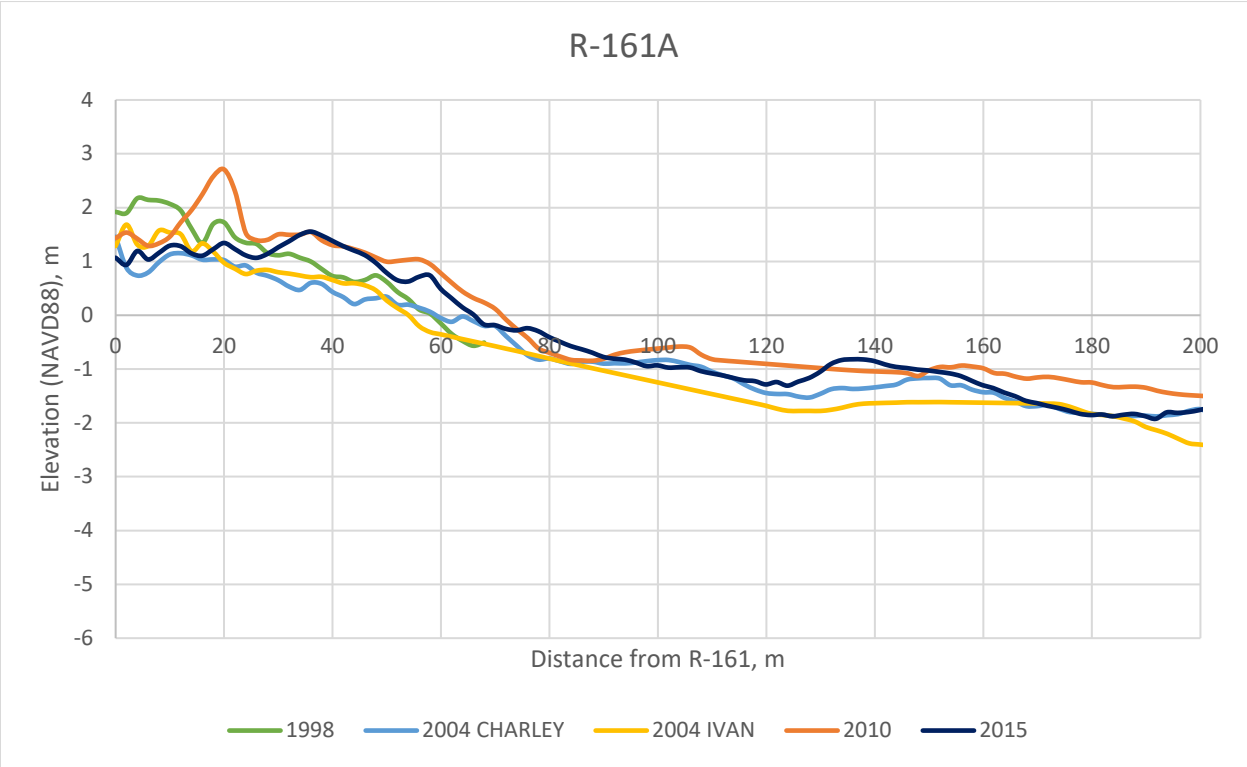


Figure A1.78. Beach profiles from LiDAR surveys with respect to NAVD88 at R-161A.

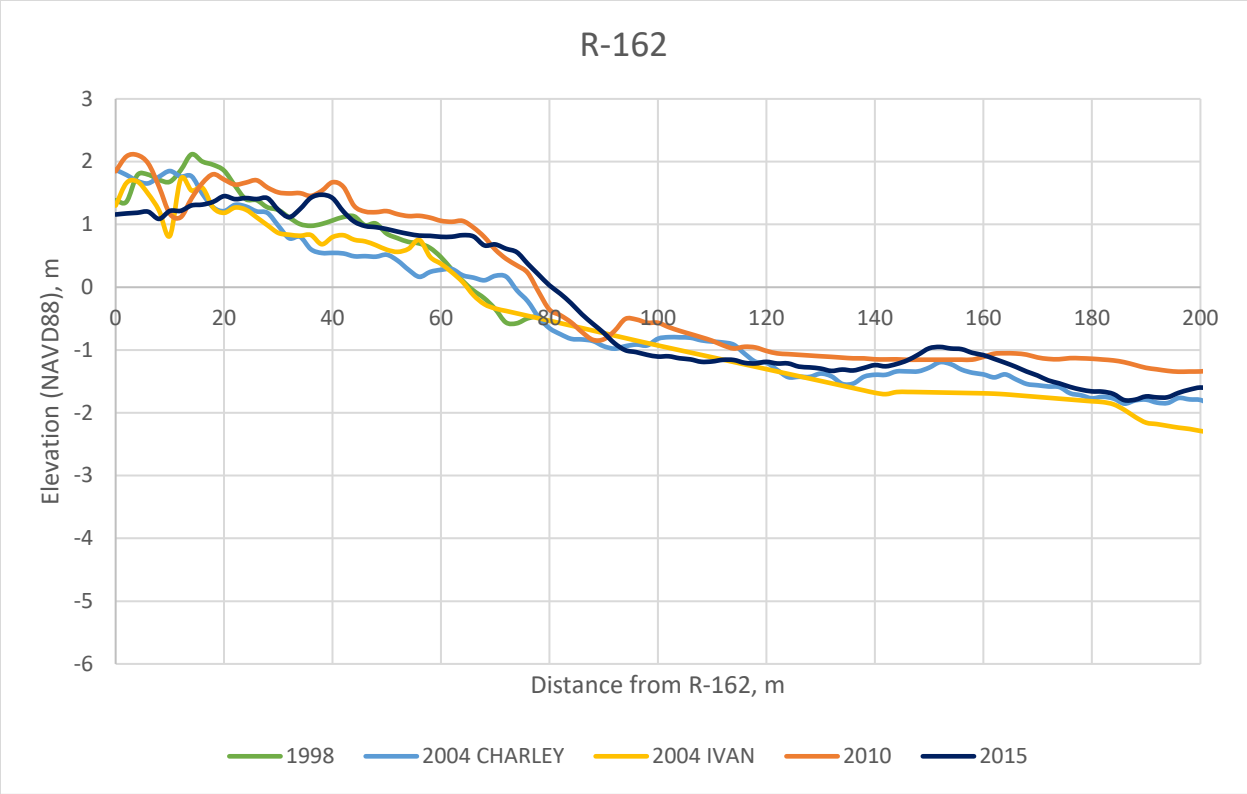


Figure A1.79. Beach profiles from LiDAR surveys with respect to NAVD88 at R-162.

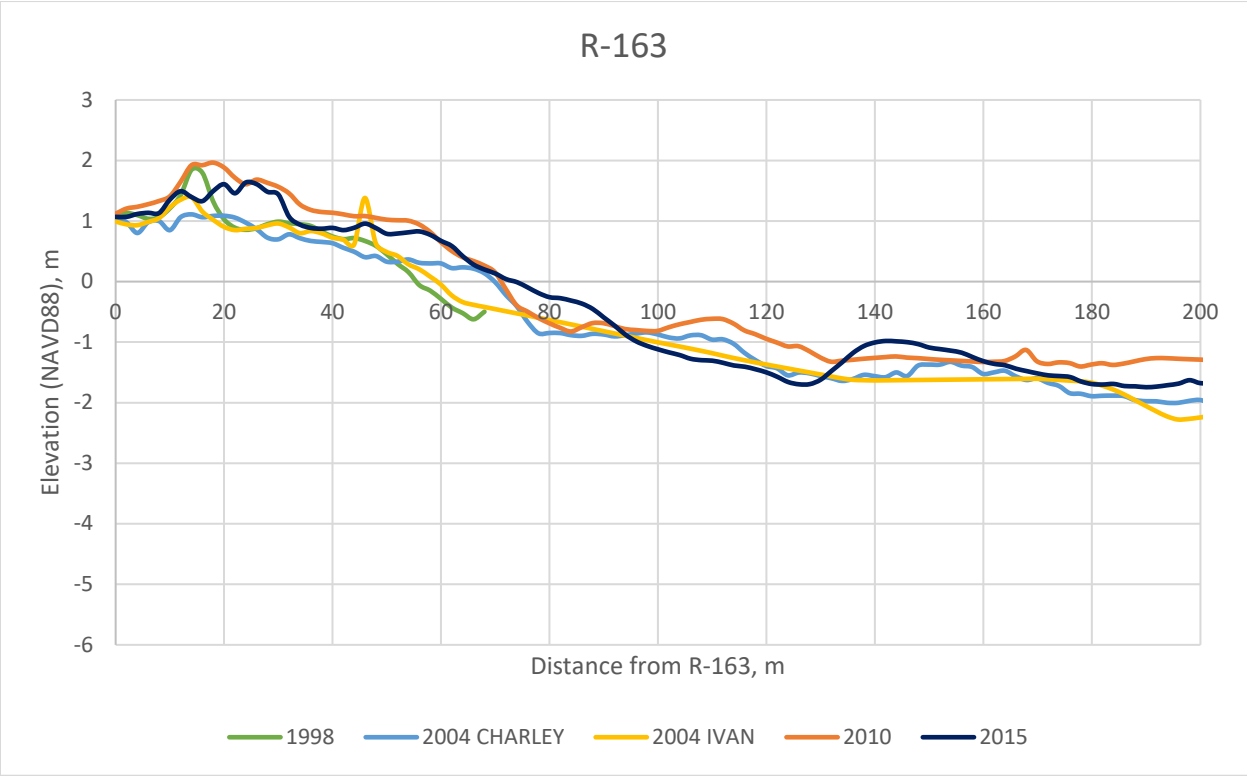


Figure A1.80. Beach profiles from LiDAR surveys with respect to NAVD88 at R-163.

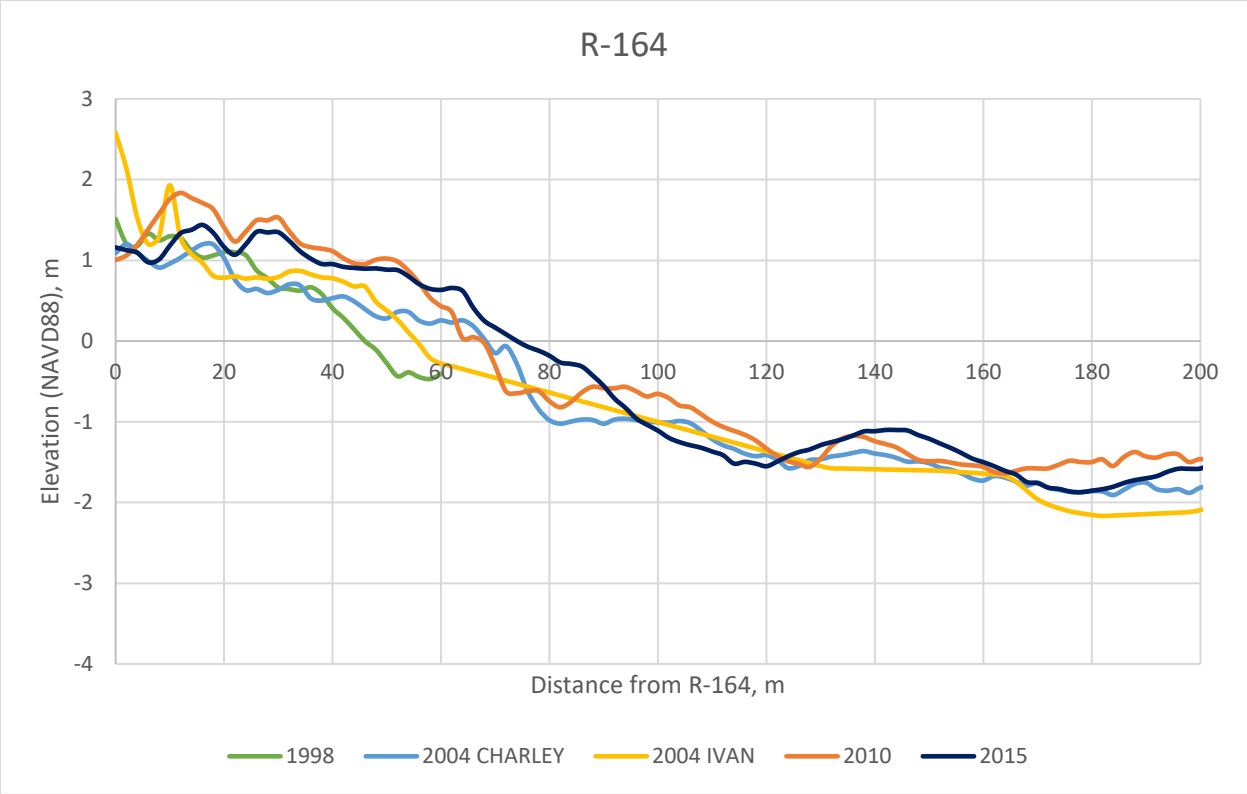


Figure A1.81. Beach profiles from LiDAR surveys with respect to NAVD88 at R-164.

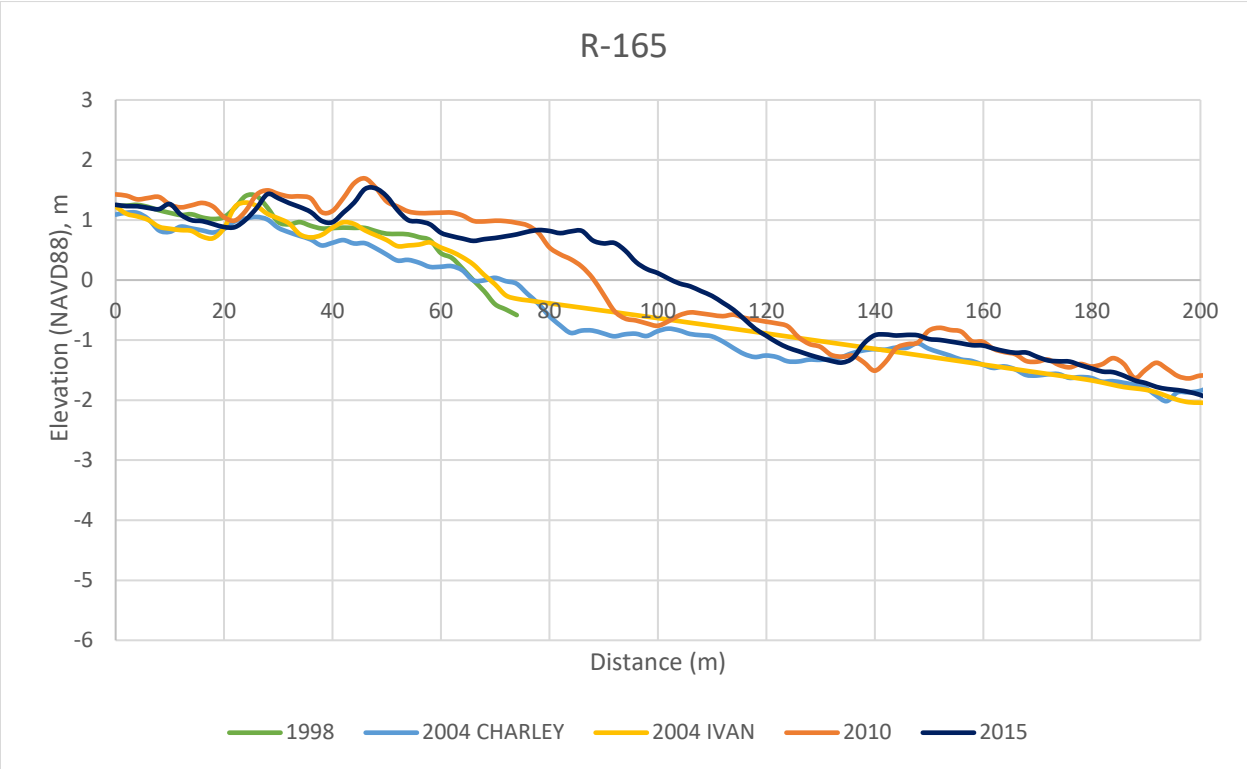


Figure A1.82. Beach profiles from LiDAR surveys with respect to NAVD88 at R-165.

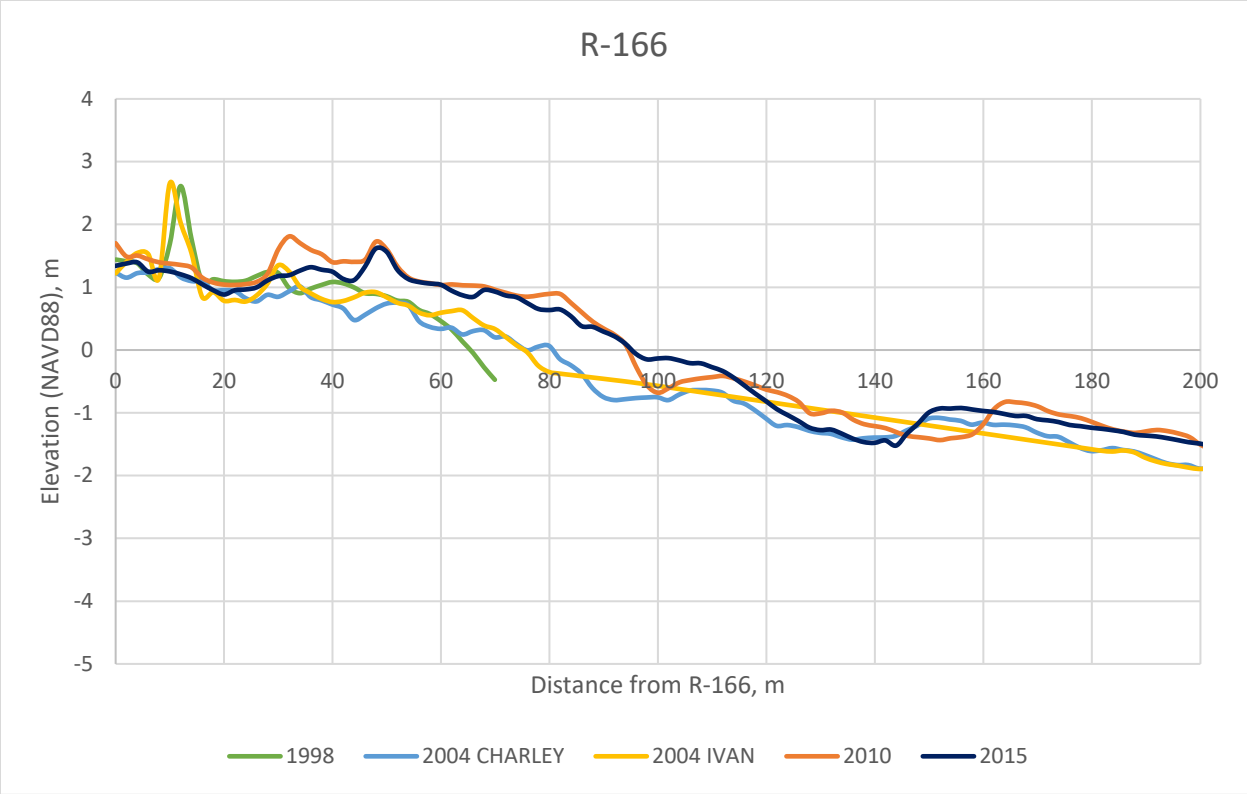


Figure A1.83. Beach profiles from LiDAR surveys with respect to NAVD88 at R-166.

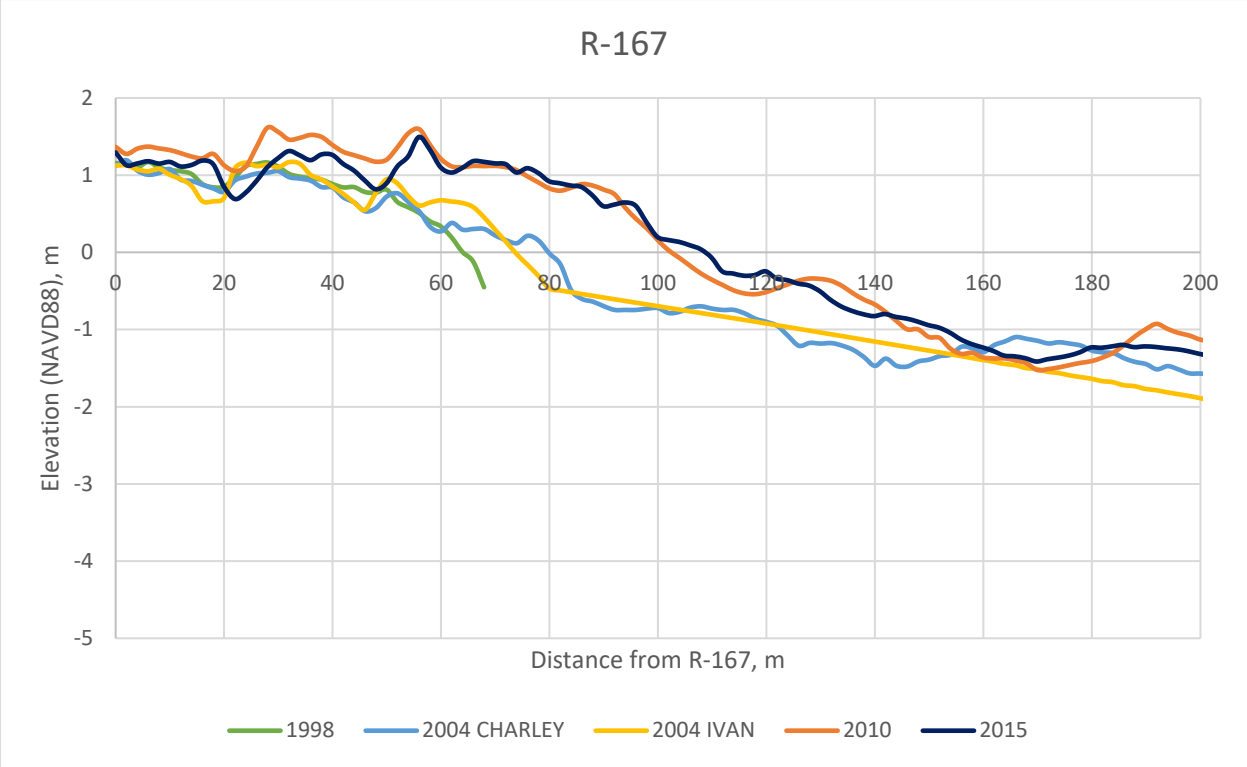


Figure A1.84. Beach profiles from LiDAR surveys with respect to NAVD88 at R-167.

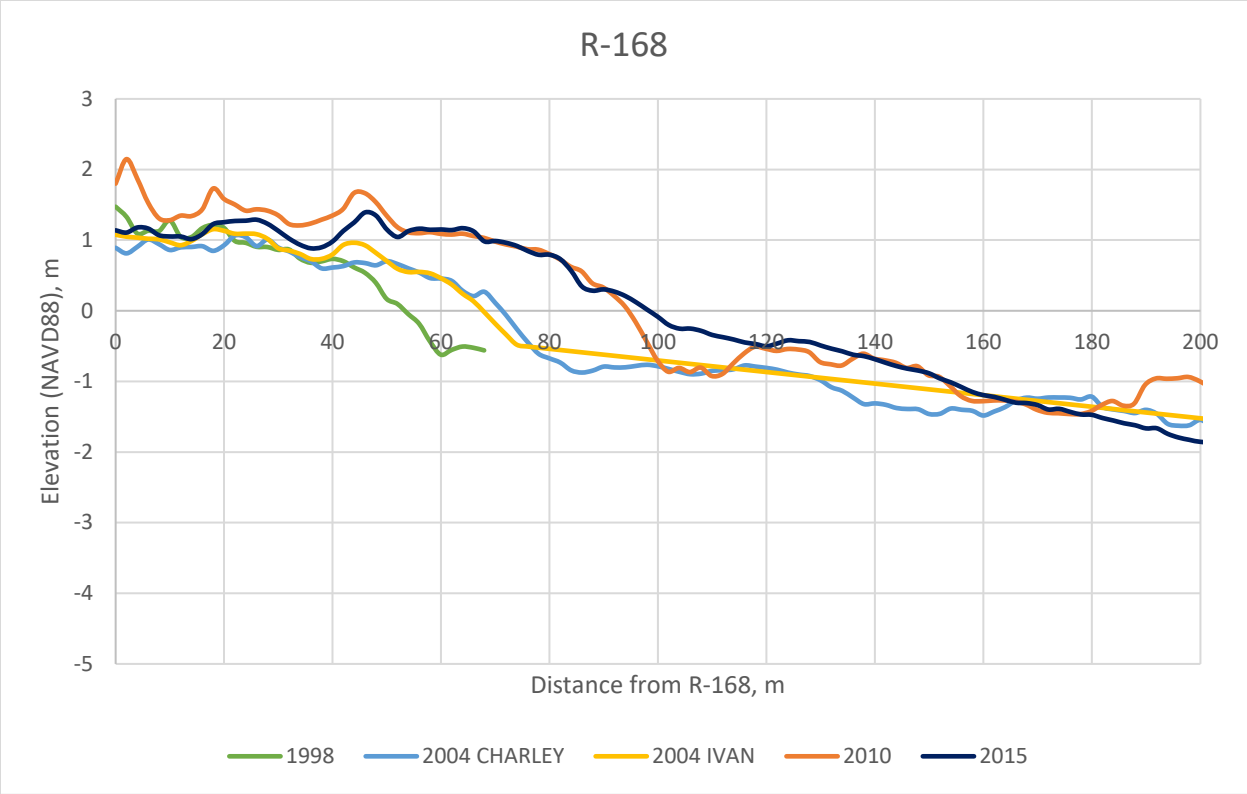


Figure A1.85. Beach profiles from LiDAR surveys with respect to NAVD88 at R-168.

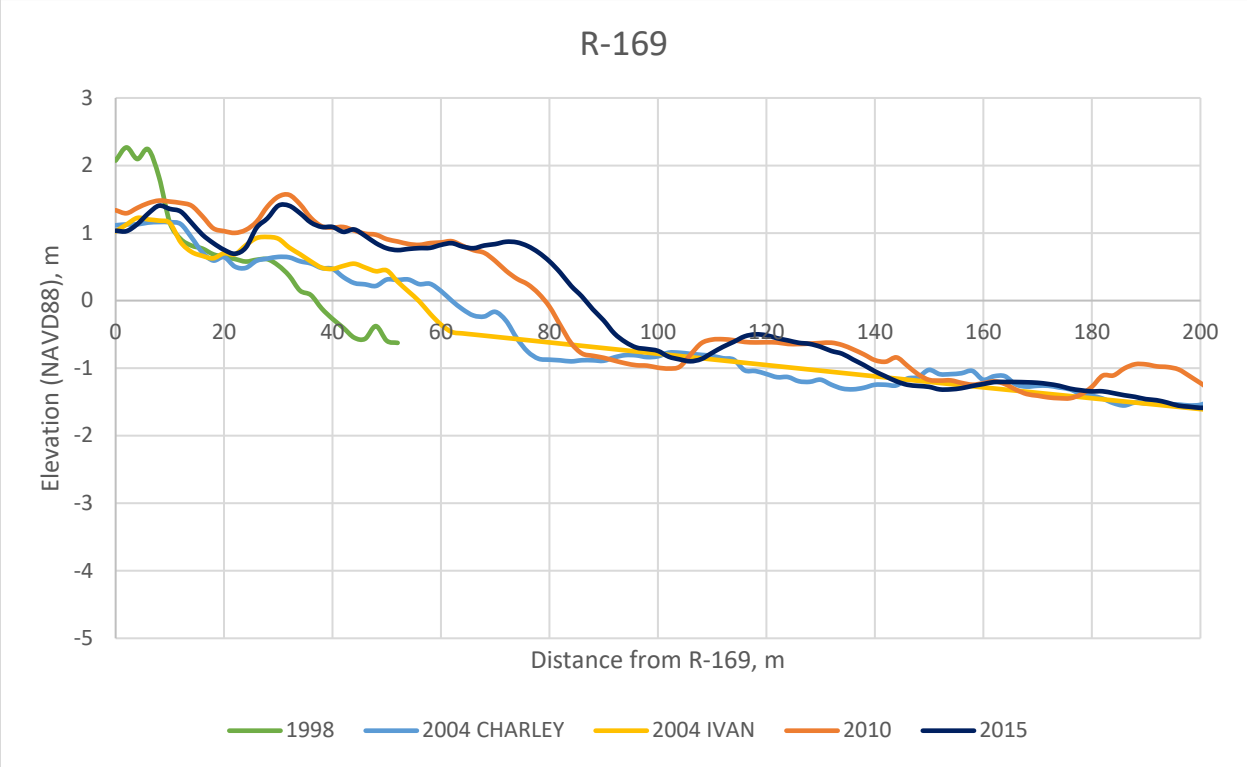


Figure A1.86. Beach profiles from LiDAR surveys with respect to NAVD88 at R-169.

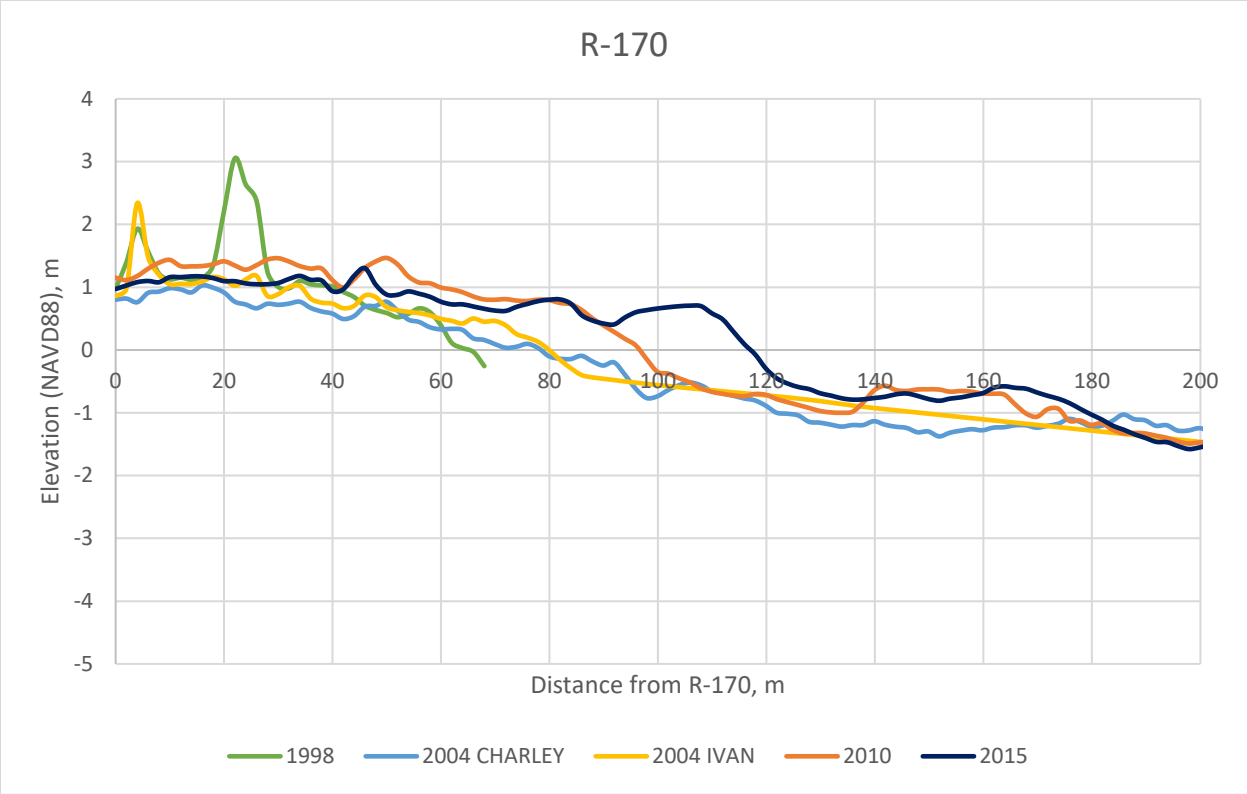


Figure A1.87. Beach profiles from LiDAR surveys with respect to NAVD88 at R-170.

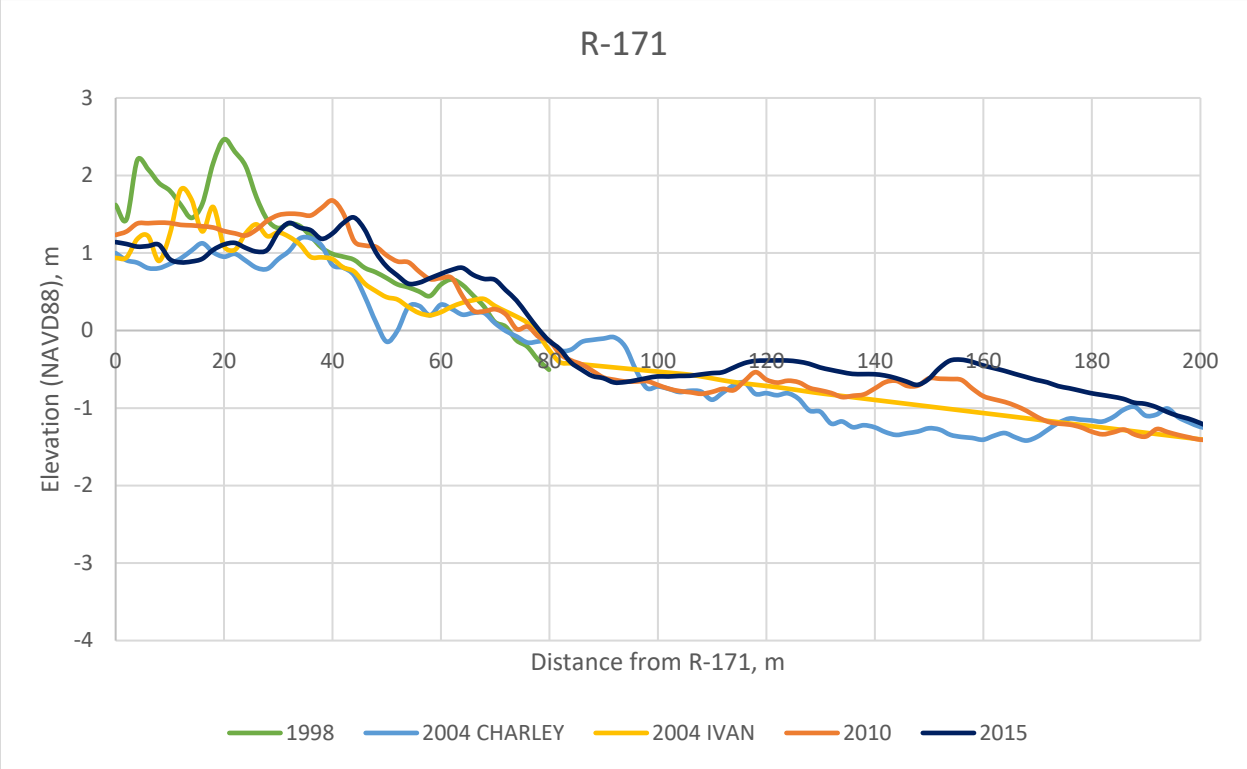


Figure A1.88. Beach profiles from LiDAR surveys with respect to NAVD88 at R-171.

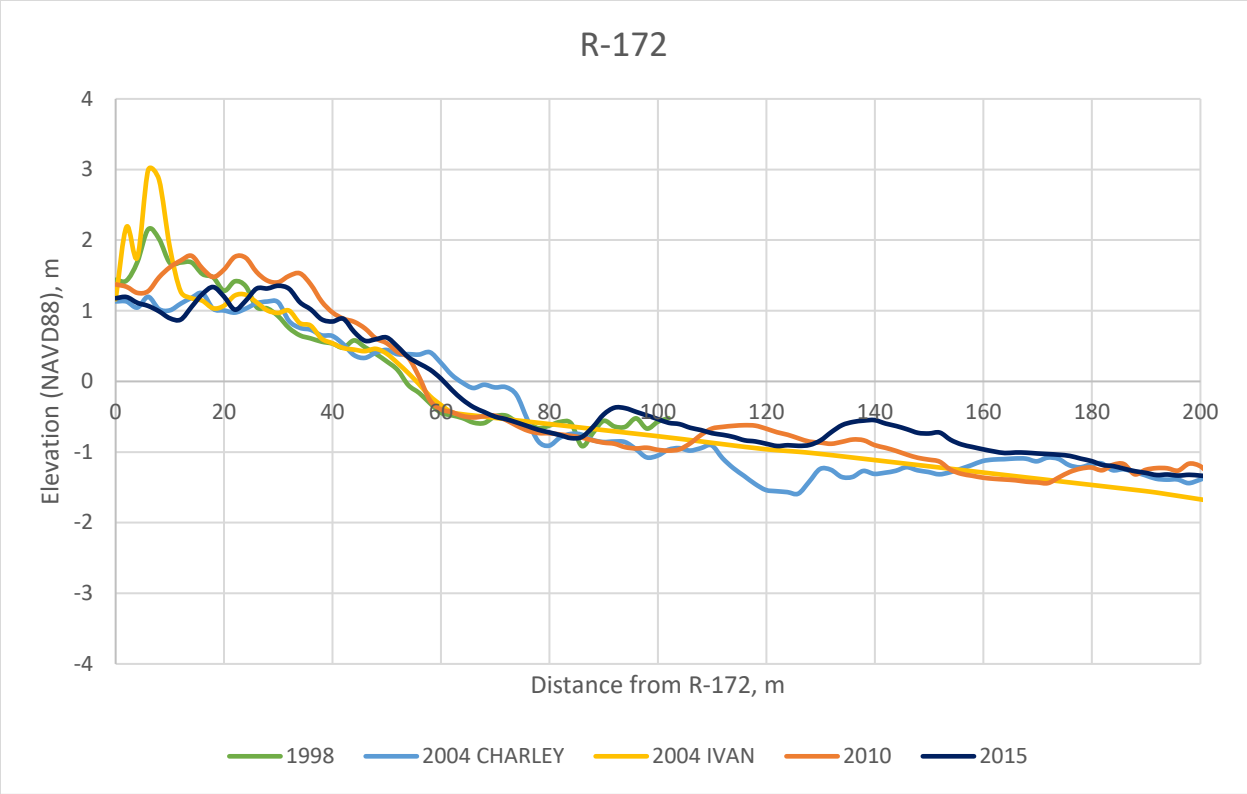


Figure A1.89. Beach profiles from LiDAR surveys with respect to NAVD88 at R-172.

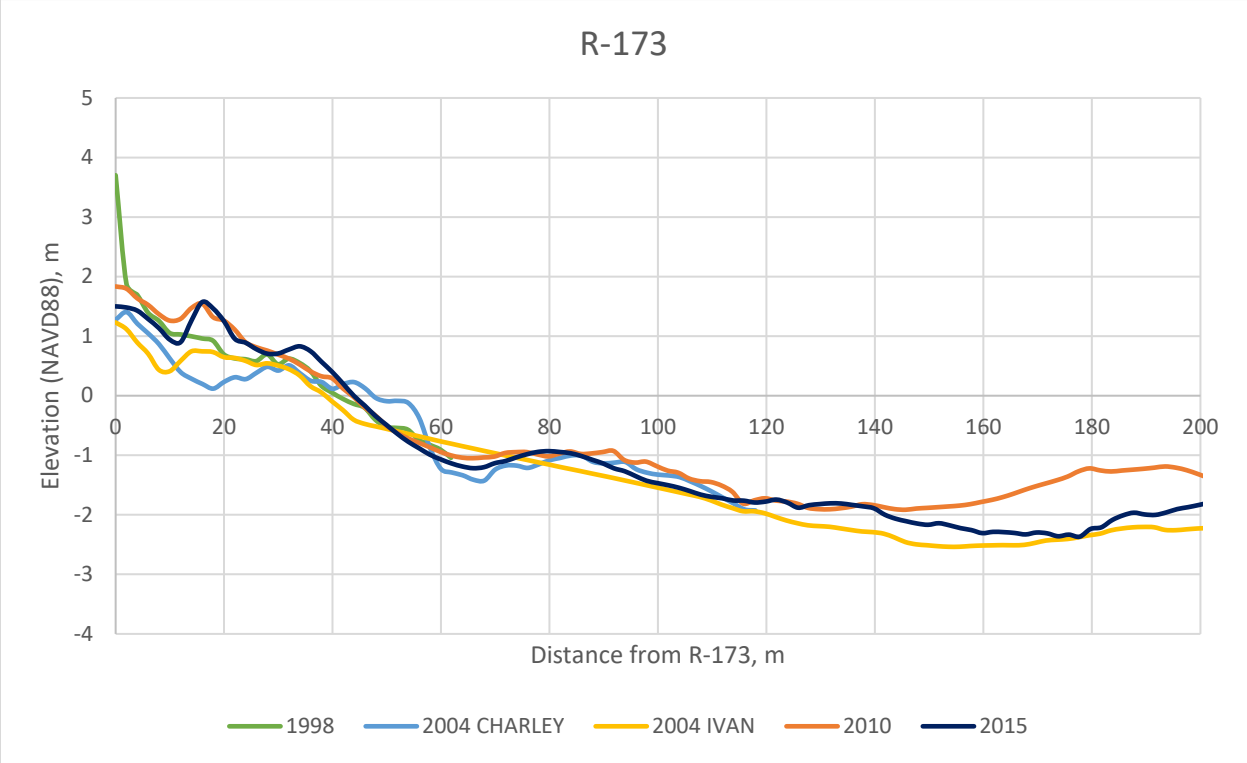


Figure A1.90. Beach profiles from LiDAR surveys with respect to NAVD88 at R-173.

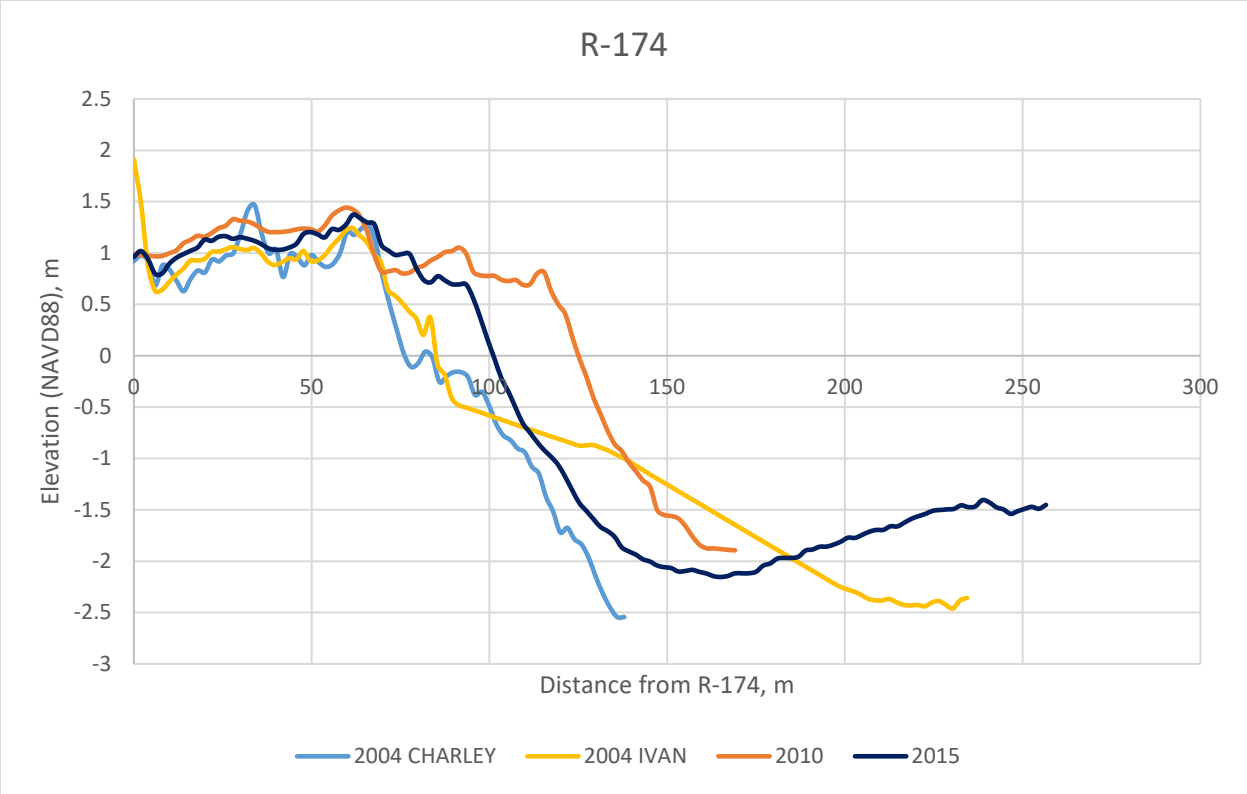


Figure A1.91. Beach profiles from LiDAR surveys with respect to NAVD88 at R-174.

Appendix II

Beach profiles for Sanibel and Captiva Islands, dating from 1974, 1982, and 1989. These data are from years prior to the advent of LiDAR. If one or more years is missing for the R monument, then these years' data were not available. The profiles extracted from LiDAR-generated digital elevation models (DEMs), beginning in 1998, are not comparable to these pre-LiDAR years. Consequently, the profiles are plotted separately and are considered too unreliable to use for sediment budgeting.

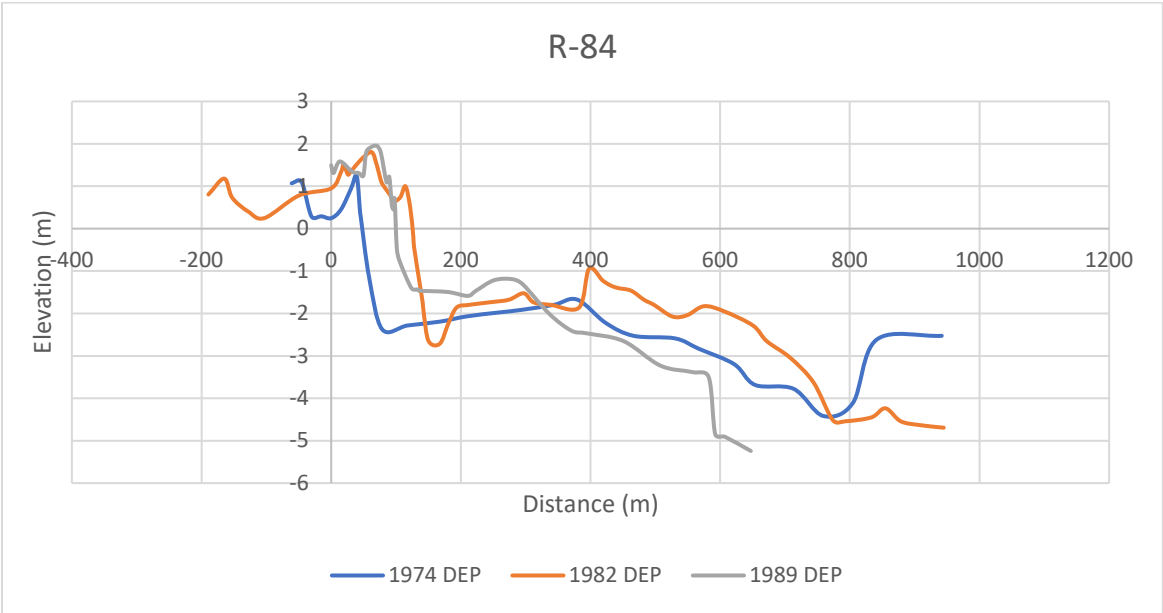


Figure A2.1. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-084.

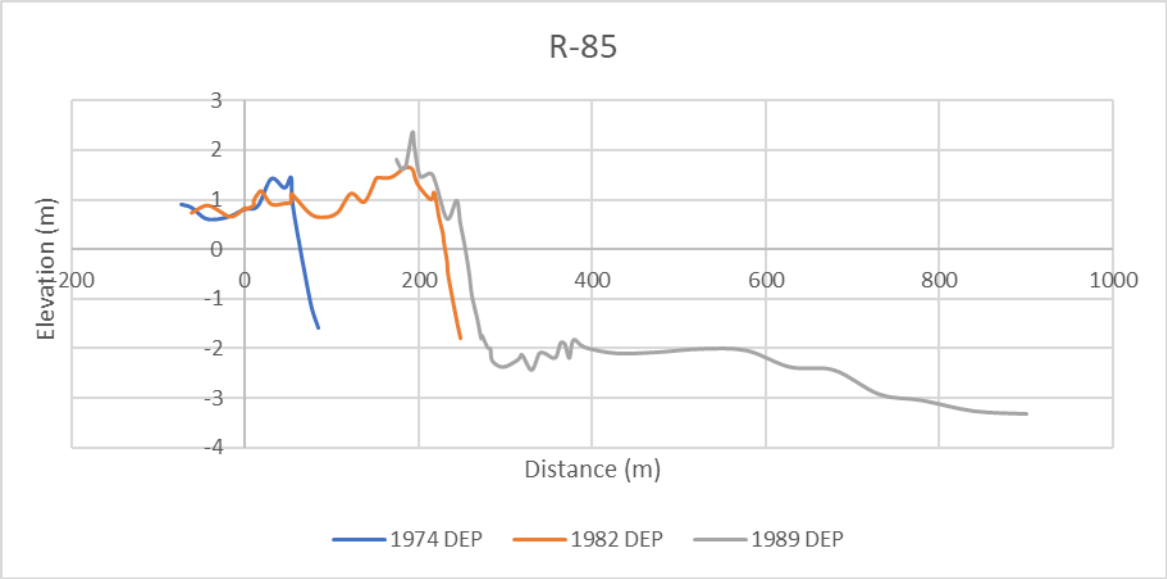


Figure A2.2. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-085.

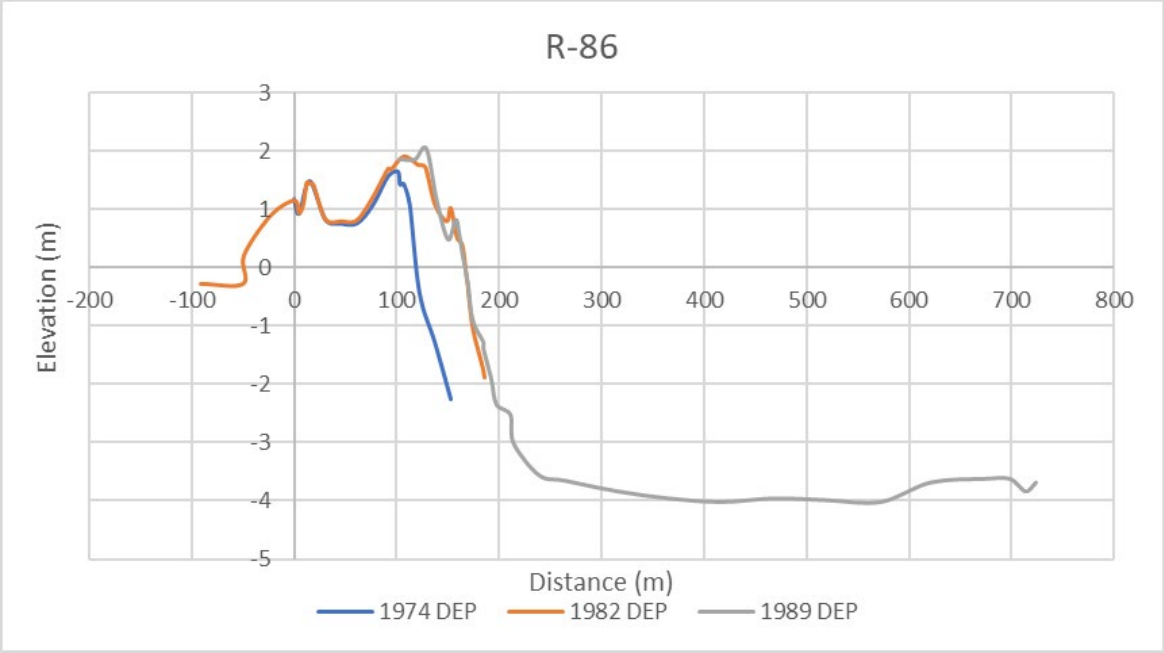


Figure A2.3. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-086.

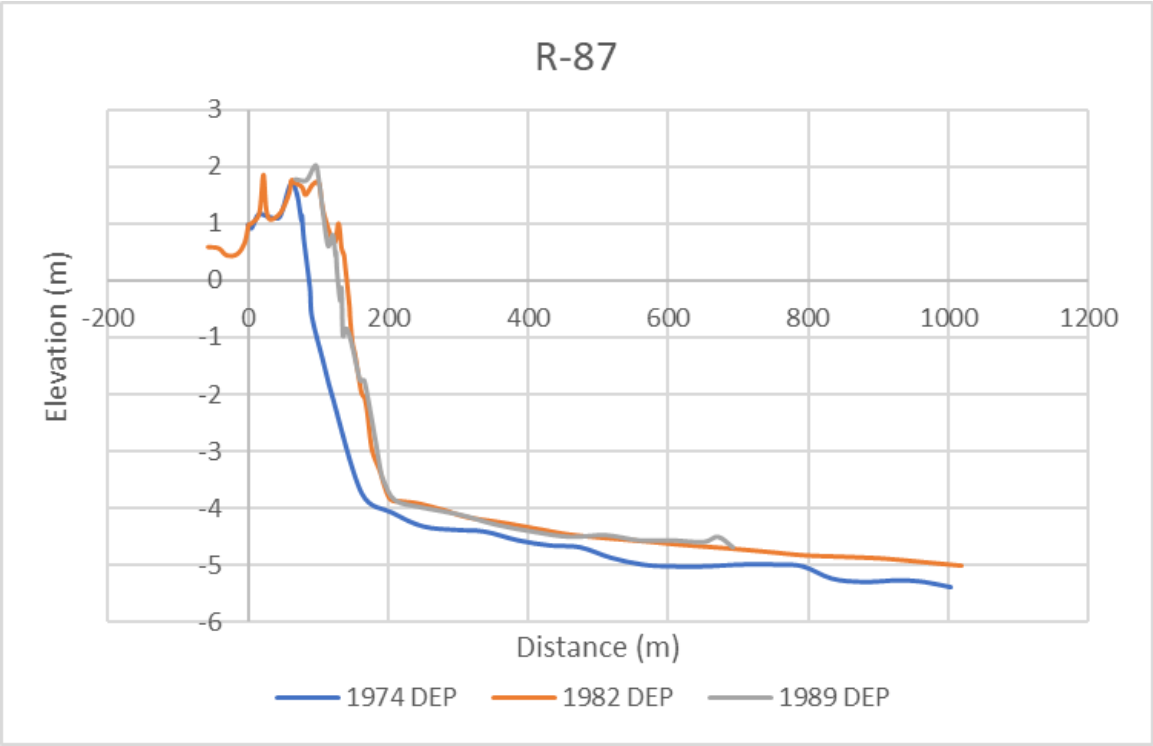


Figure A2.4. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-087.

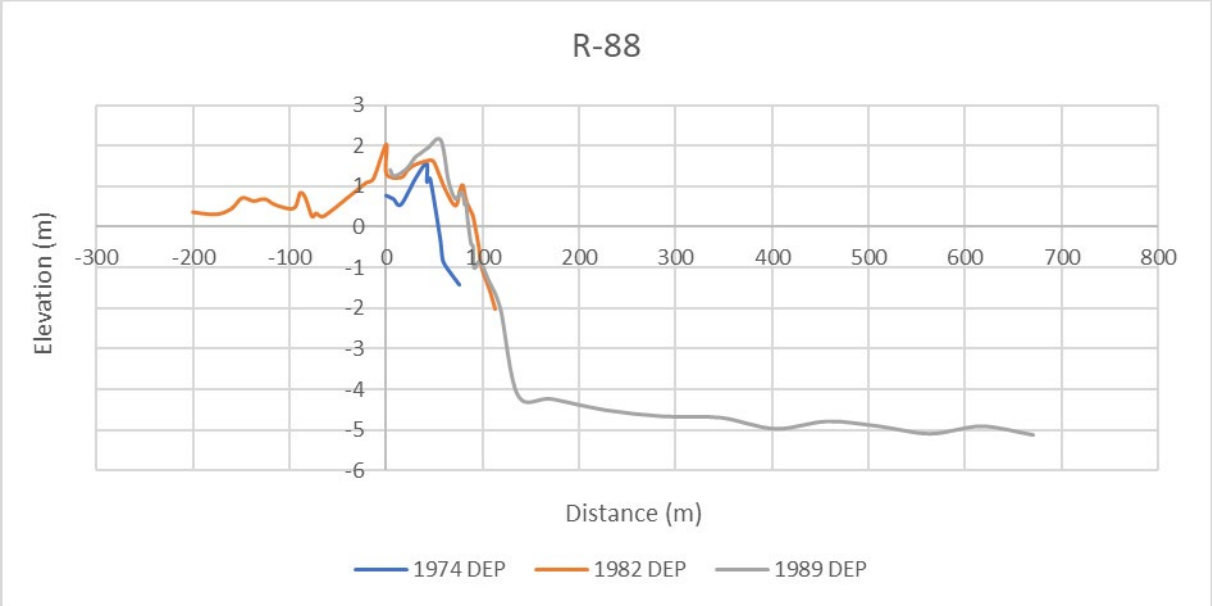


Figure A2.5. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-088.

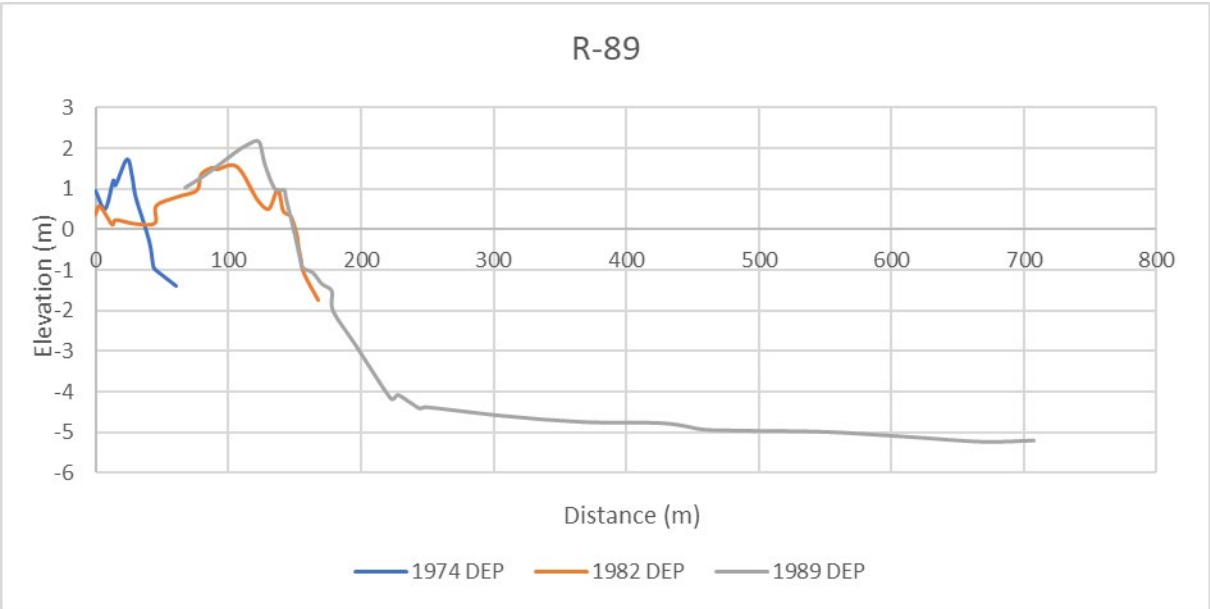


Figure A2.6. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-089.

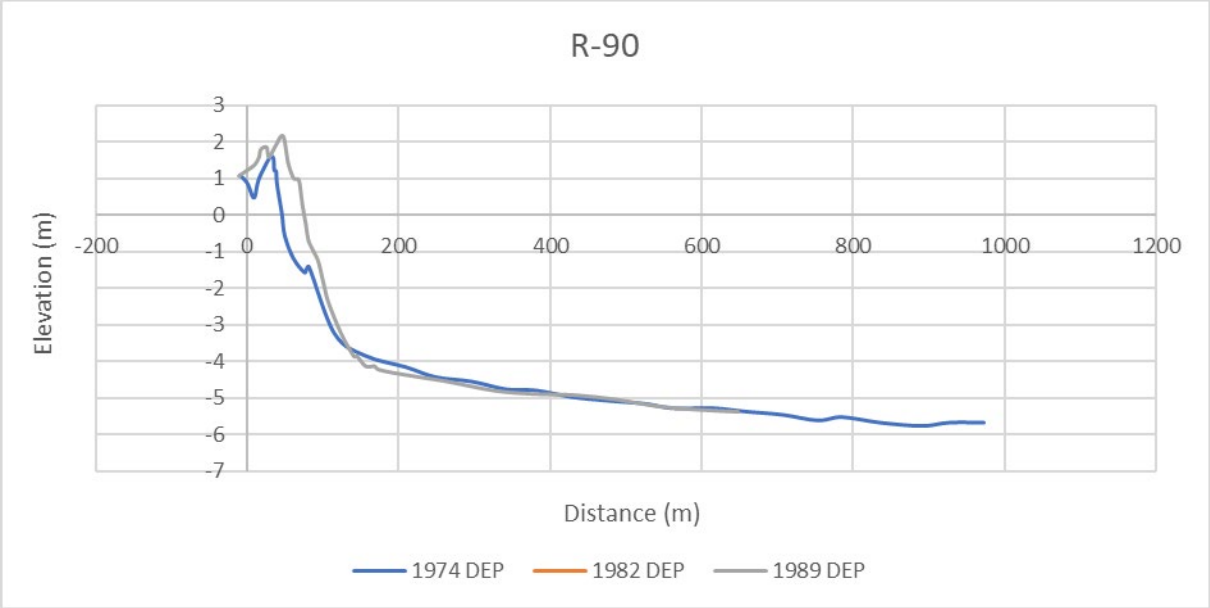


Figure A2.7. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-090.

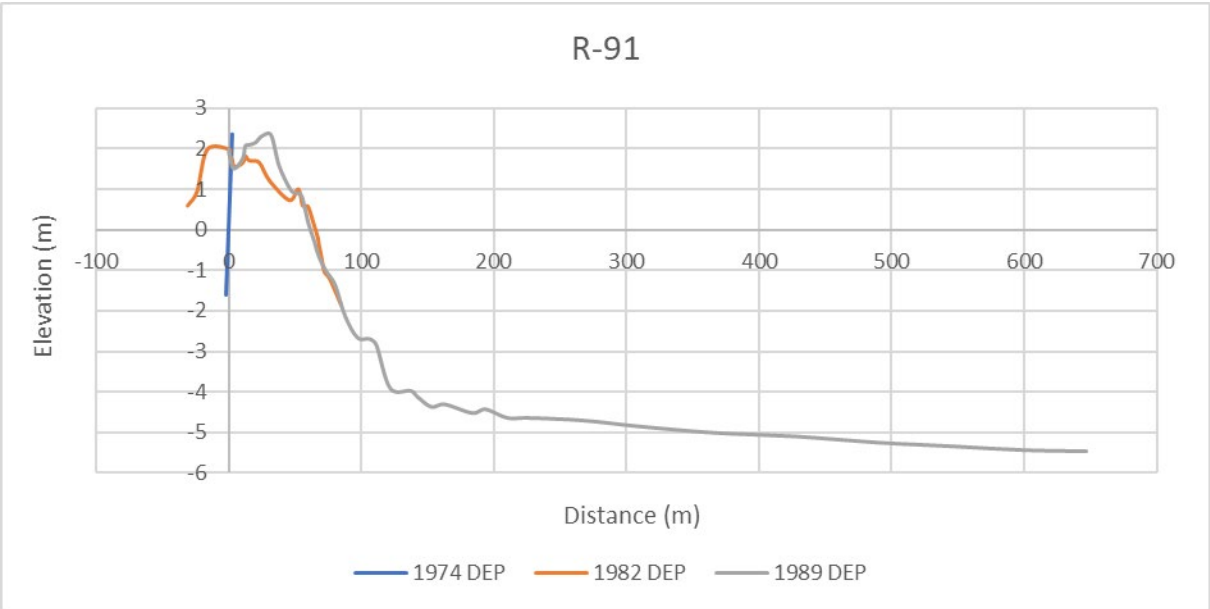


Figure A2.8. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-091.

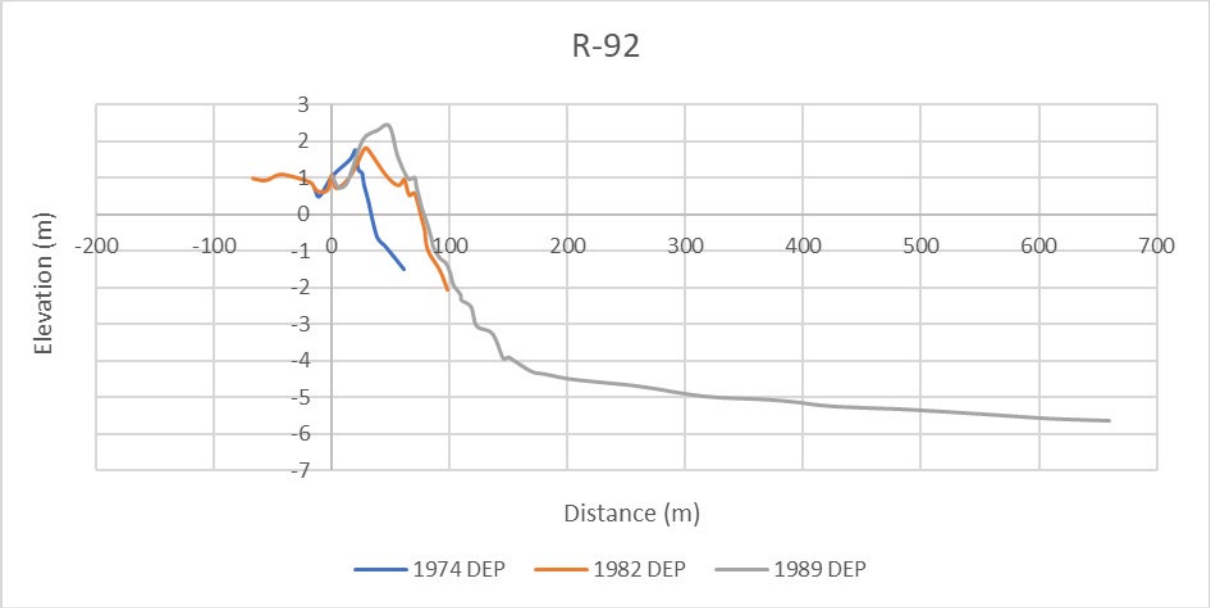


Figure A2.9. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-092.

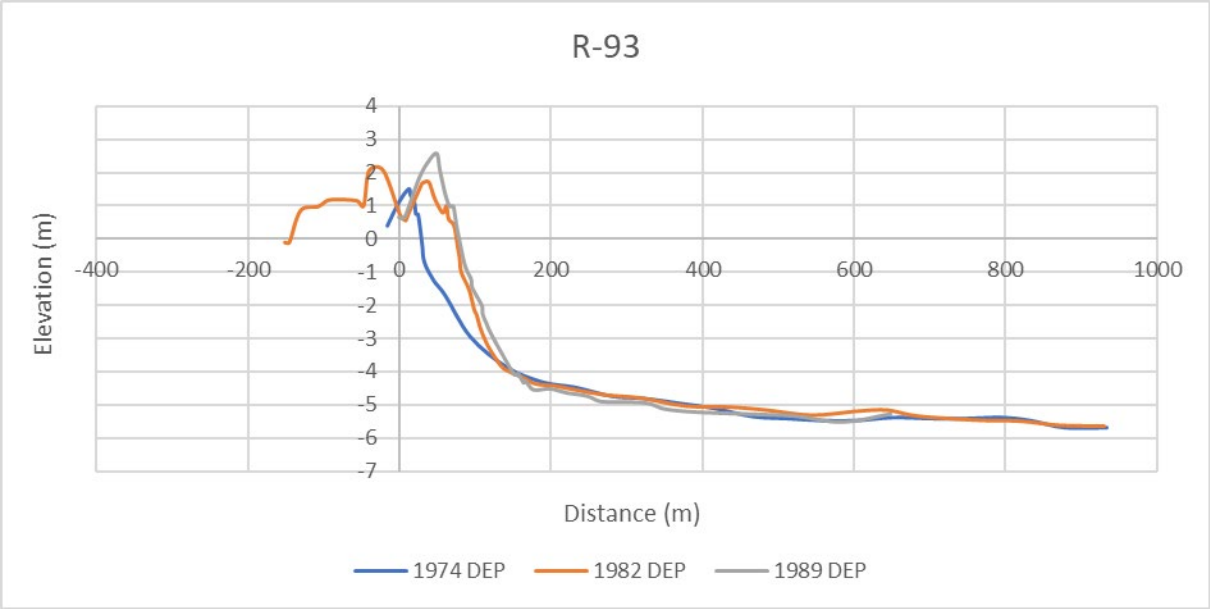


Figure A2.10. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-093.

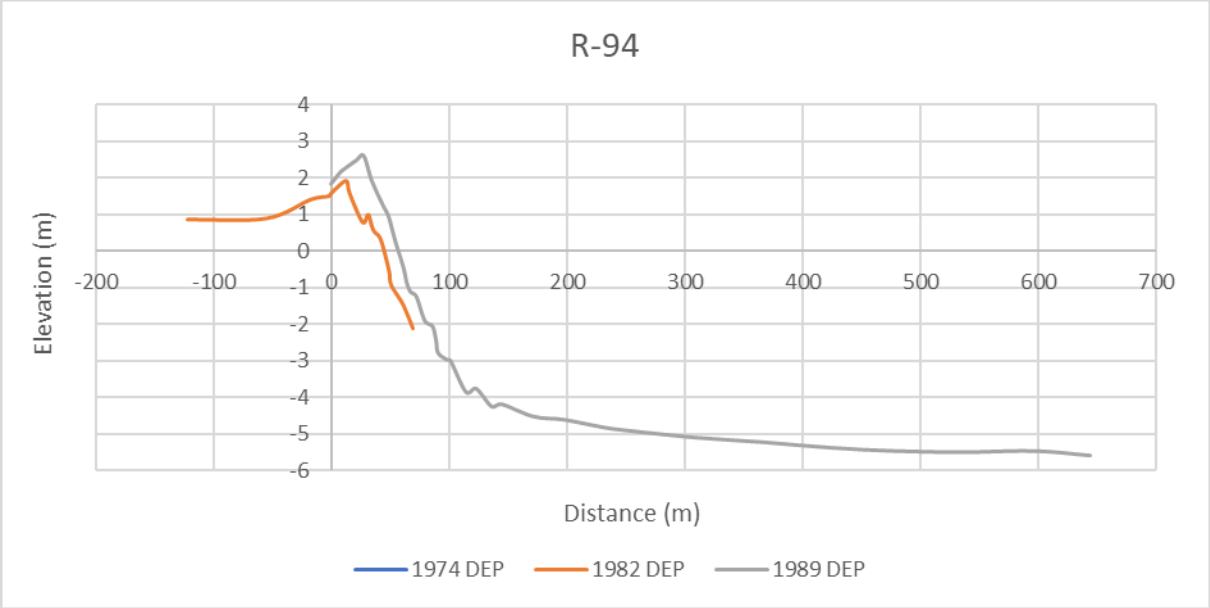


Figure A2.11. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-094.

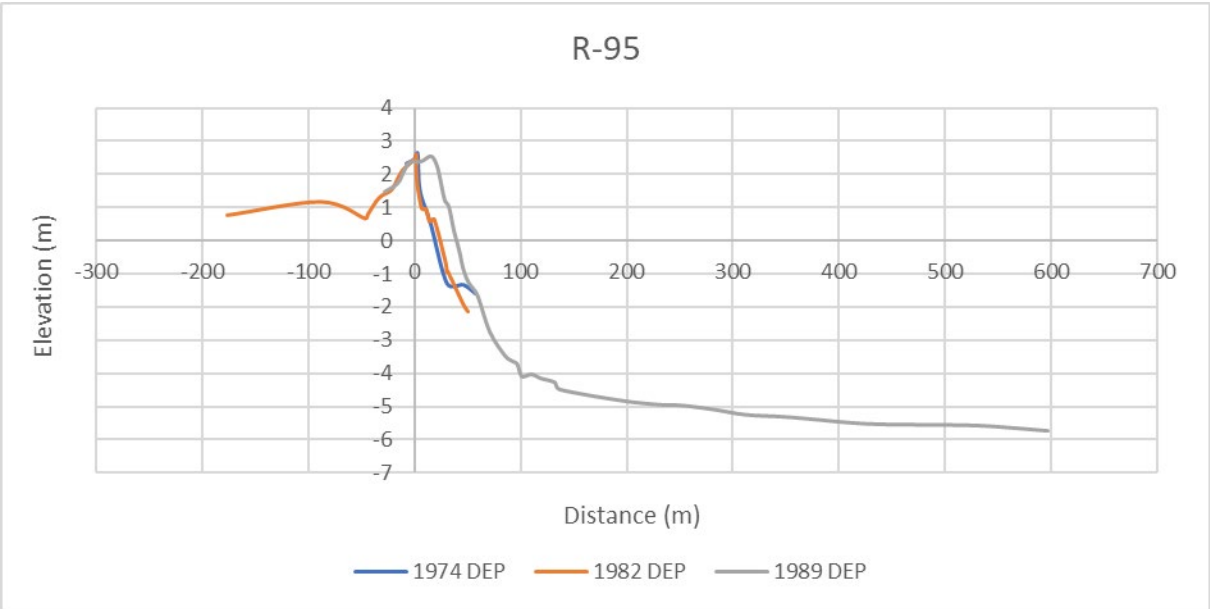


Figure A2.12. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-095.

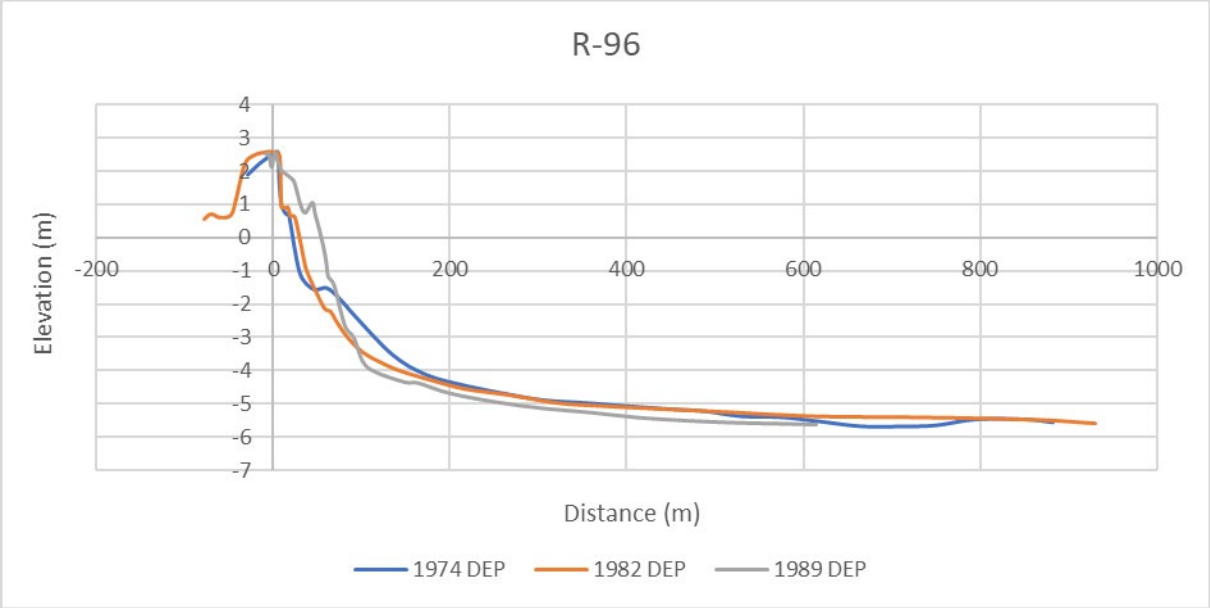


Figure A2.13. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-096.

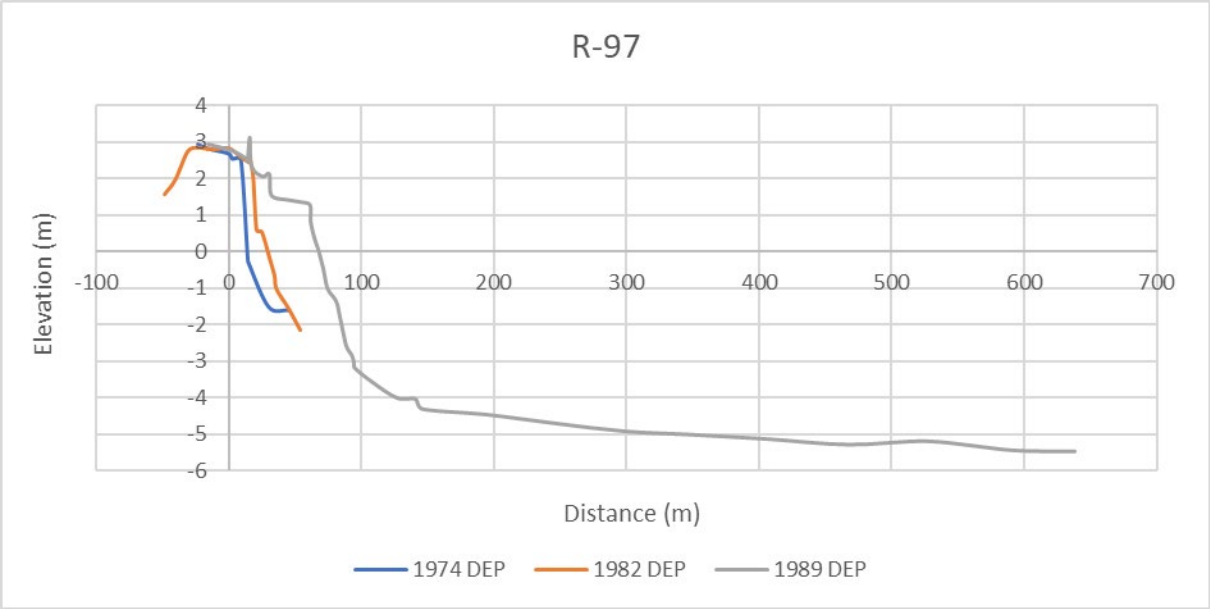


Figure A2.14. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-097.

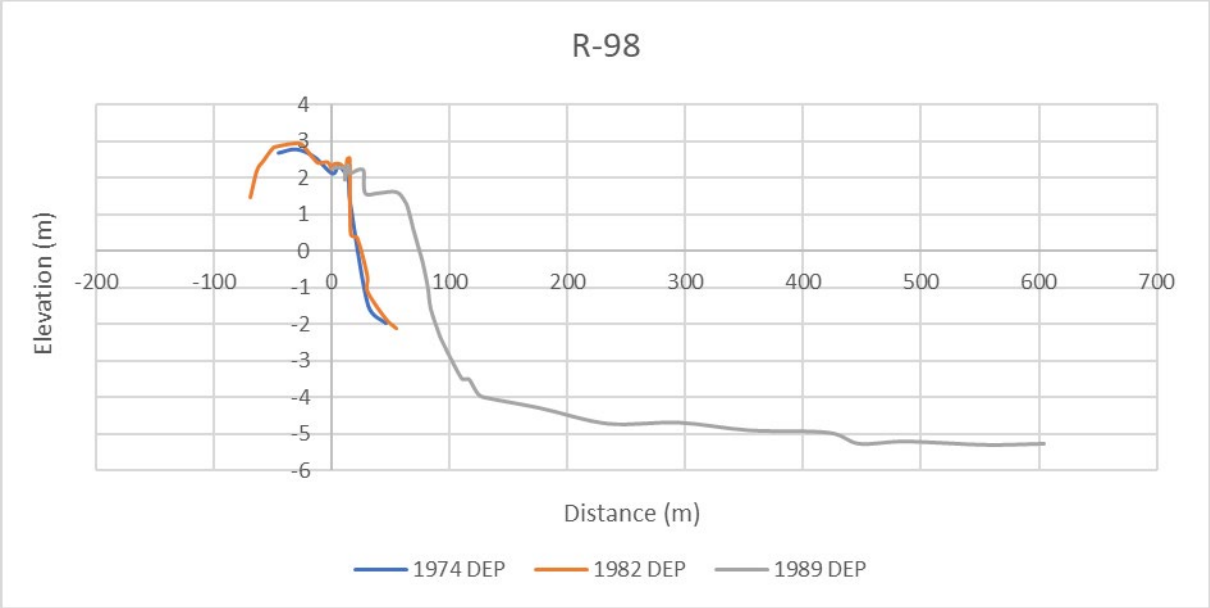


Figure A2.15. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-098.

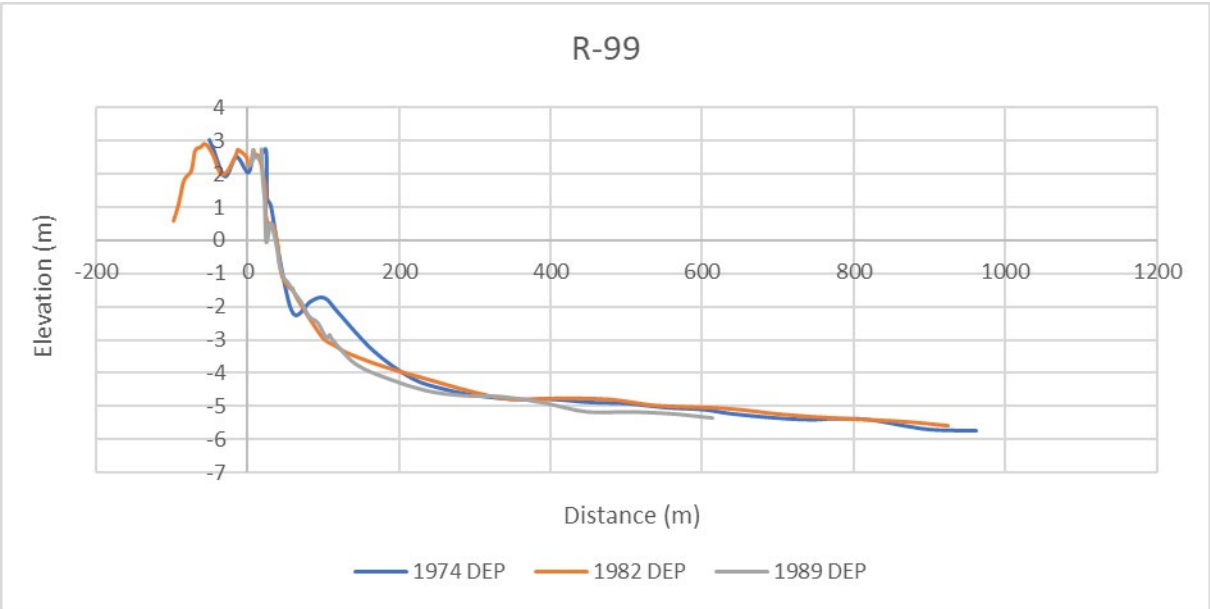


Figure A2.16. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-099.

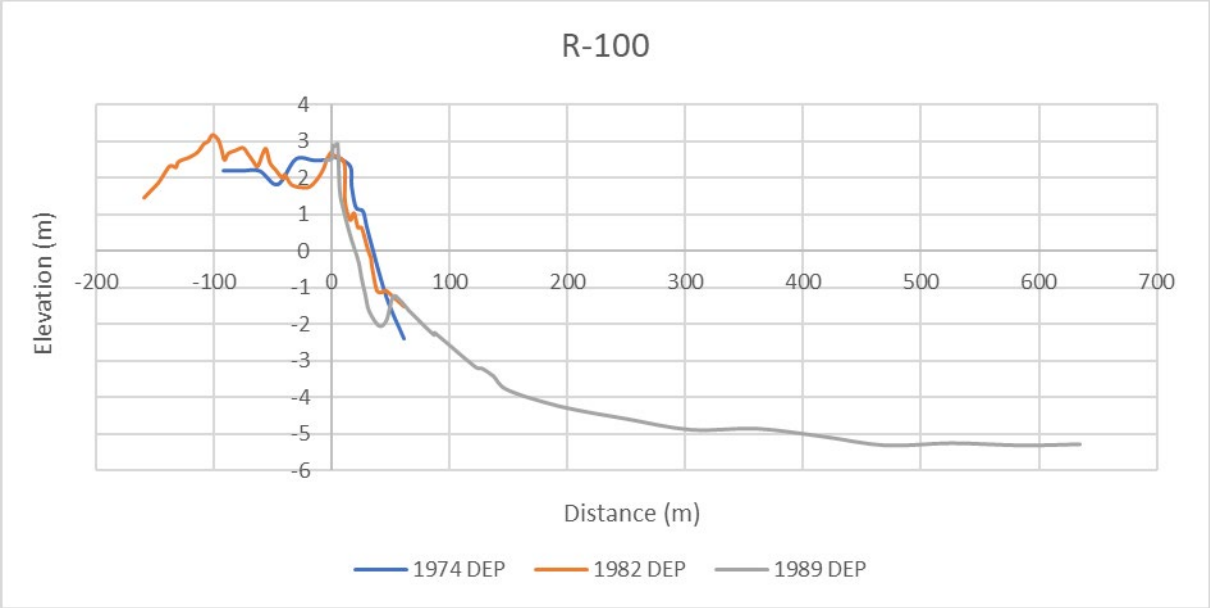


Figure A2.17. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-100.

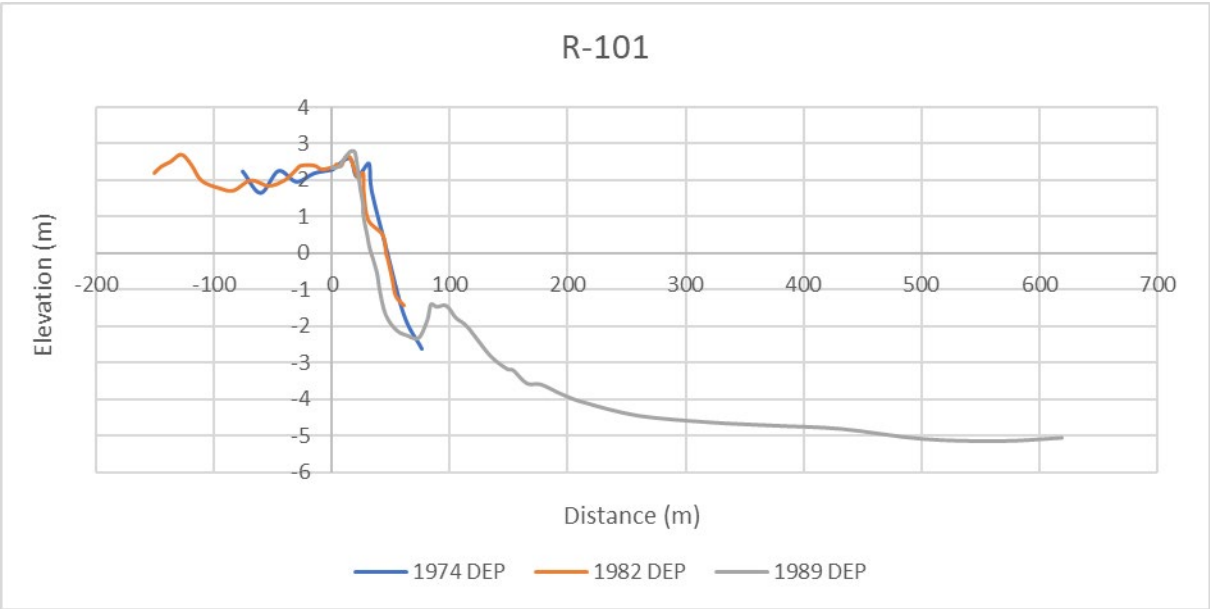


Figure A2.18. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-101.

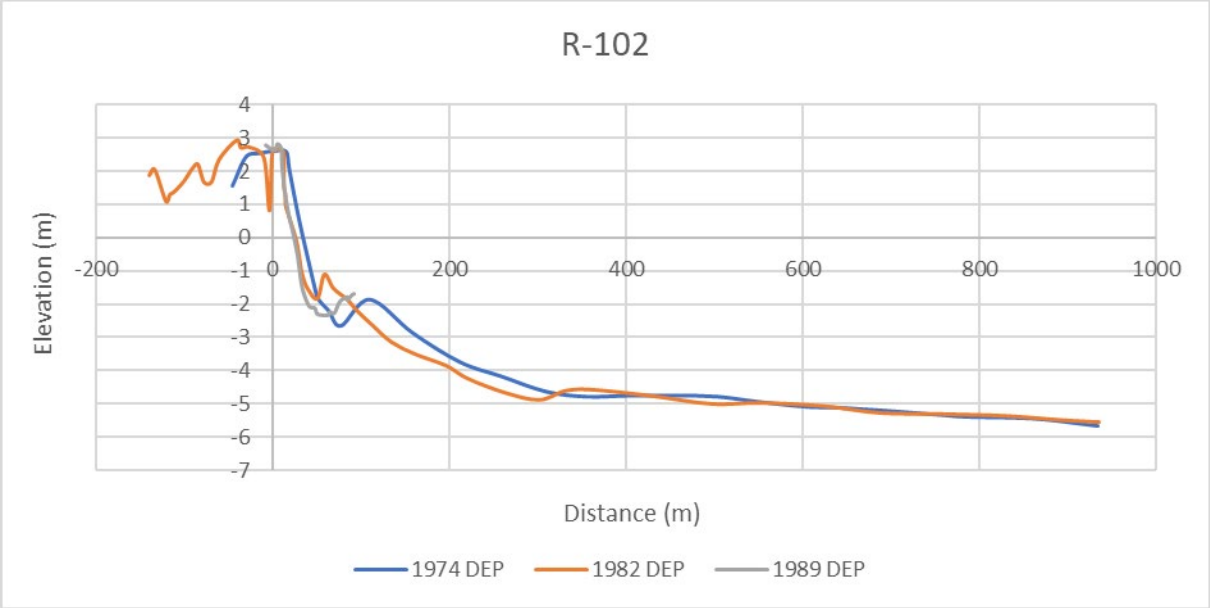


Figure A2.19. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-102.

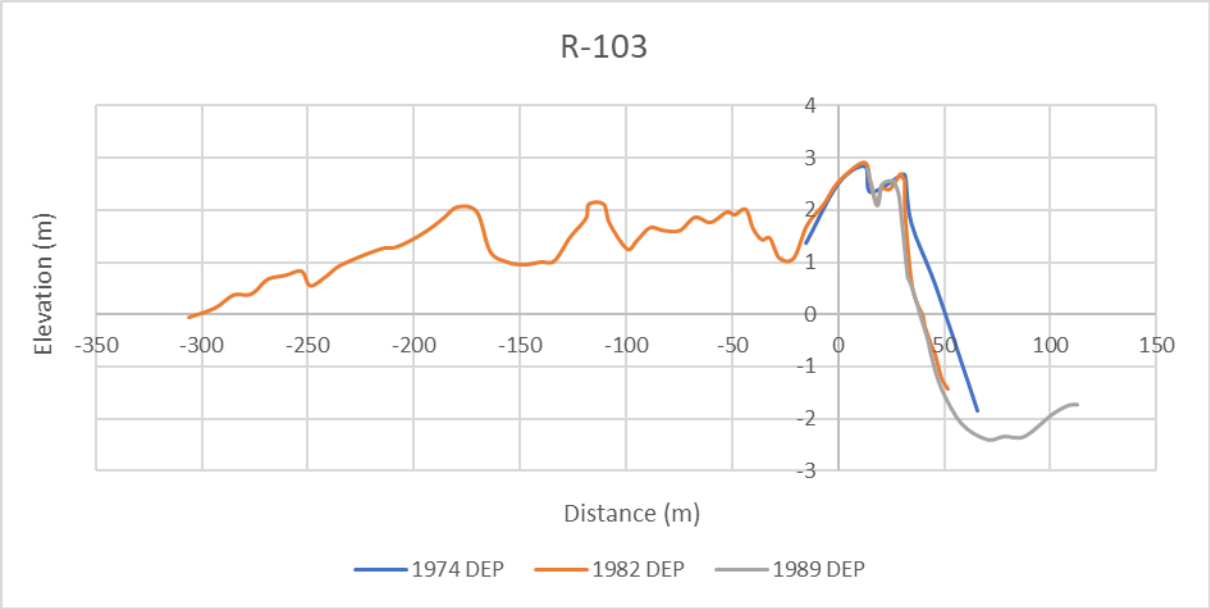


Figure A2.20. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-103.

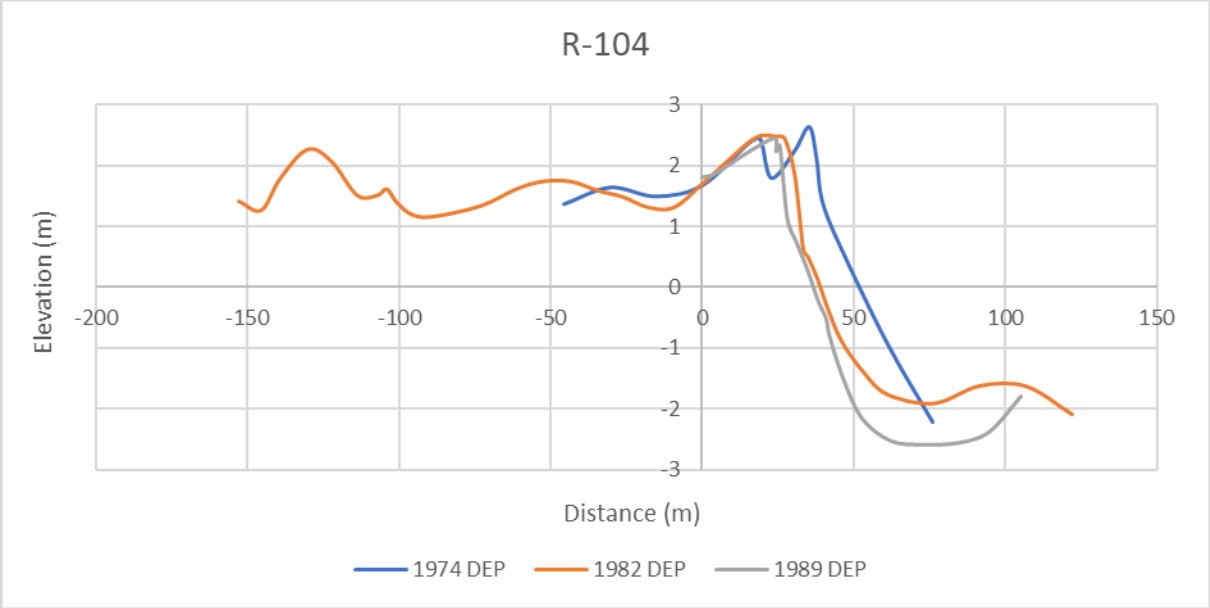


Figure A2.21. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-104.

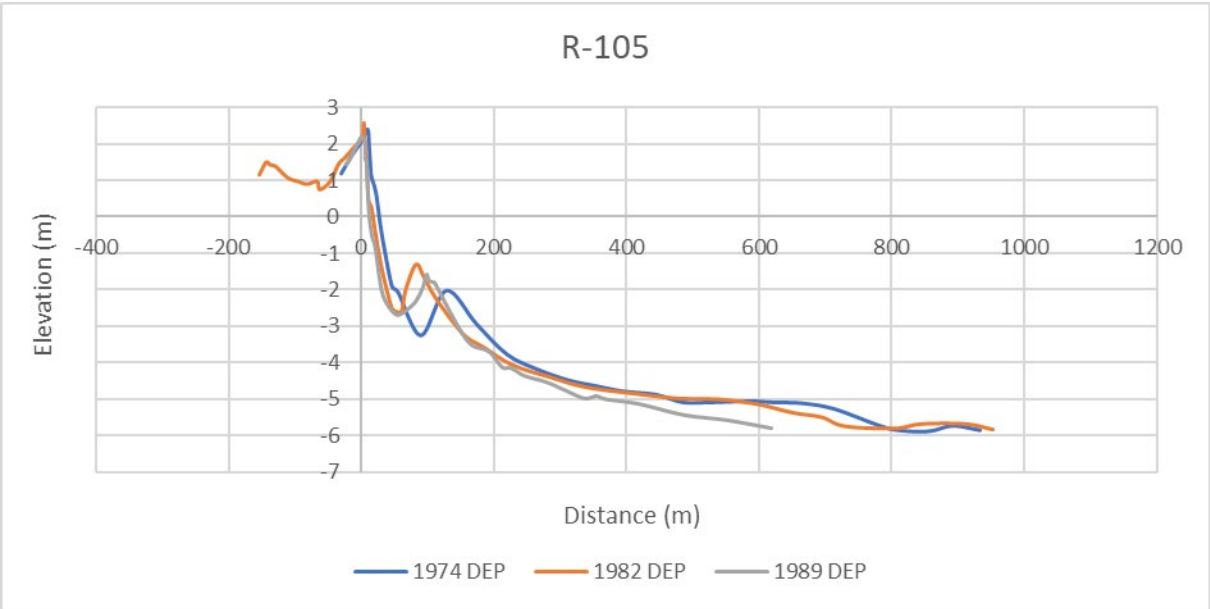


Figure A2.22. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-105.

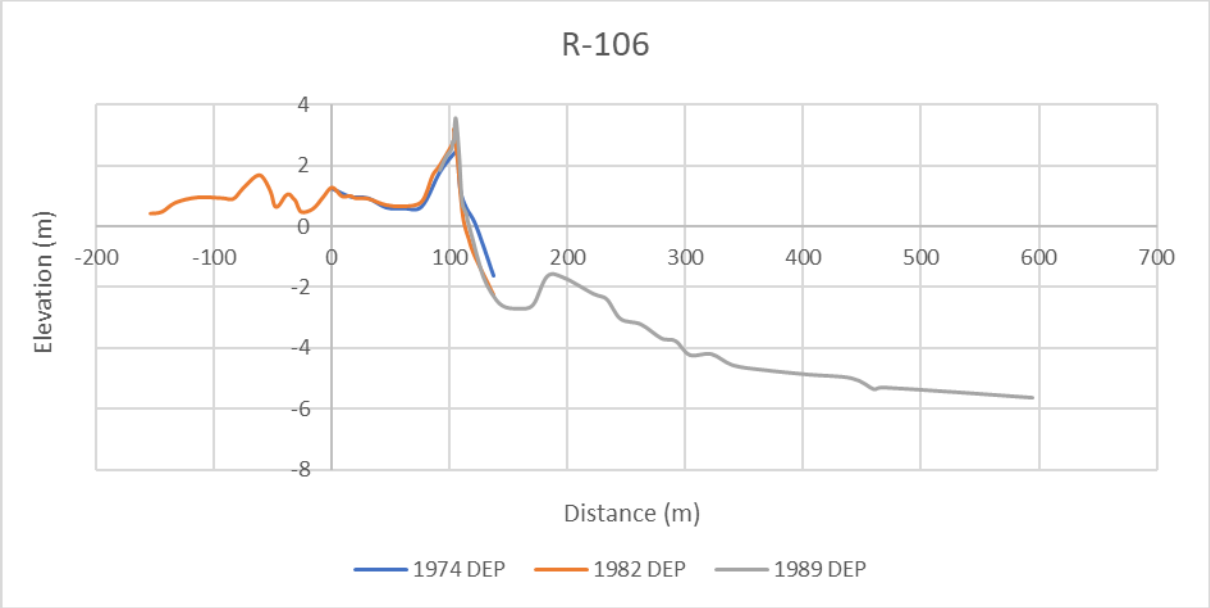


Figure A2.23. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-106.

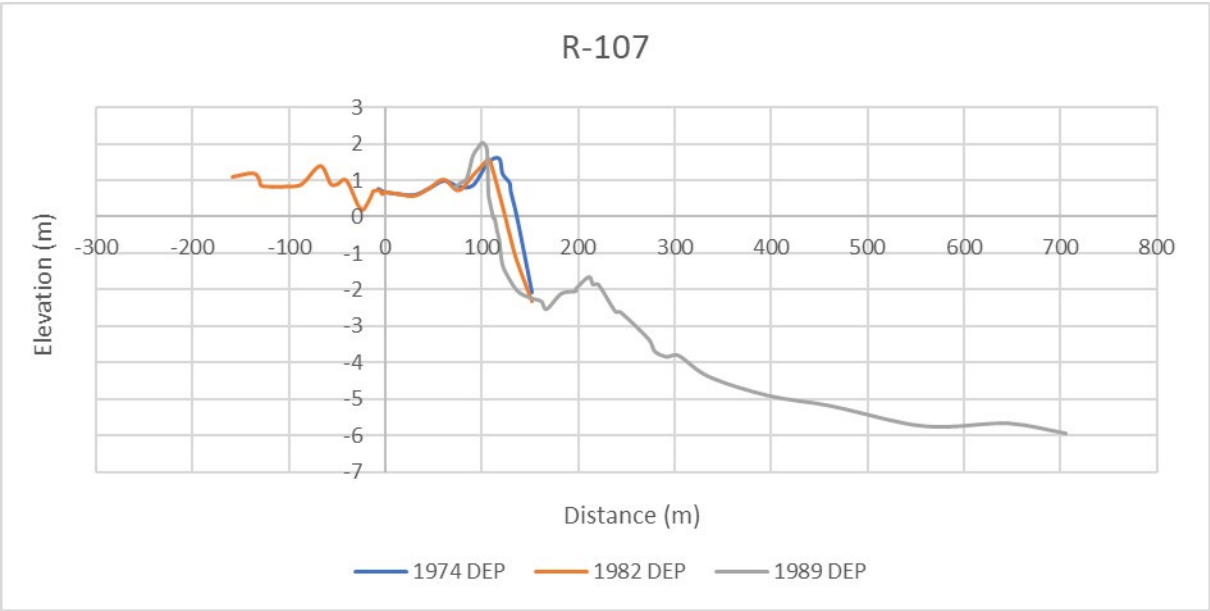


Figure A2.24. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-107.

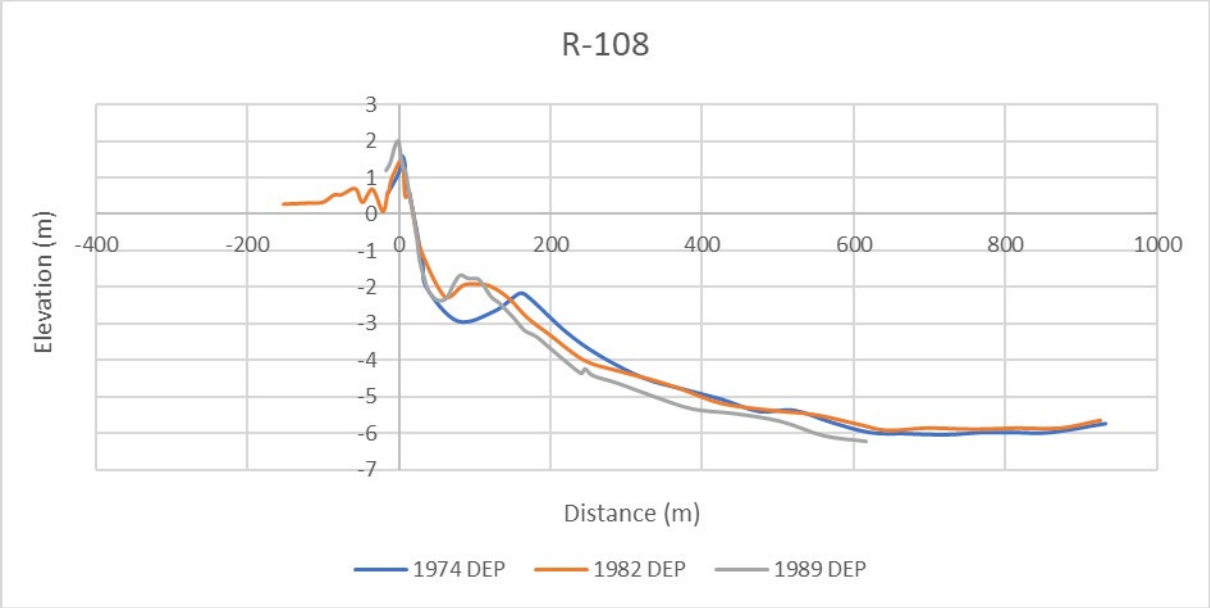


Figure A2.25. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-108.

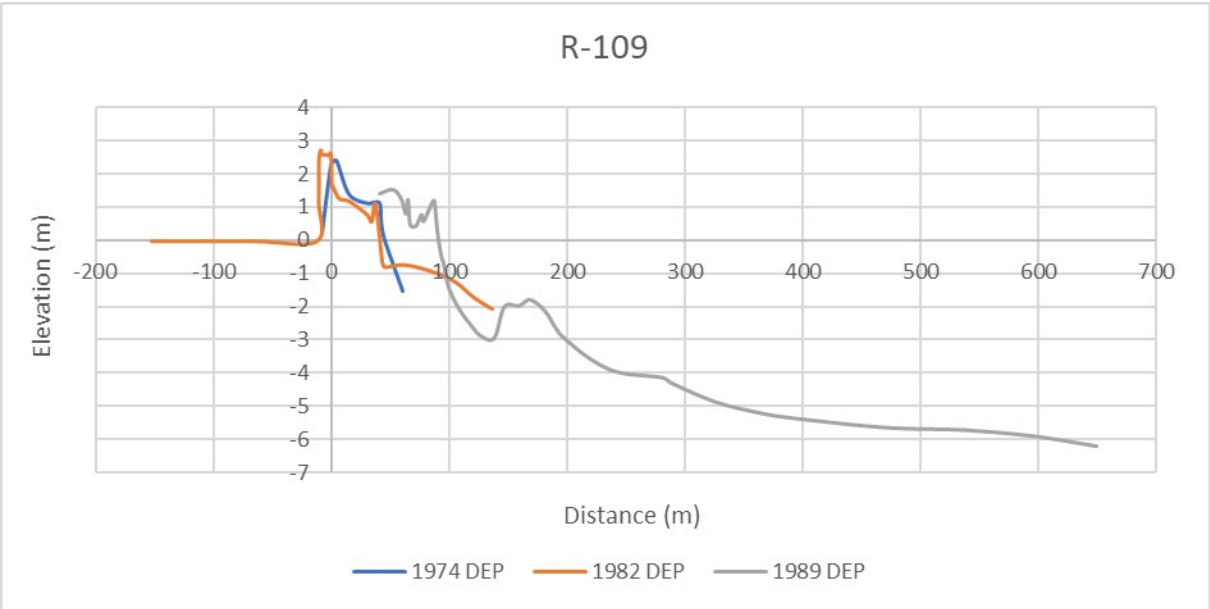


Figure A2.26. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-109.

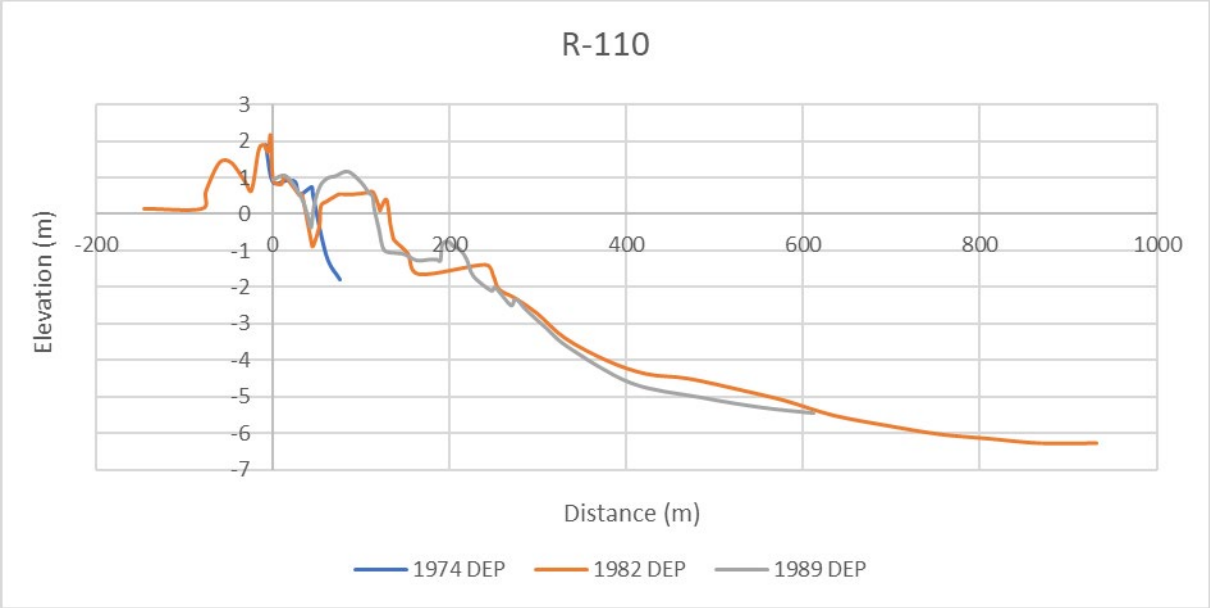


Figure A2.27. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-110.

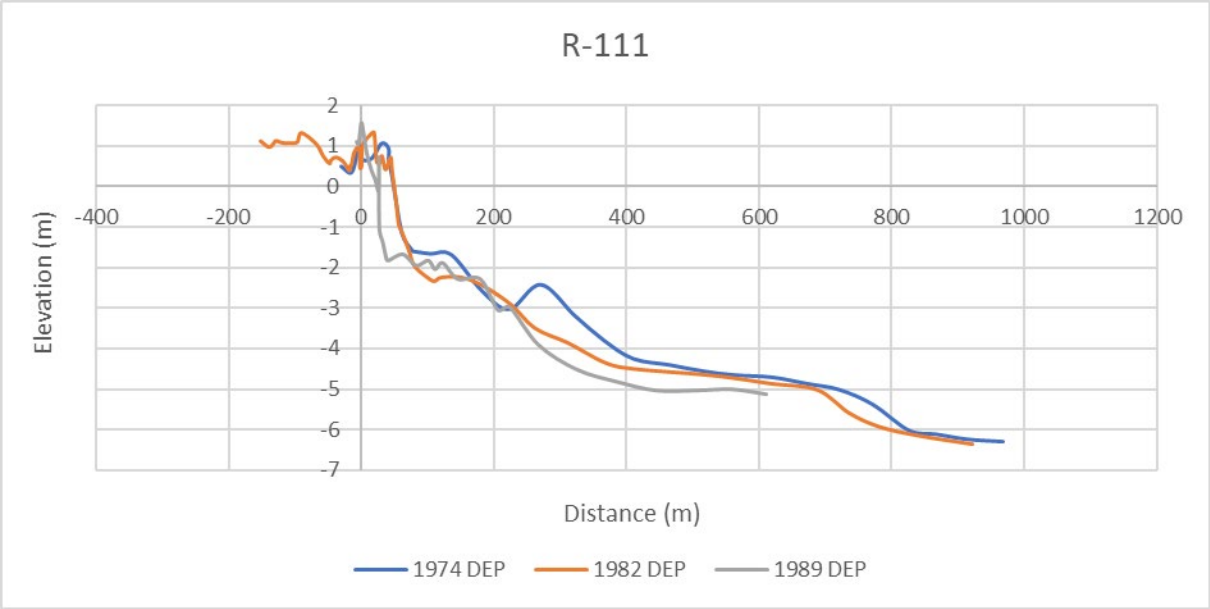


Figure A2.28. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-111.

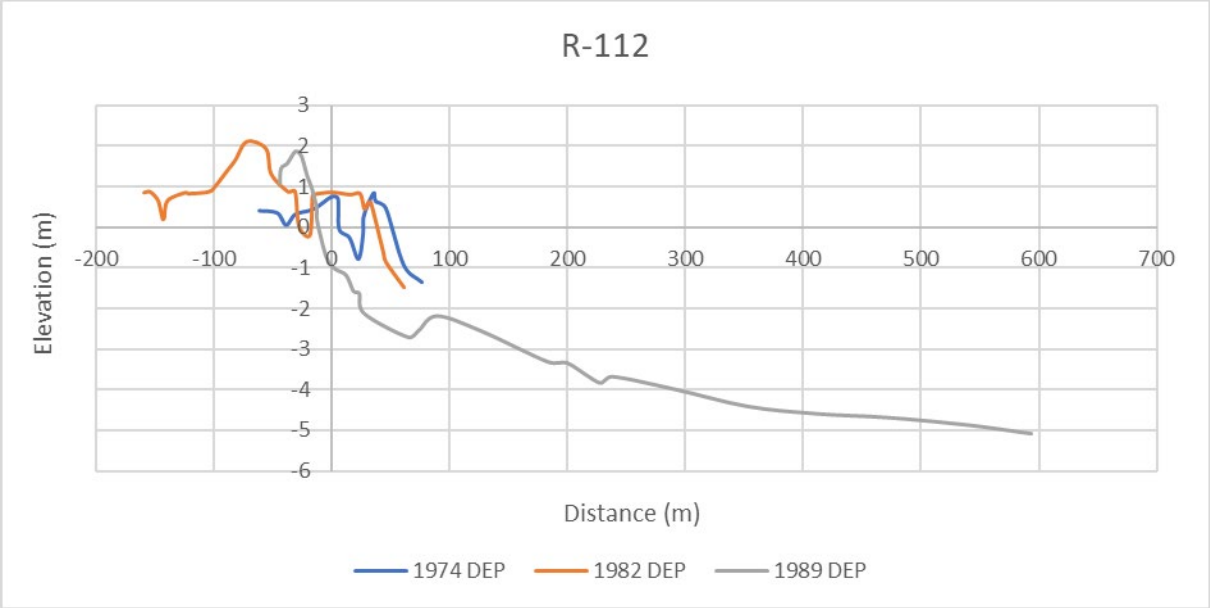


Figure A2.29. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-112.

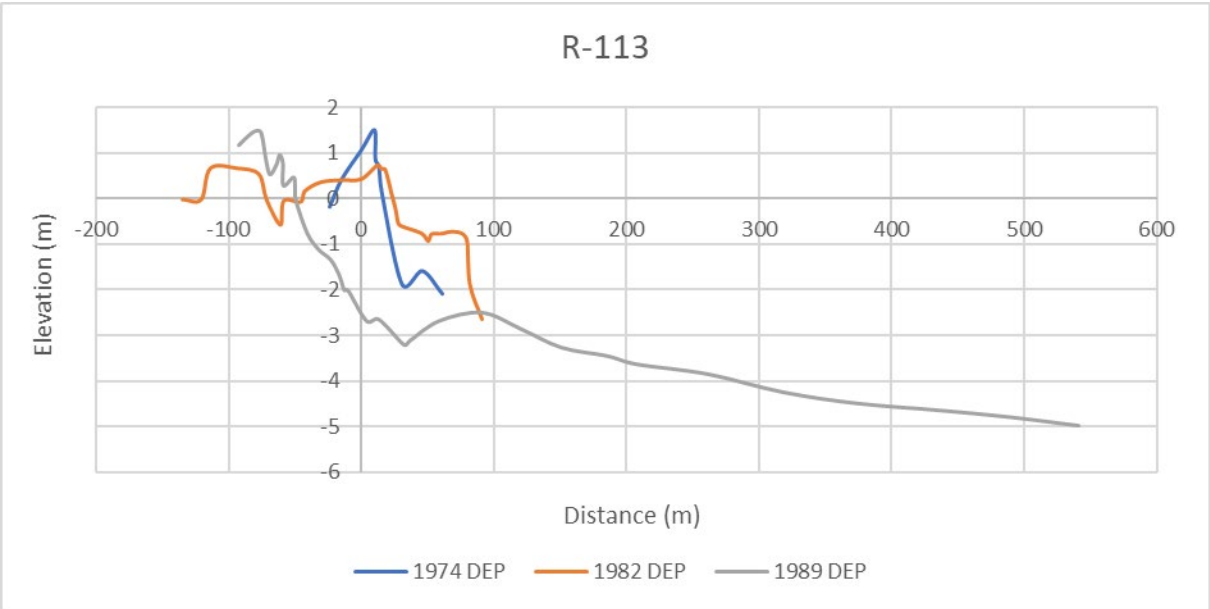


Figure A2.30. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-113.

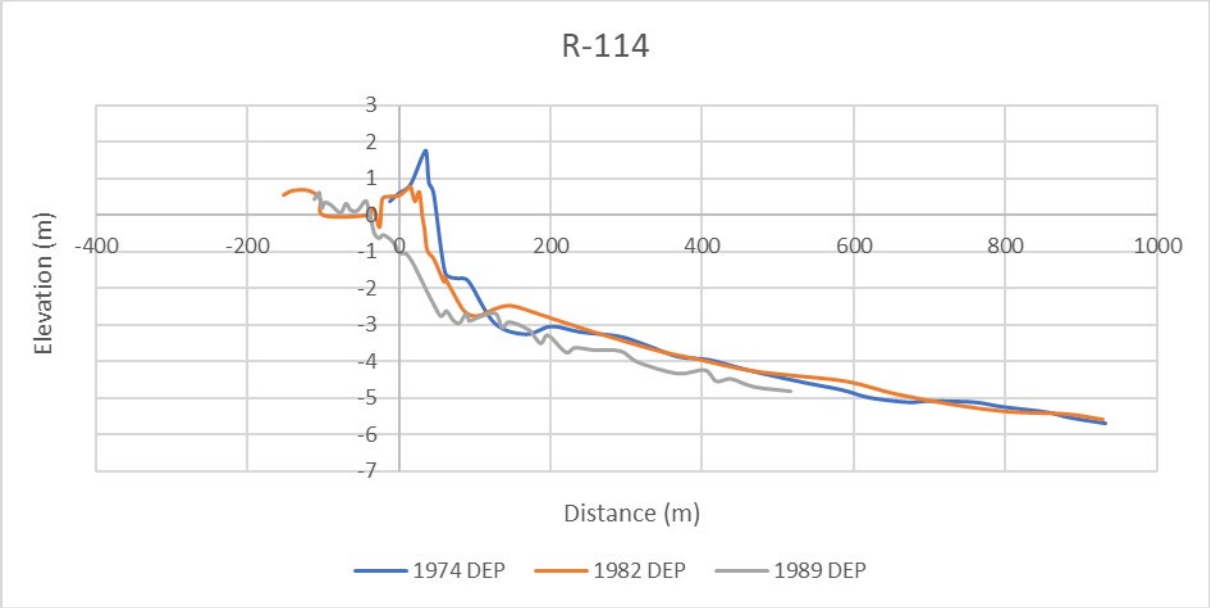


Figure A2.31. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-114.

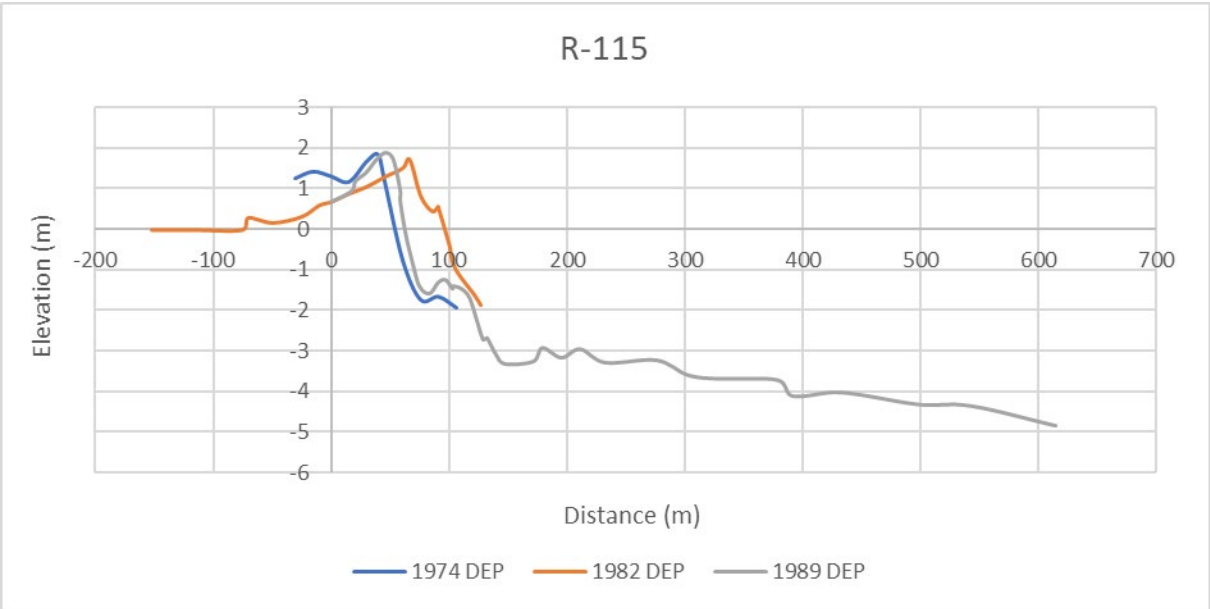


Figure A2.32. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-115.

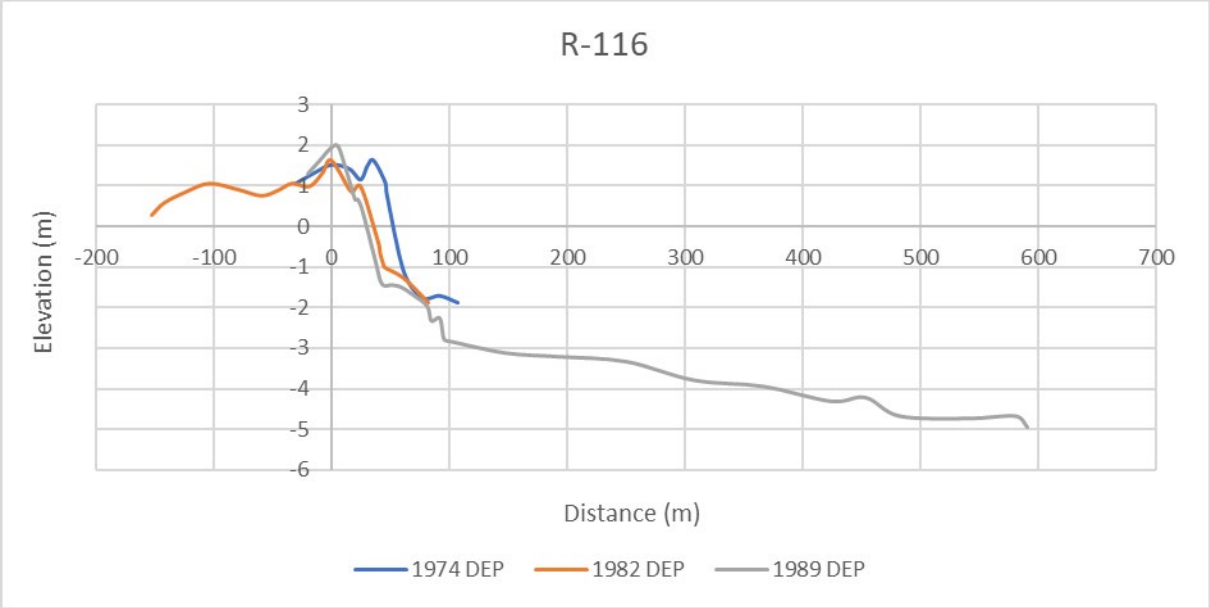


Figure A2.33. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-116.

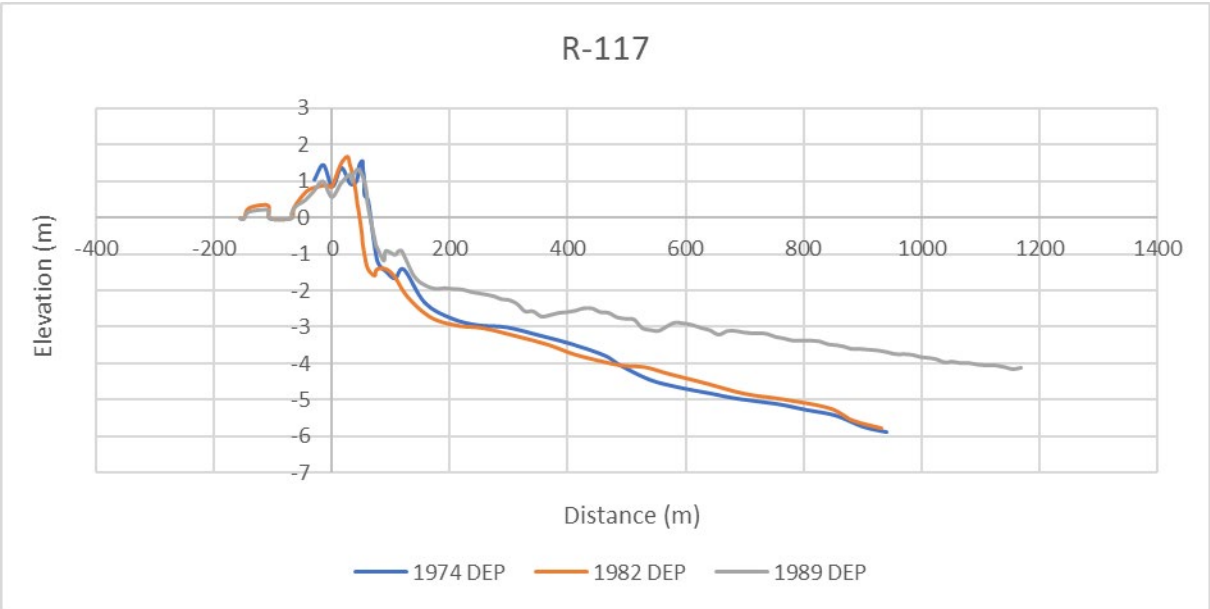


Figure A2.34. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-117.

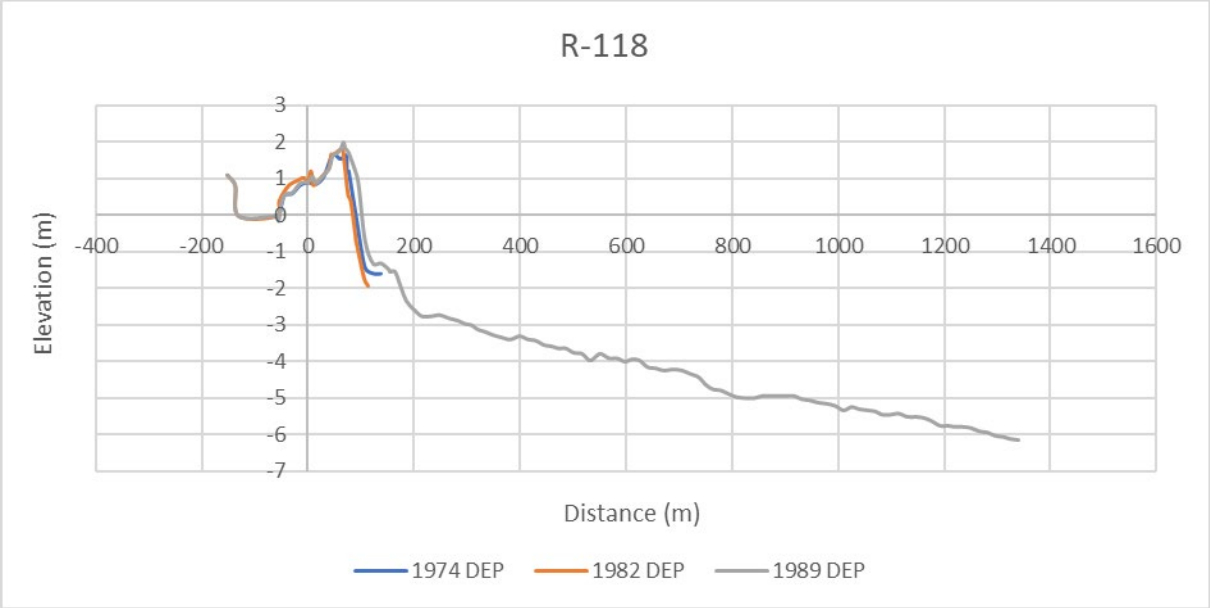


Figure A2.35. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-118.

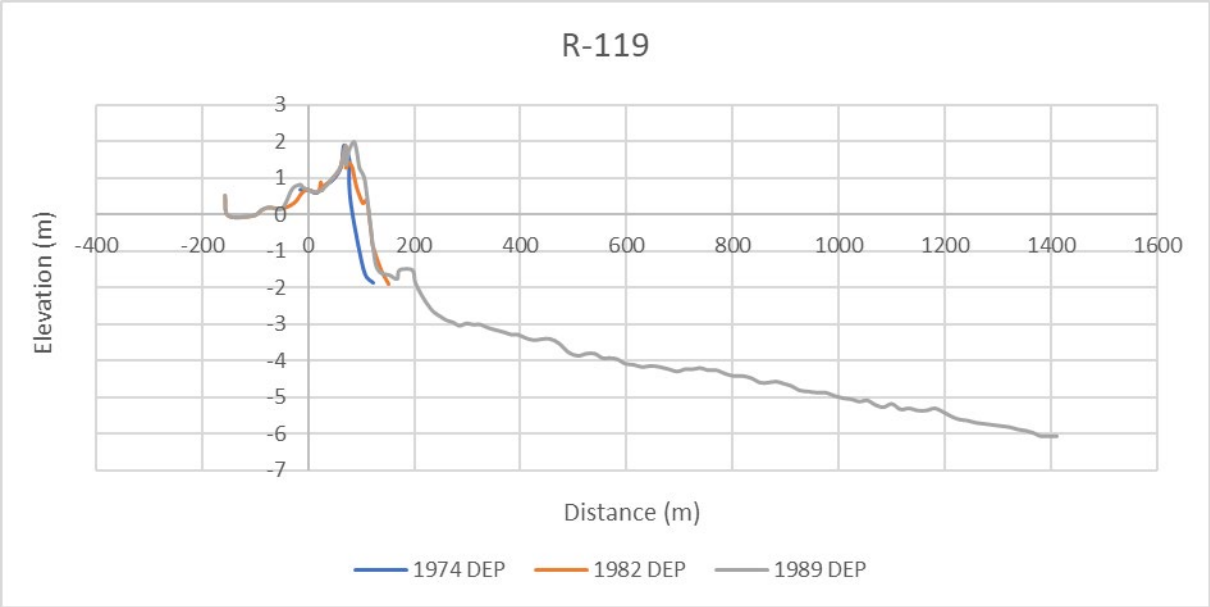


Figure A2.36. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-119.

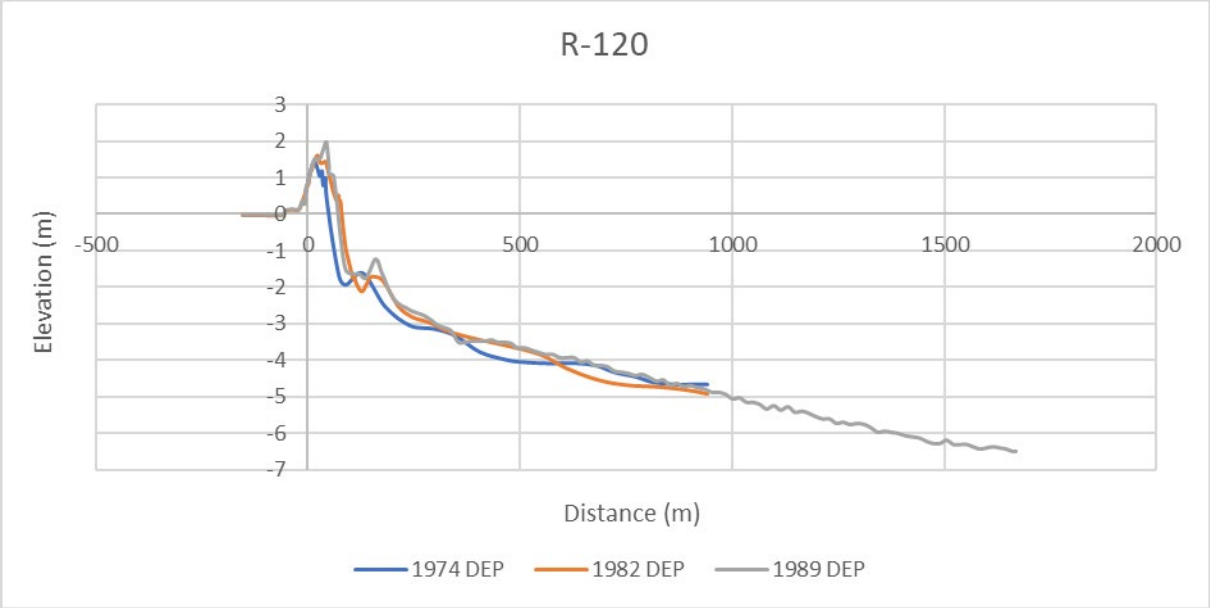


Figure A2.37. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-120.

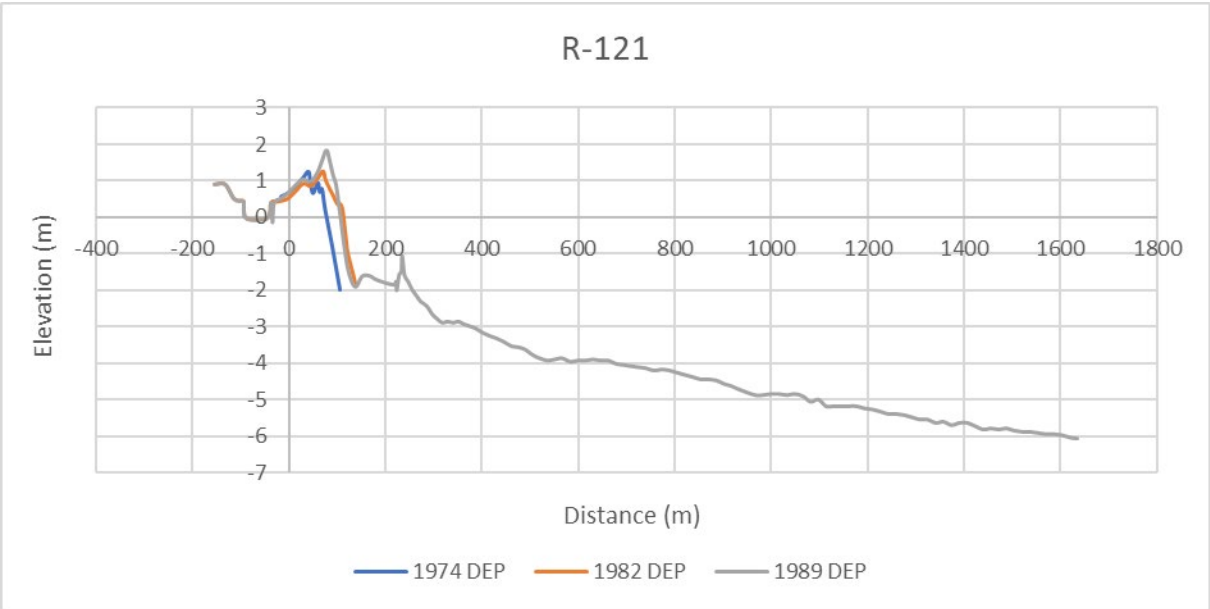


Figure A2.38. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-121.

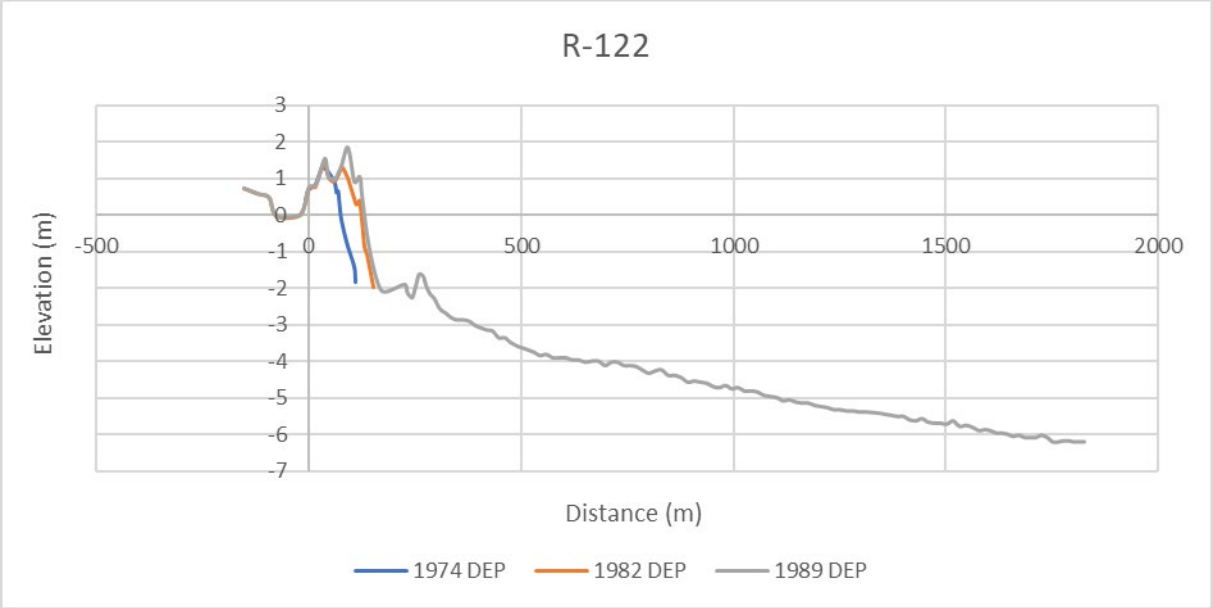


Figure A2.39. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-122.

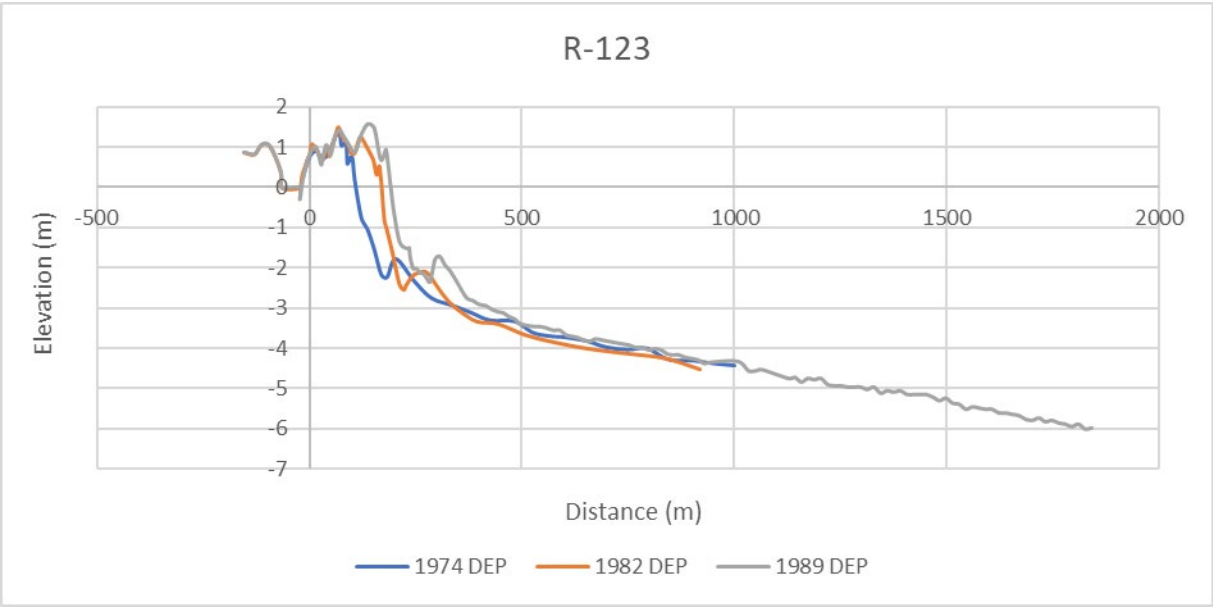


Figure A2.40. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-123.

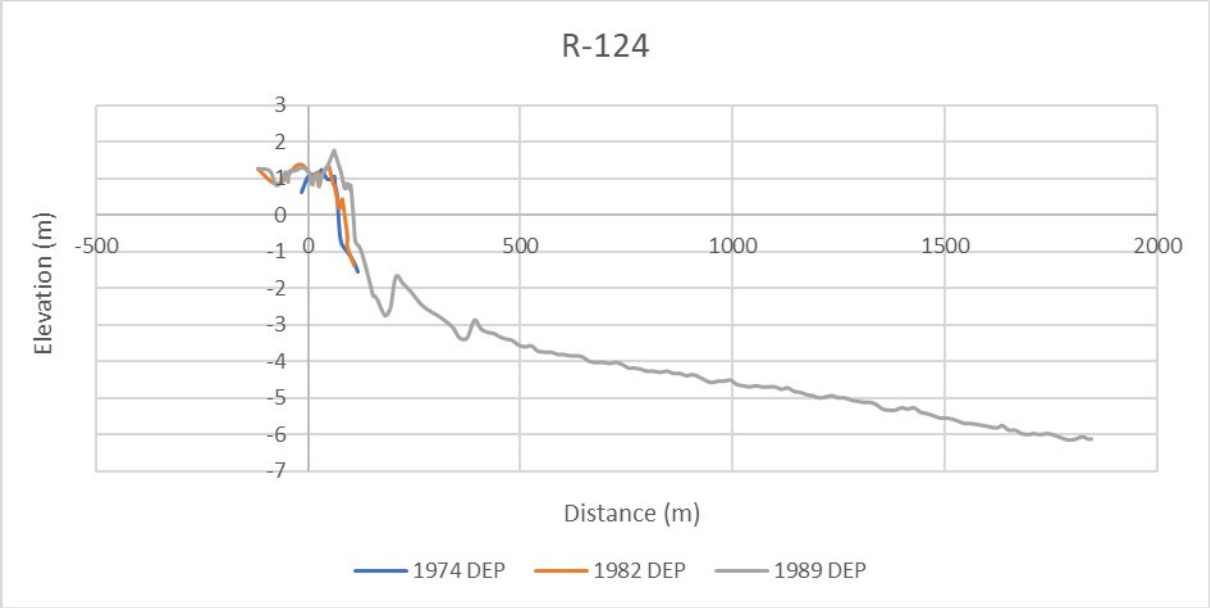


Figure A2.41. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-124.

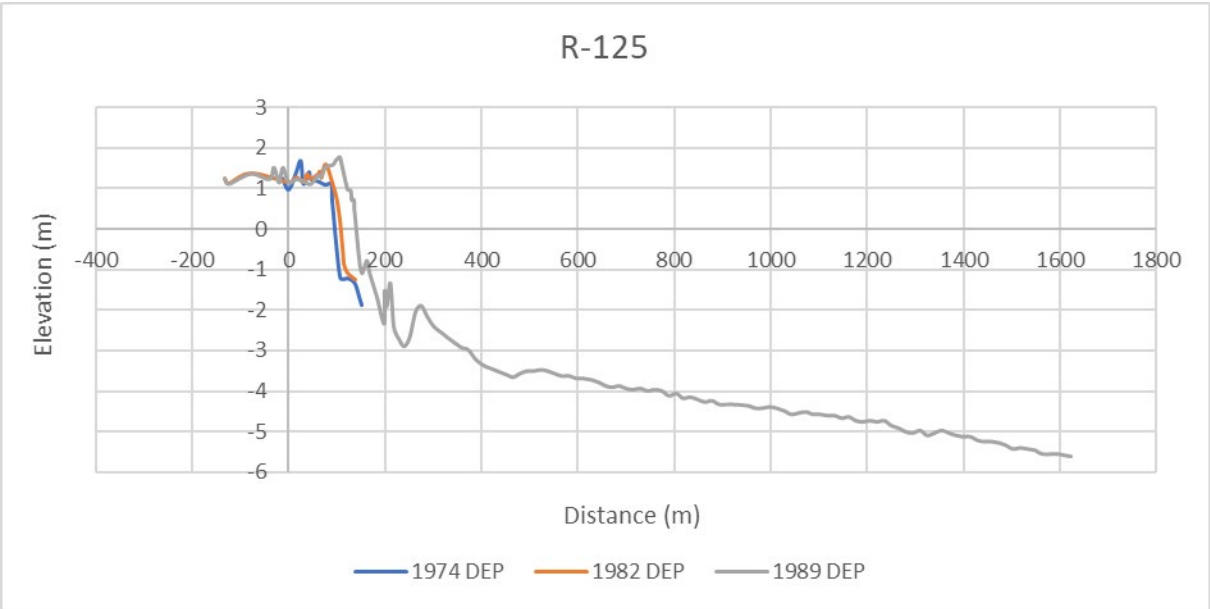


Figure A2.42. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-125.

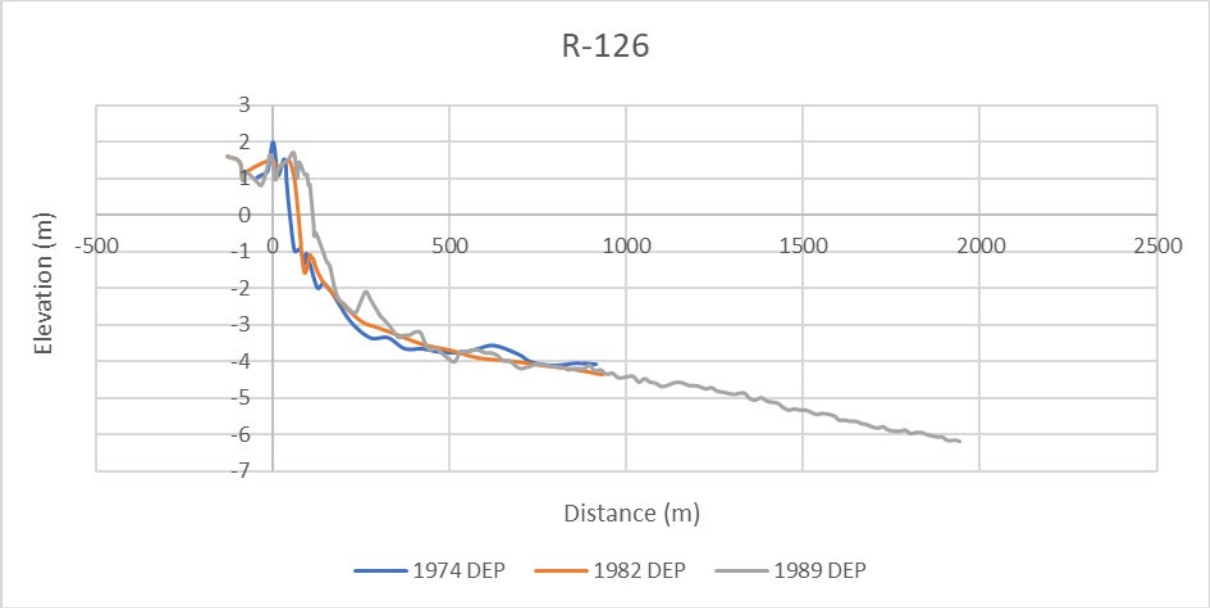


Figure A2.43. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-126.

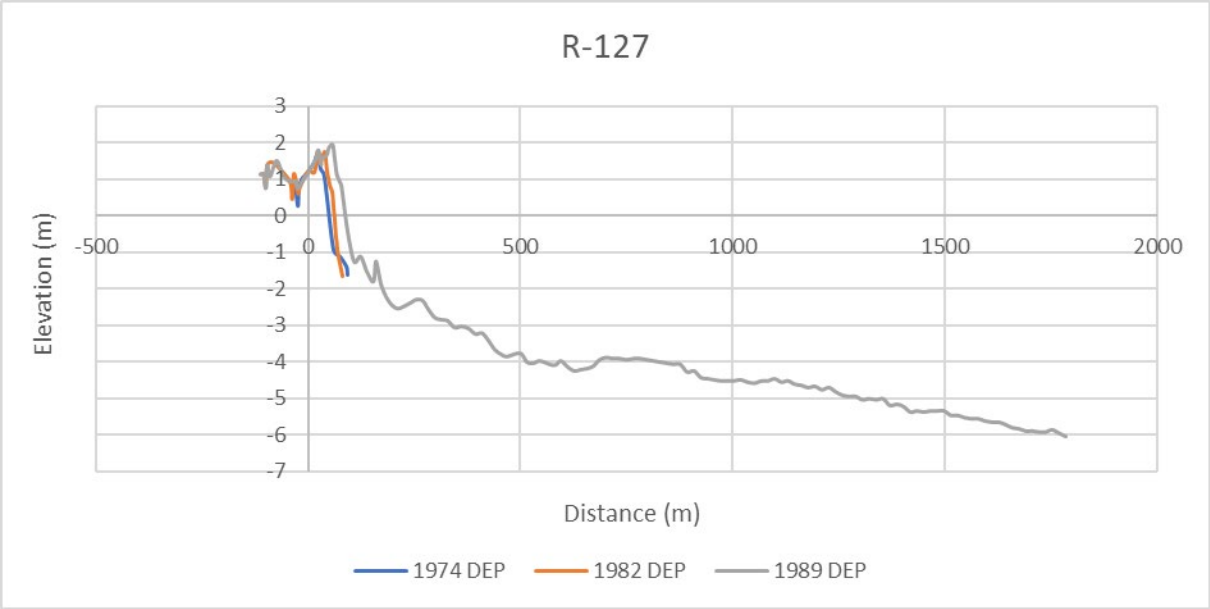


Figure A2.44. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-127.

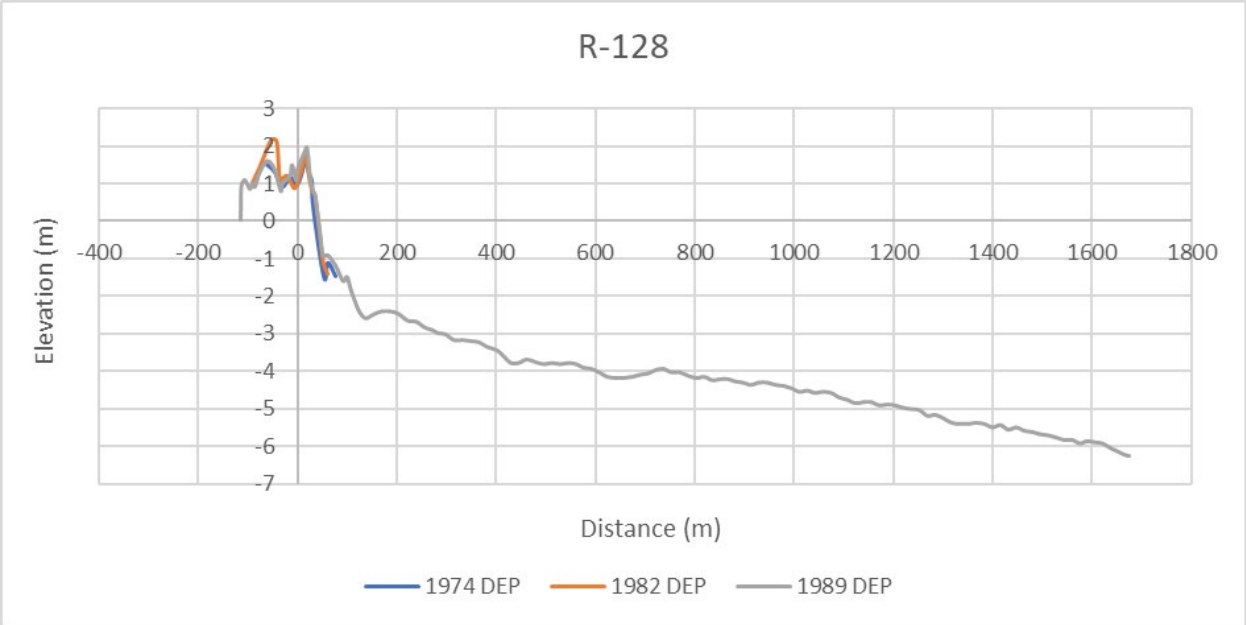
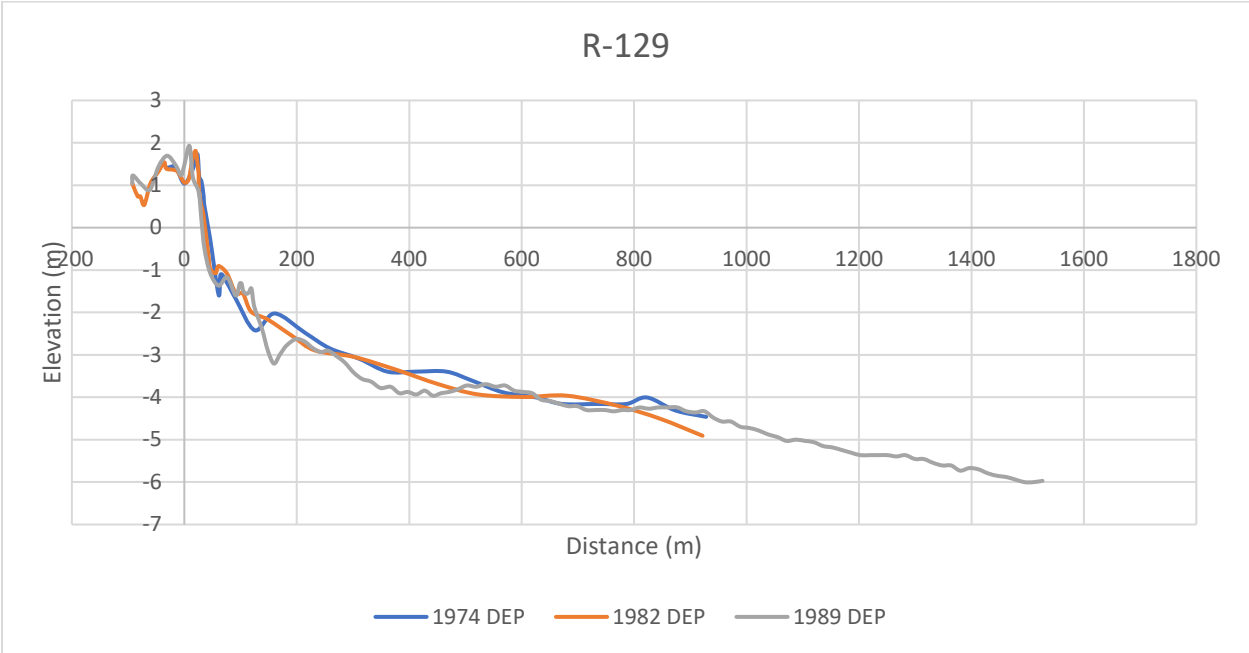


Figure A2.45. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-128.



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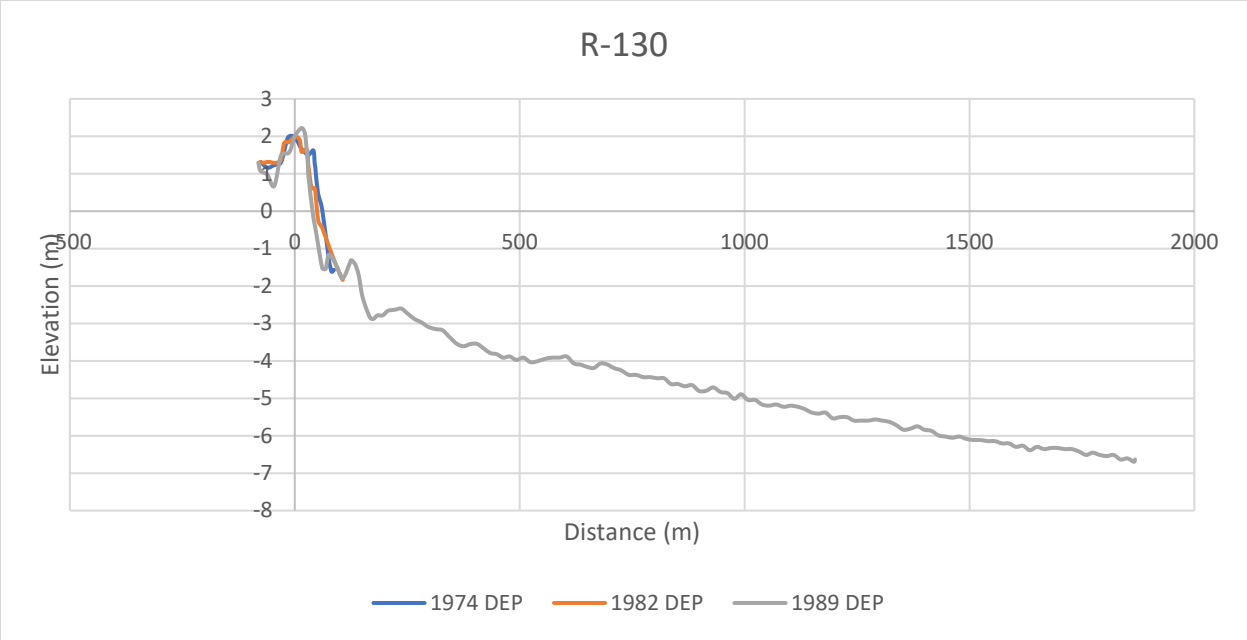


Figure A2.47. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-130.

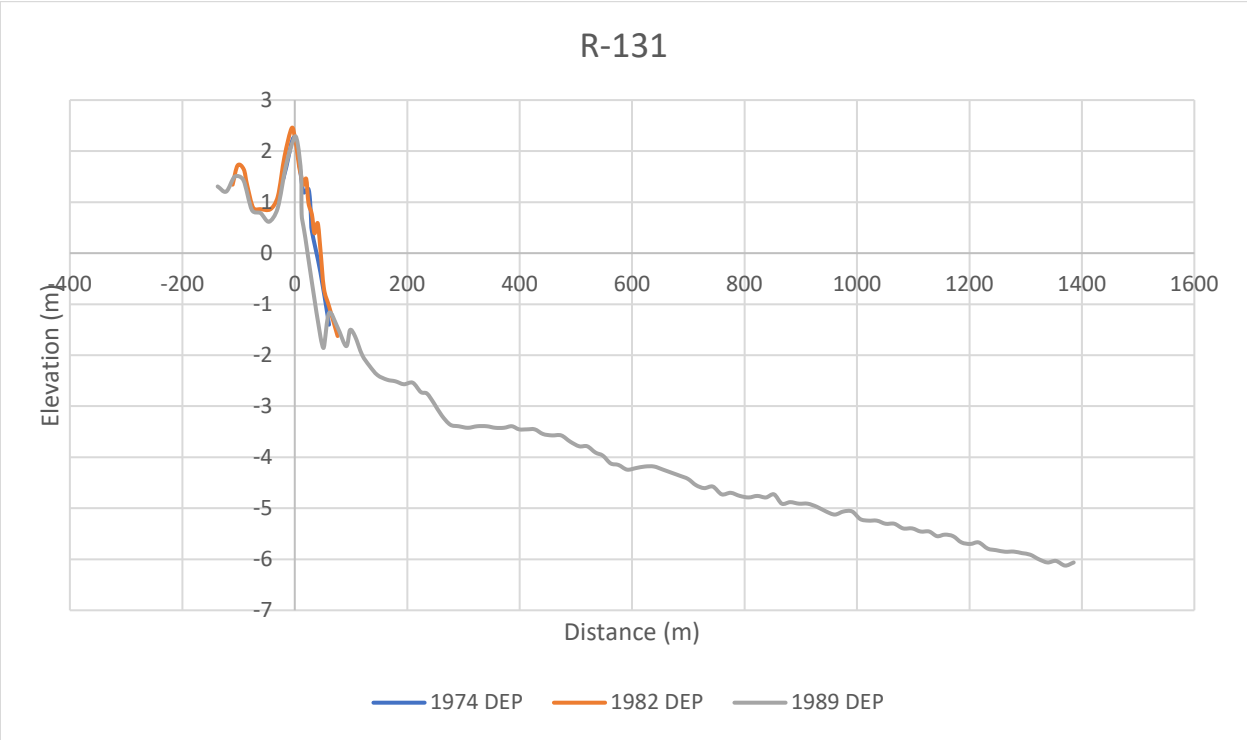


Figure A2.48. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-131.

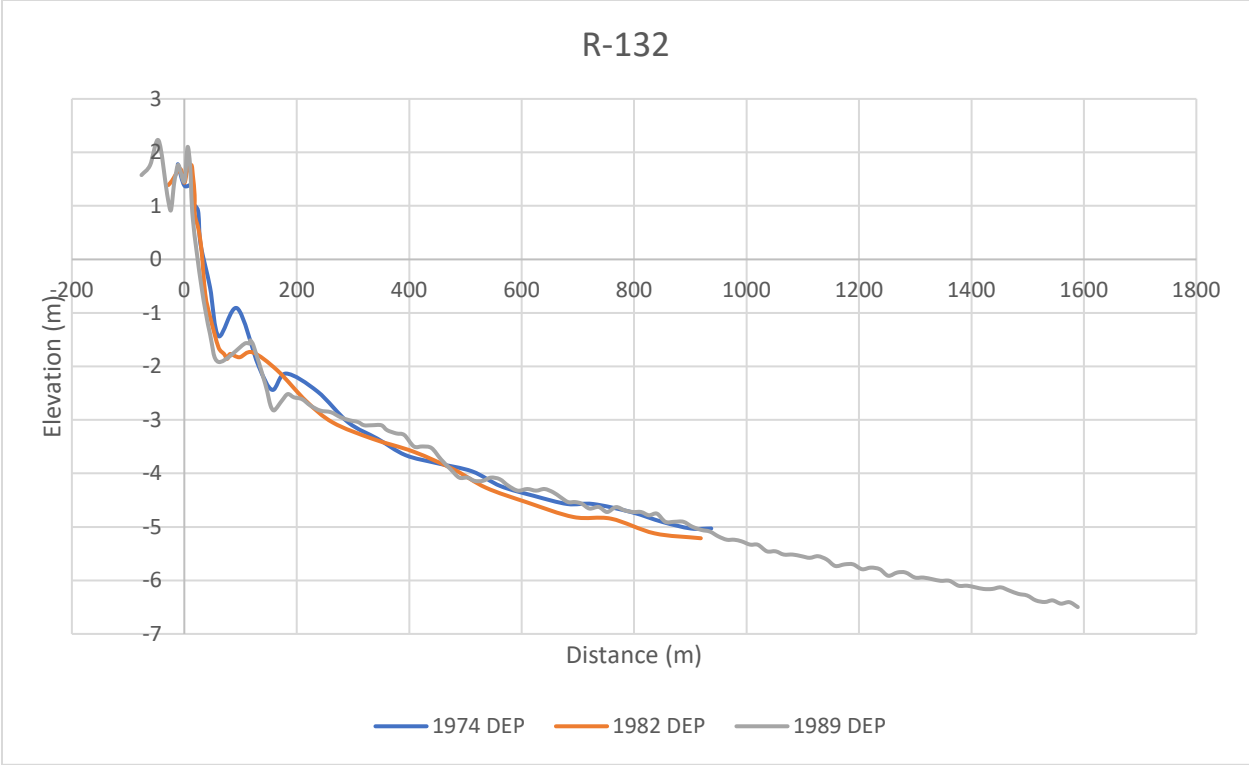


Figure A2.49. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-132.

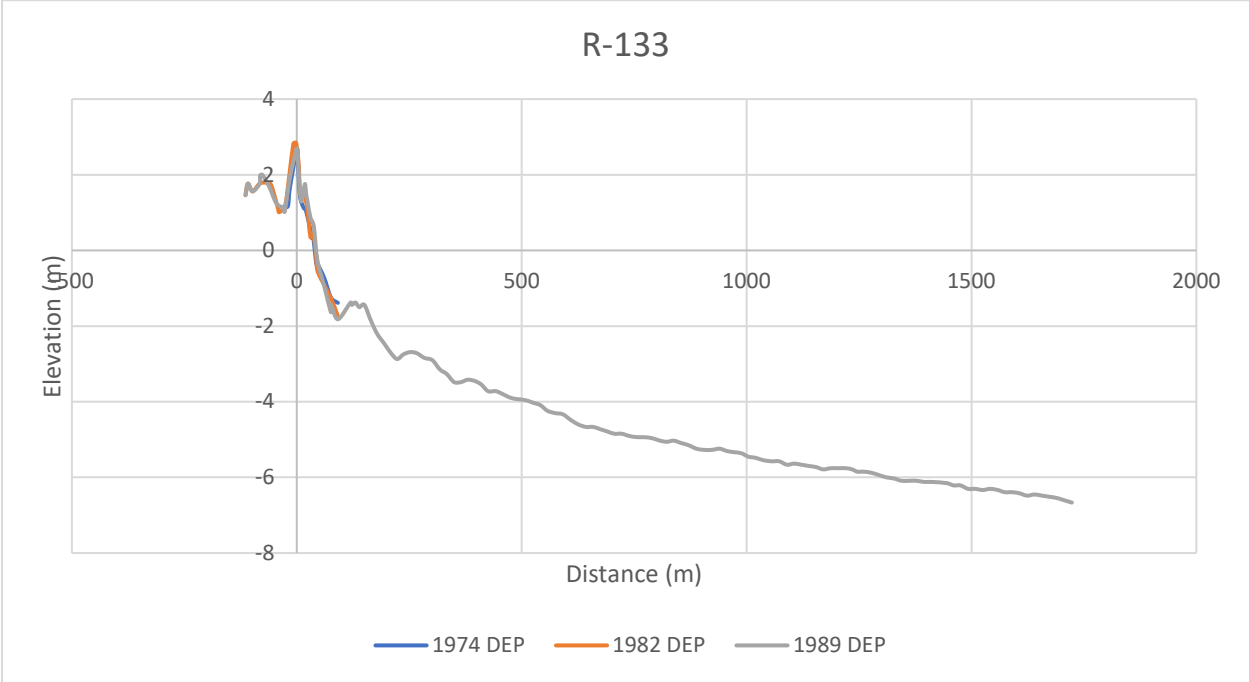


Figure A2.50. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-133.

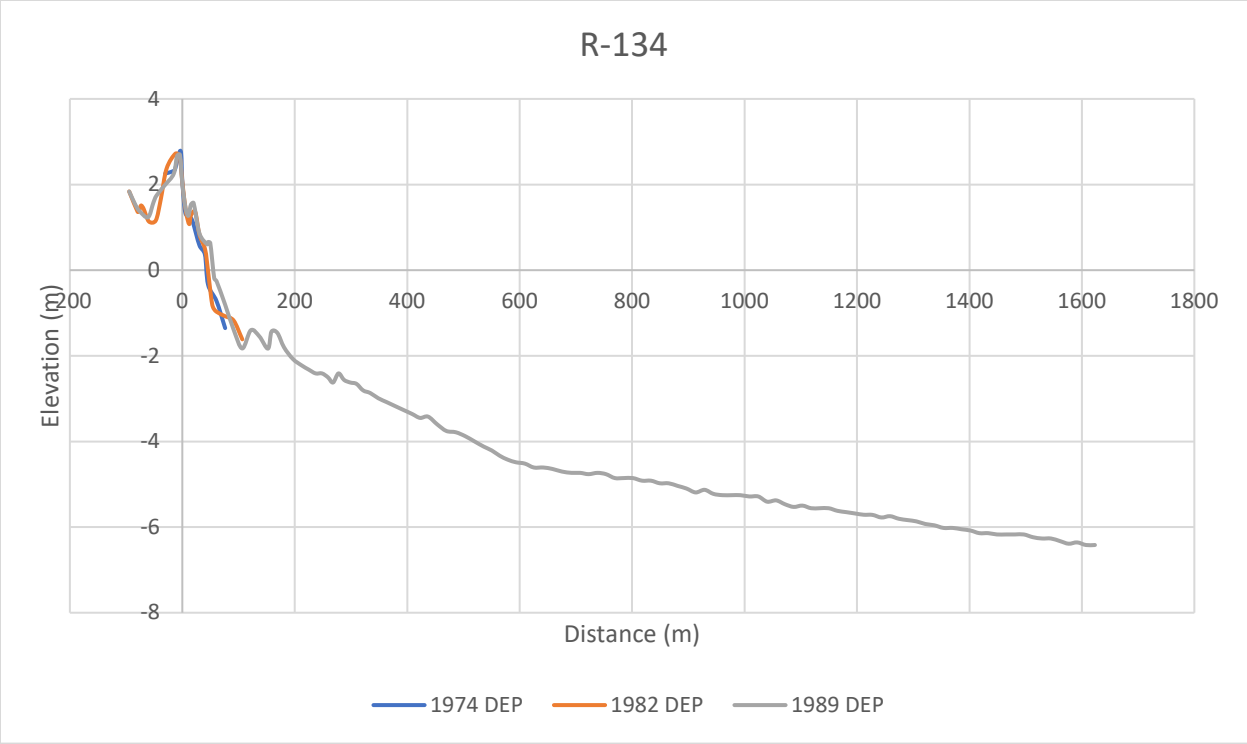
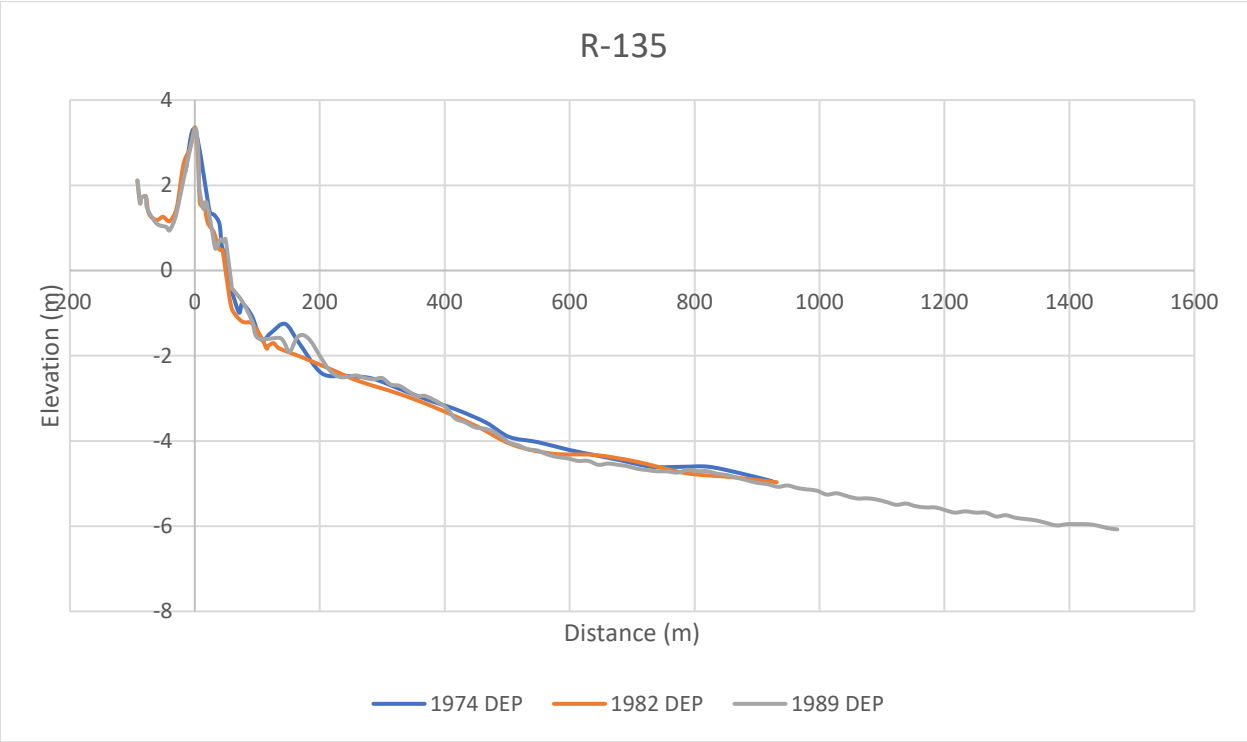


Figure A2.51. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-134.



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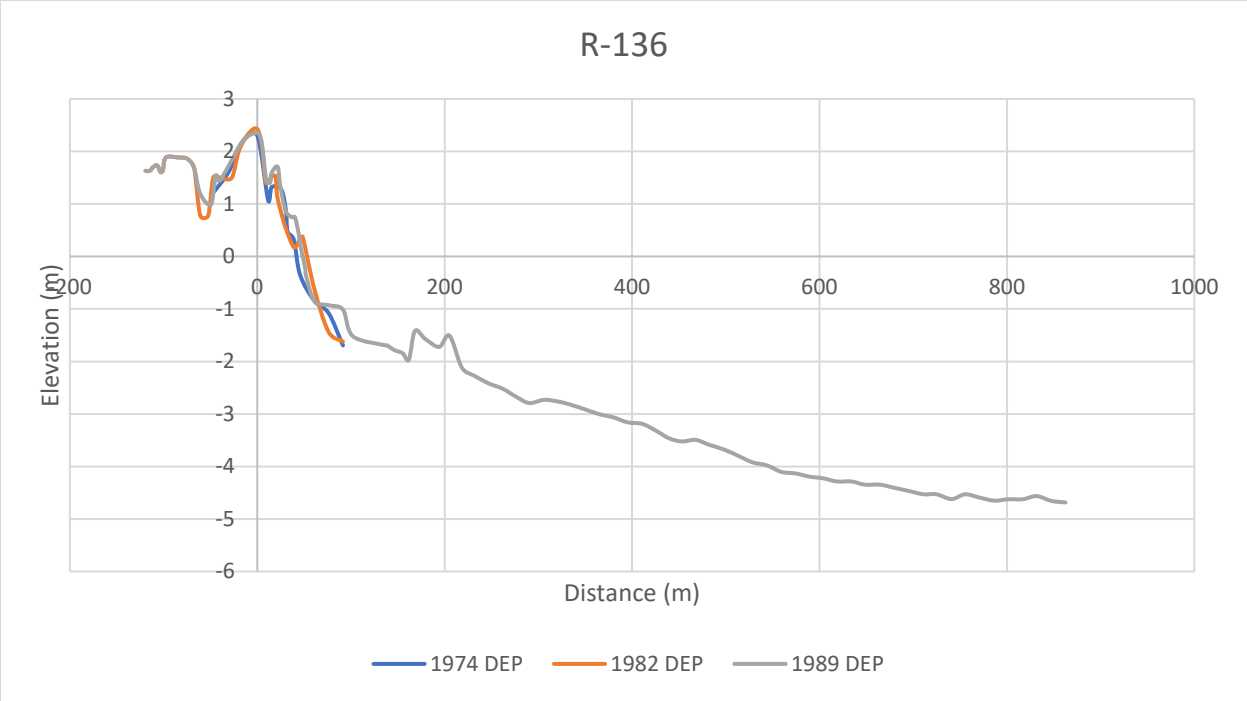

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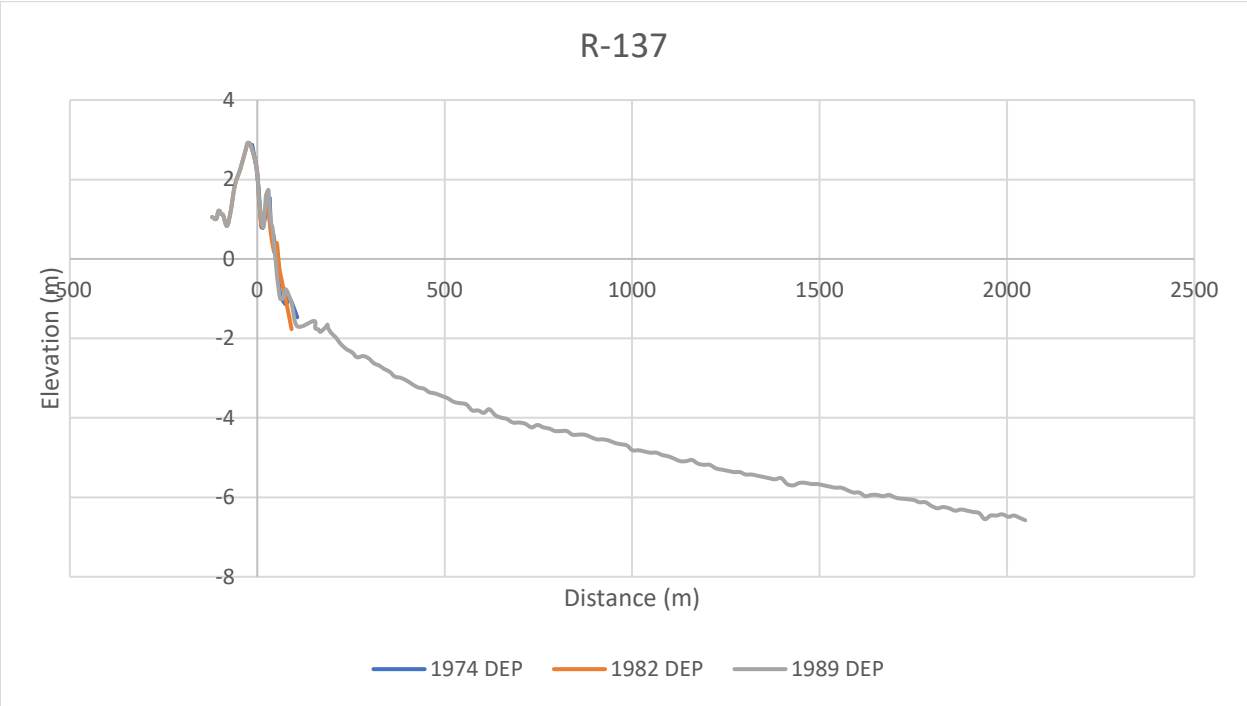

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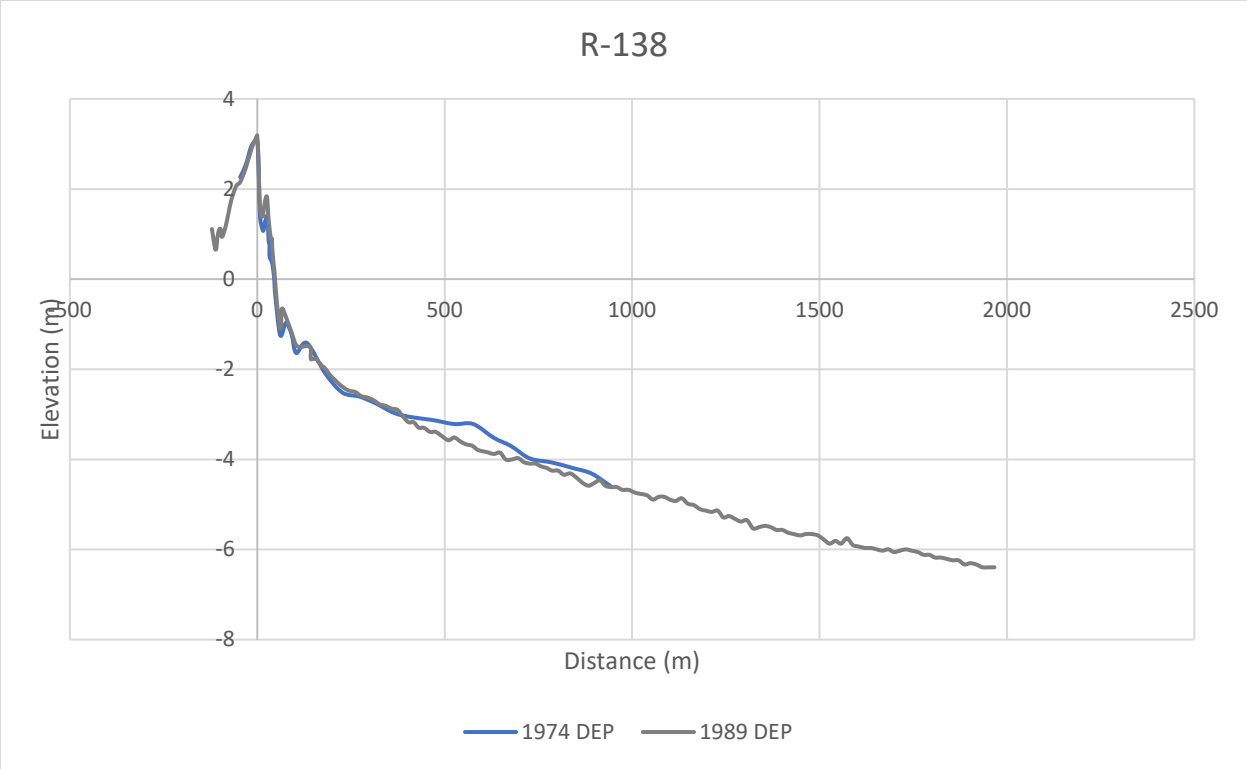


Figure A2.55. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-138.

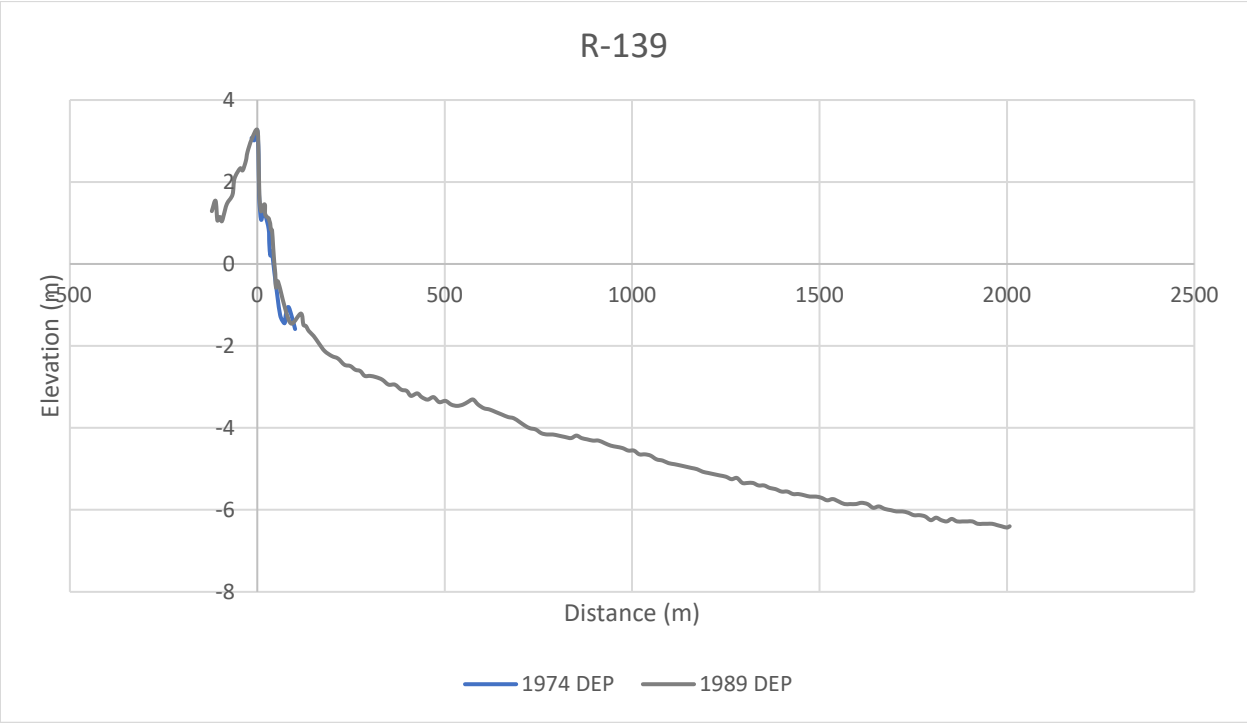


Figure A2.56. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-139.

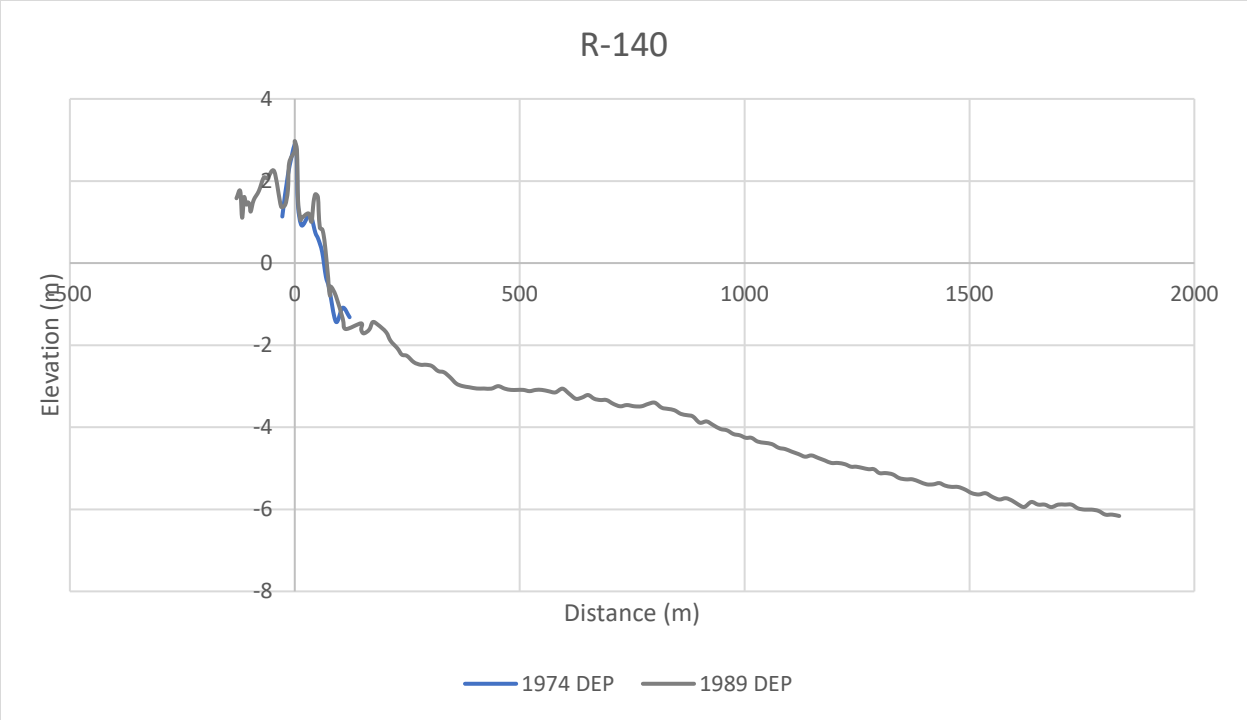


Figure A2.57. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-140.

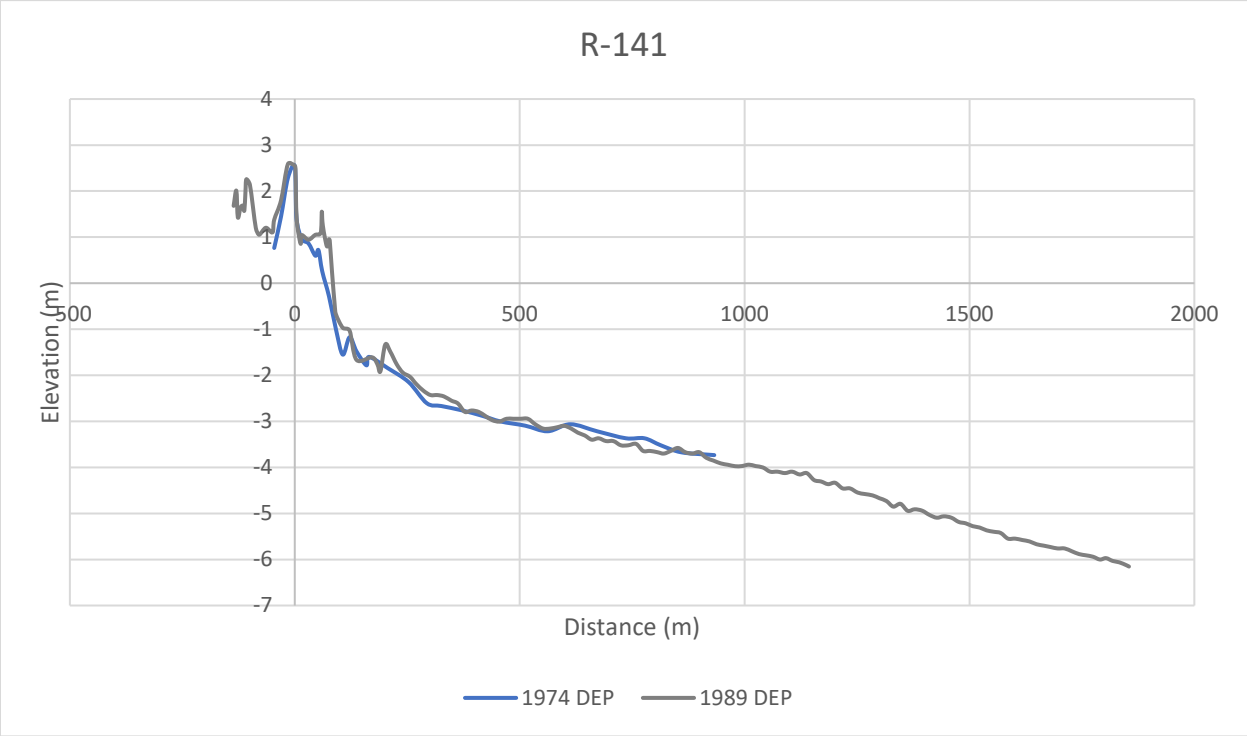


Figure A2.58. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-141.

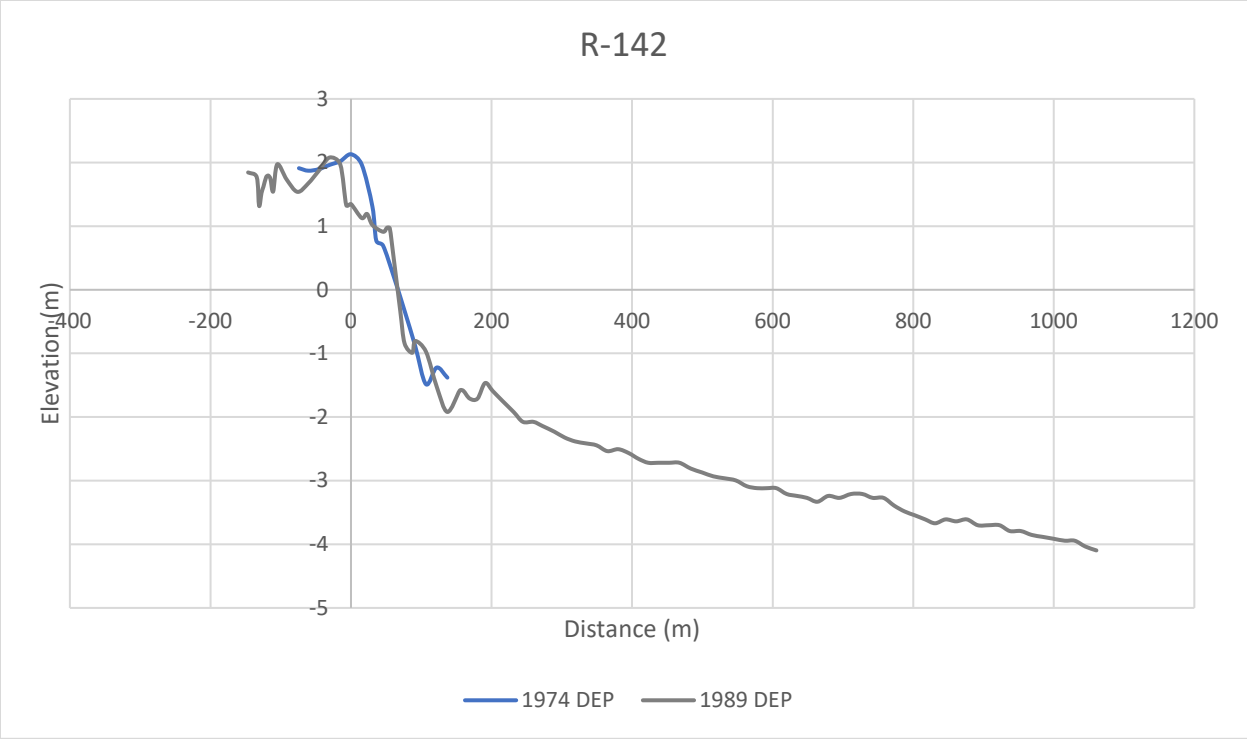


Figure A2.59. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-142.

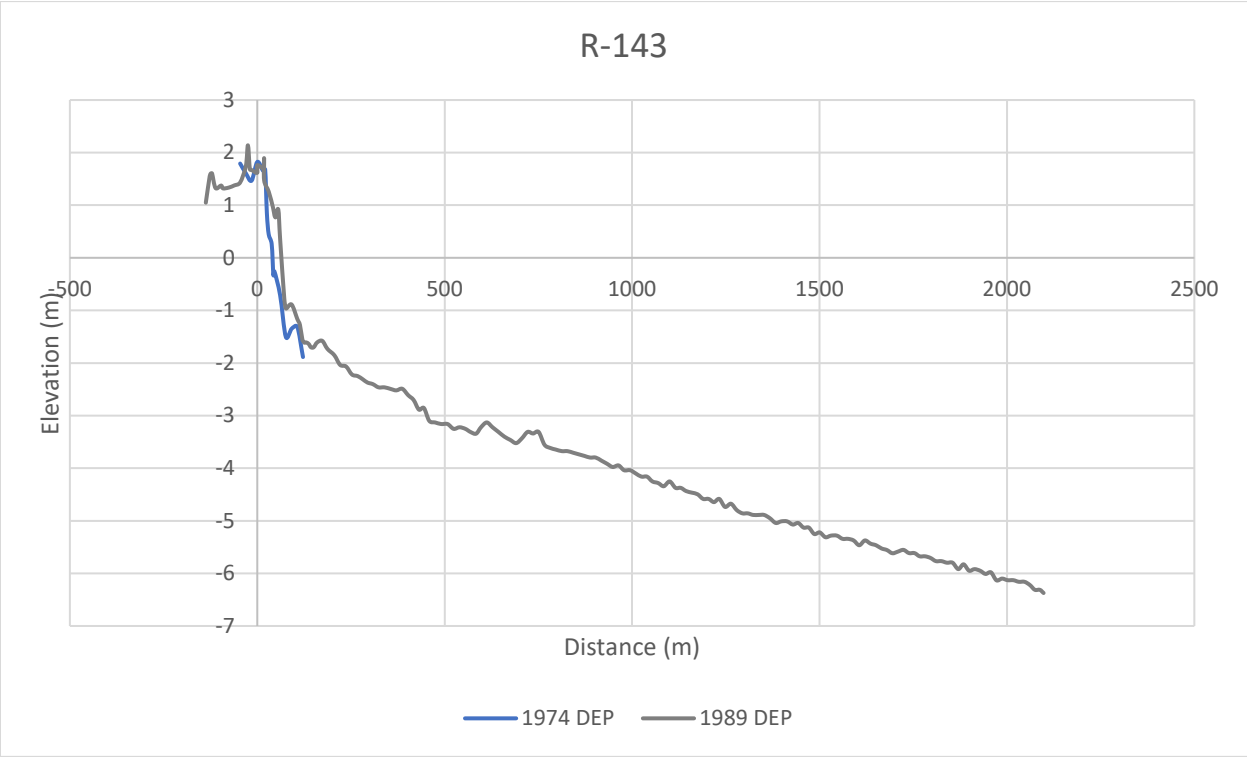


Figure A2.60. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-143.

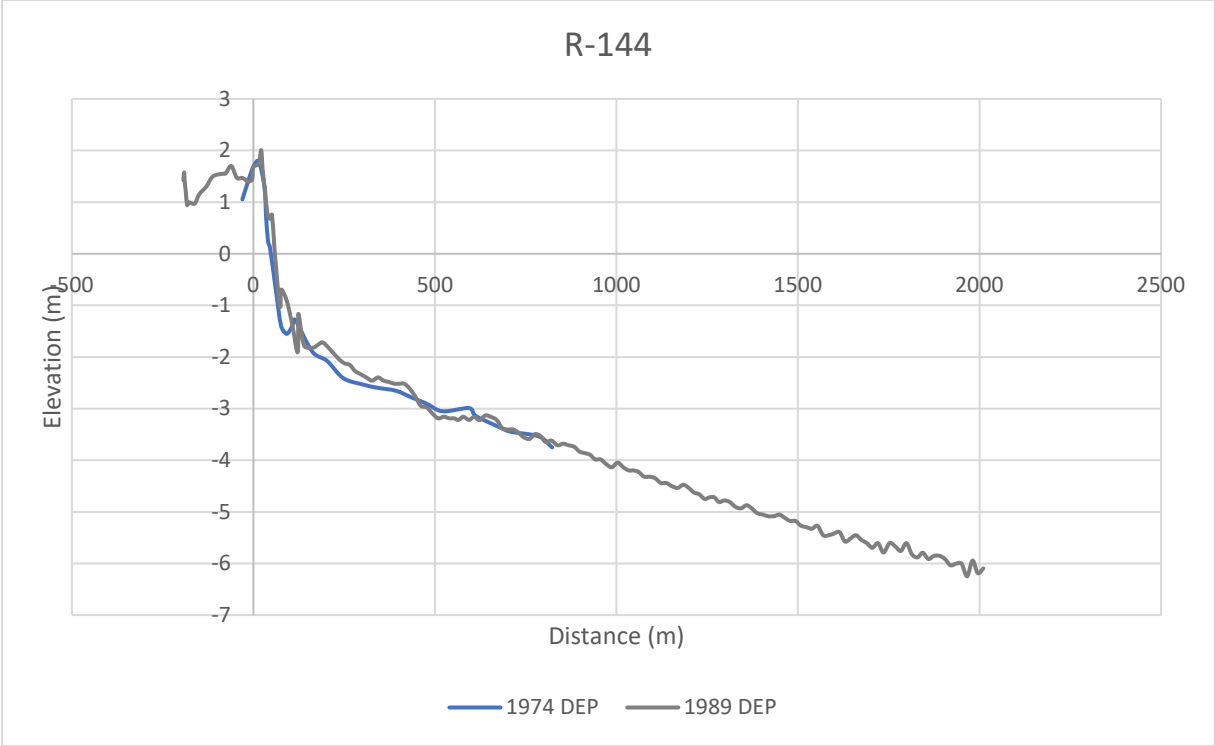


Figure A2.61. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-144.

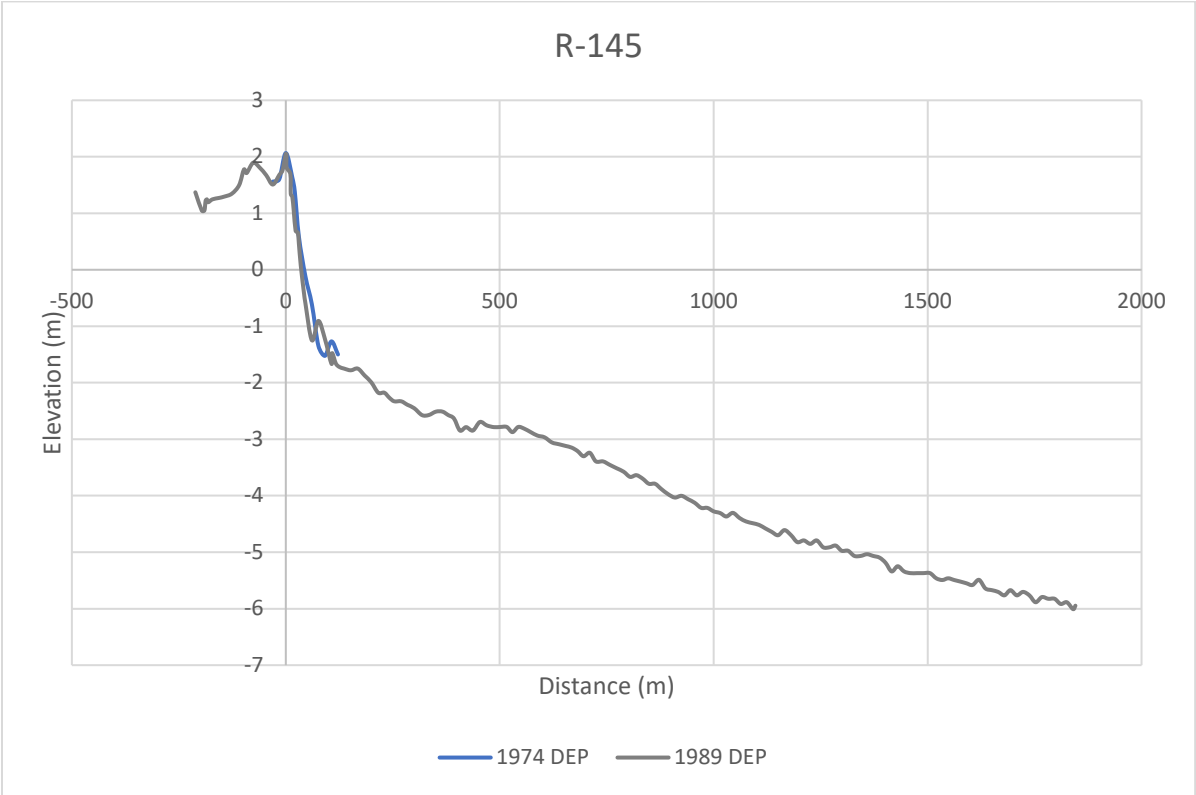


Figure A2.62. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-145.

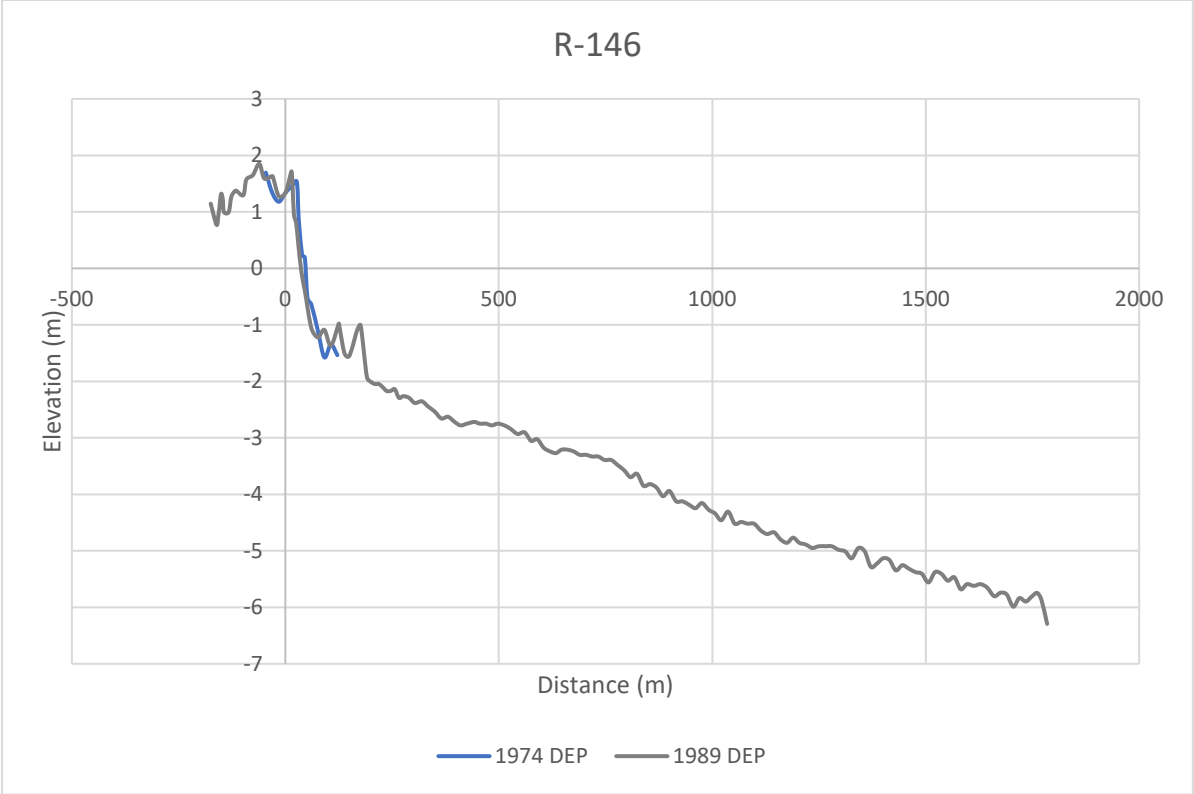
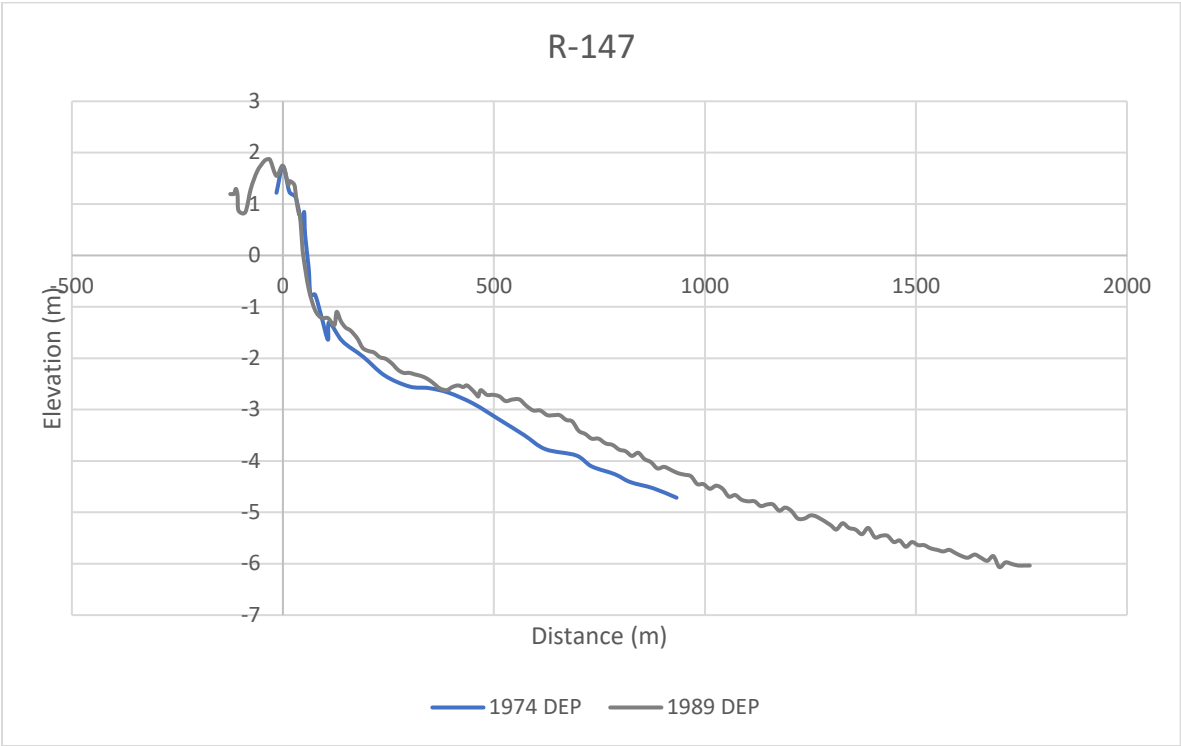


Figure A2.63. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-146.



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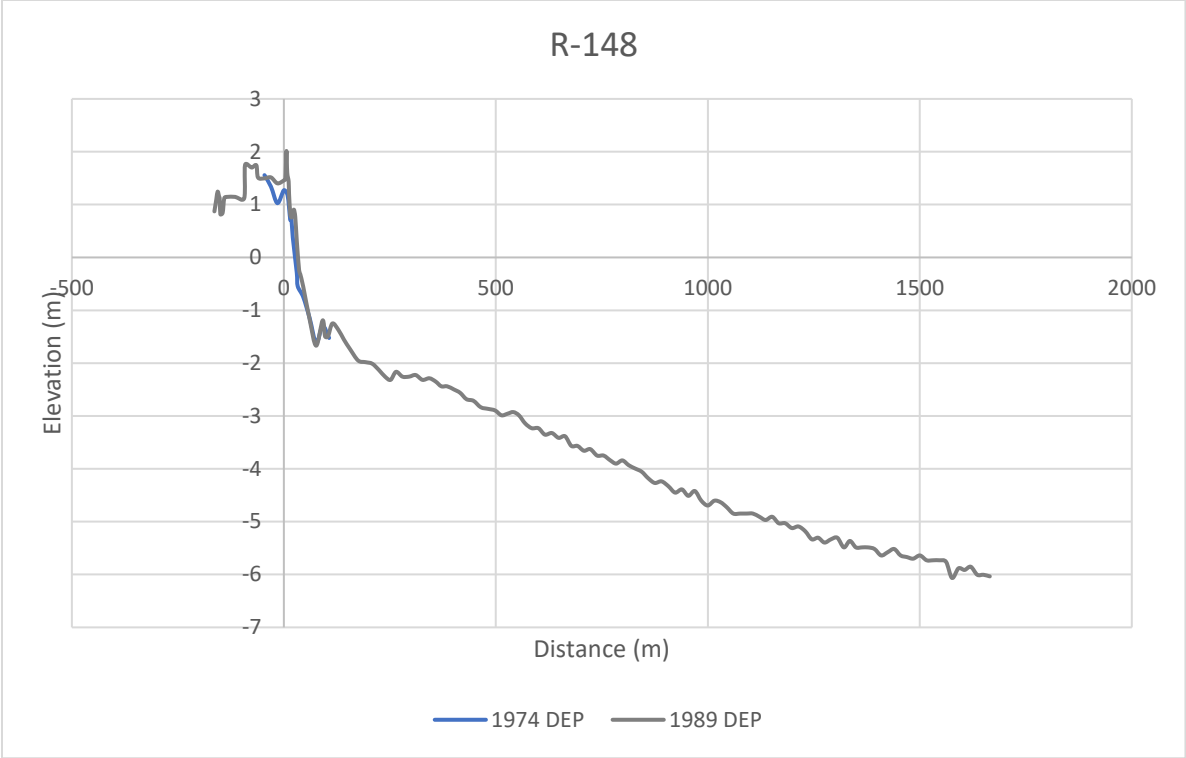

Figure A2.65. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-148.

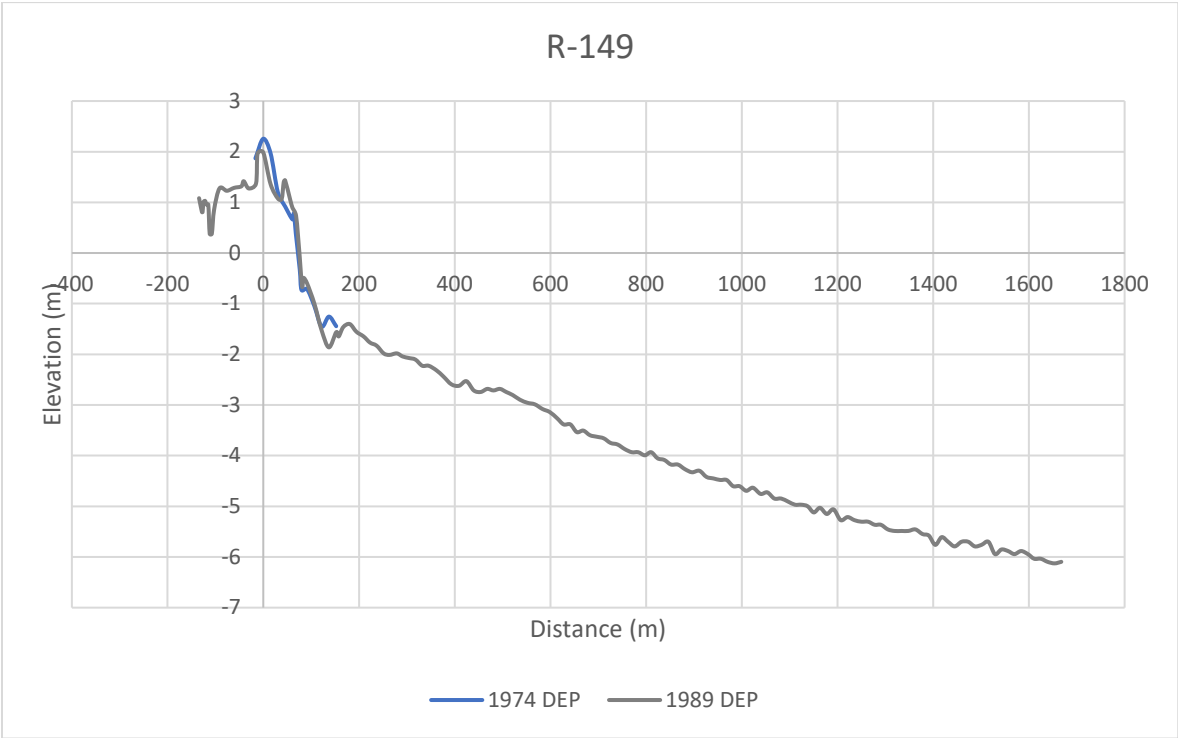

Figure A2.66. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-149.

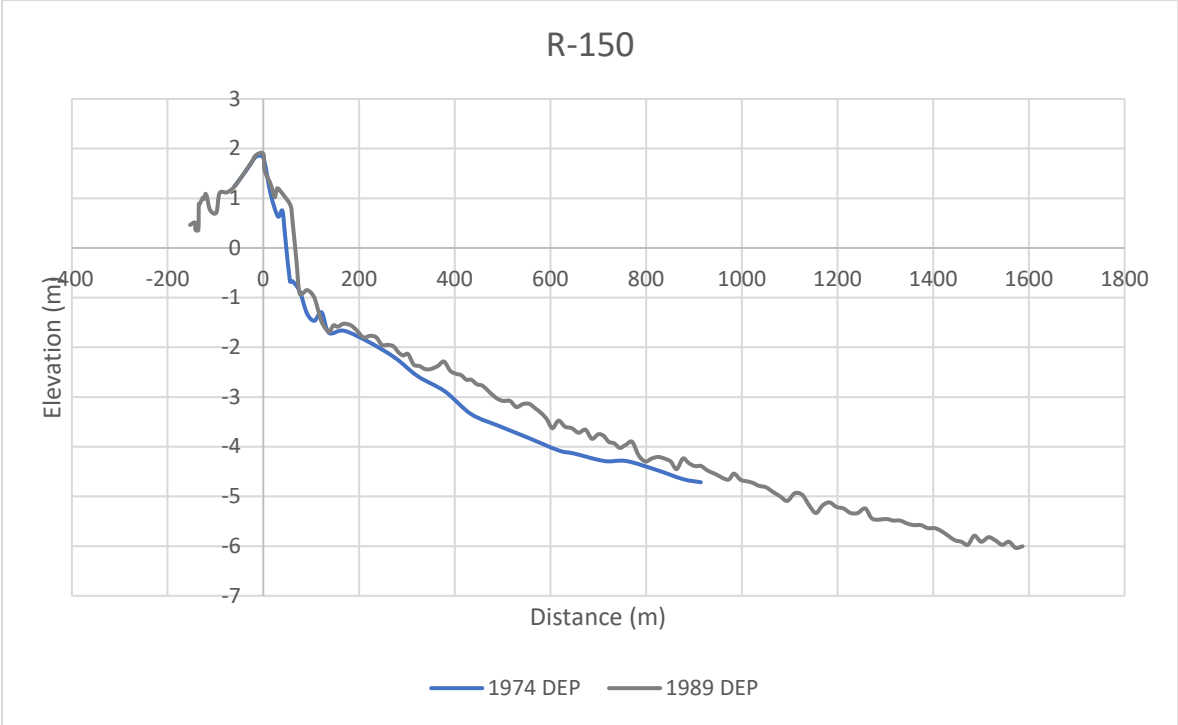

Figure A2.67. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-150.

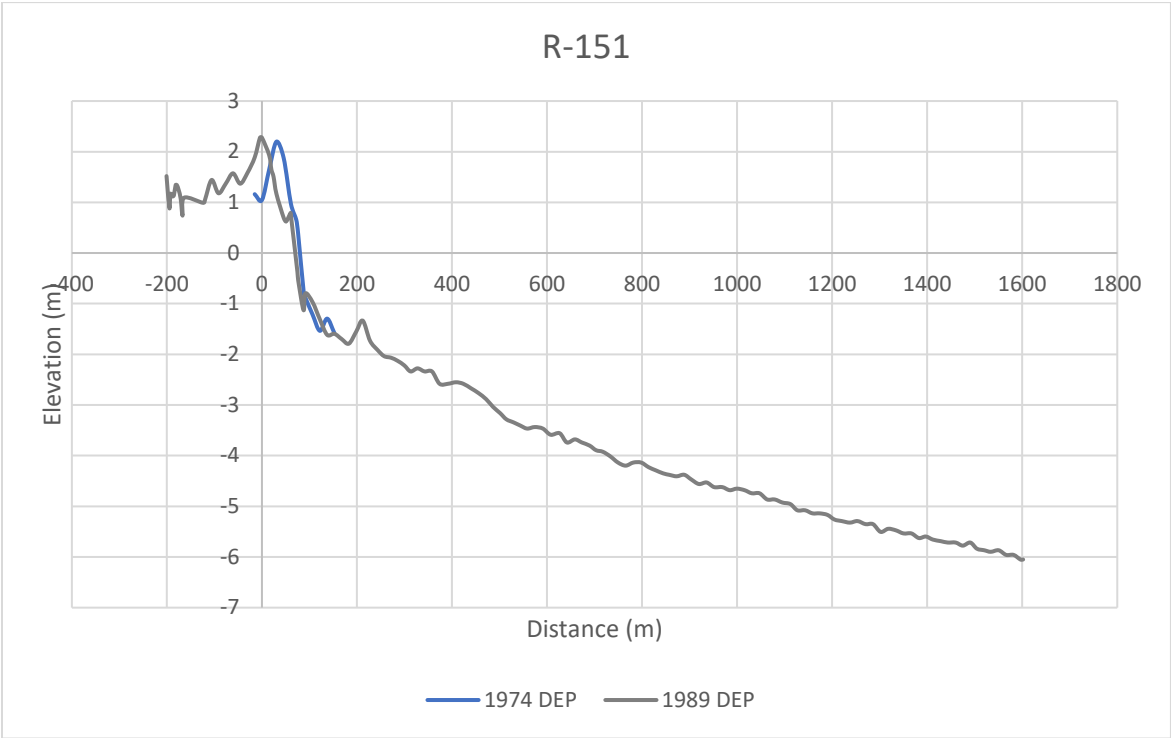

Figure A2.68. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-151.

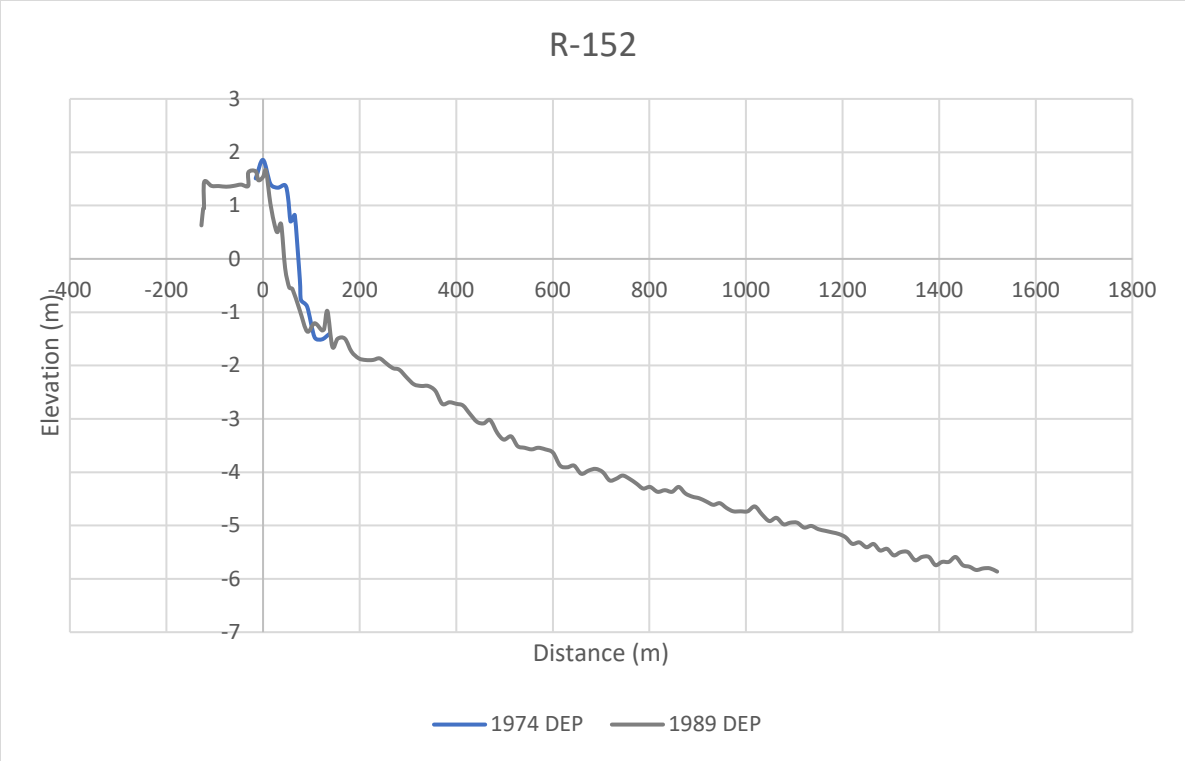

Figure A2.69. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-152.

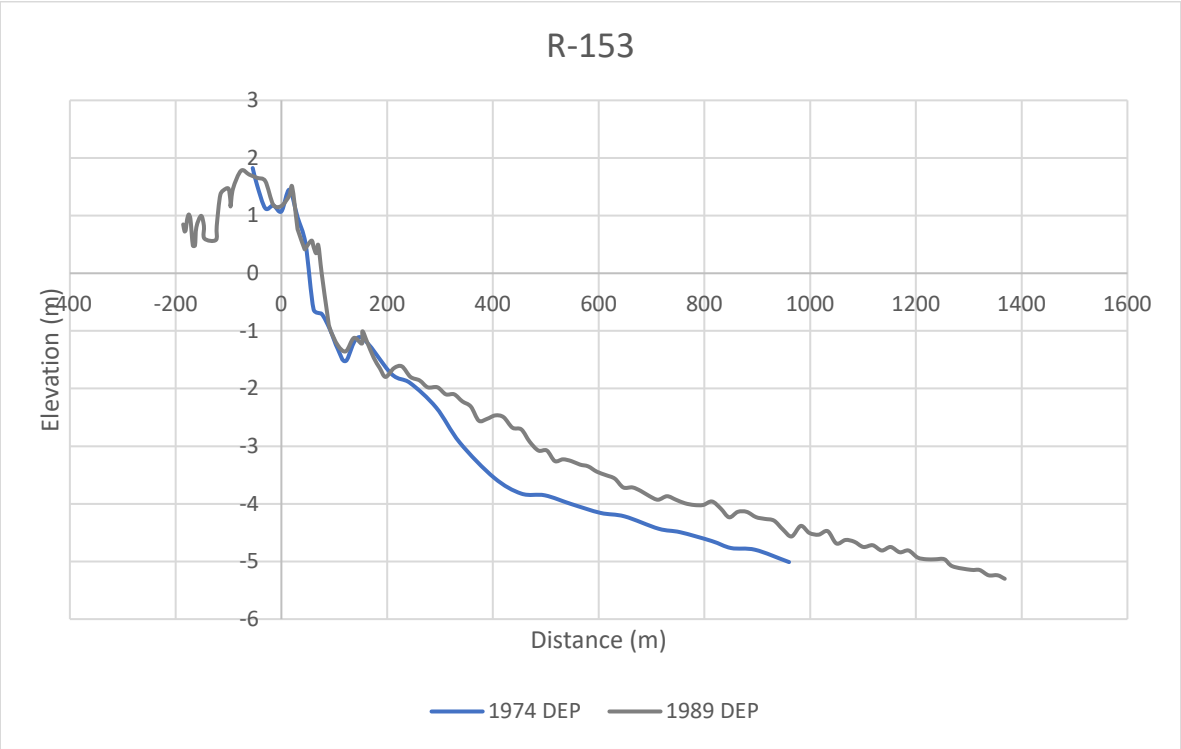

Figure A2.70. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-153.

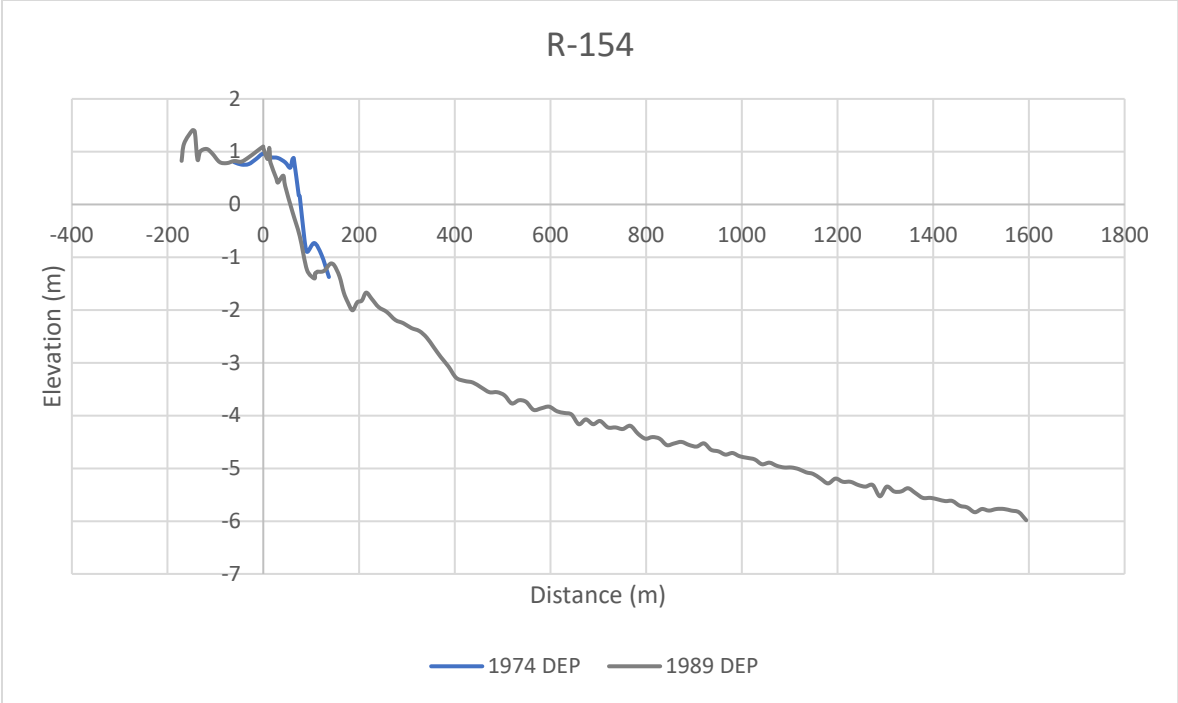

Figure A2.71. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-154.

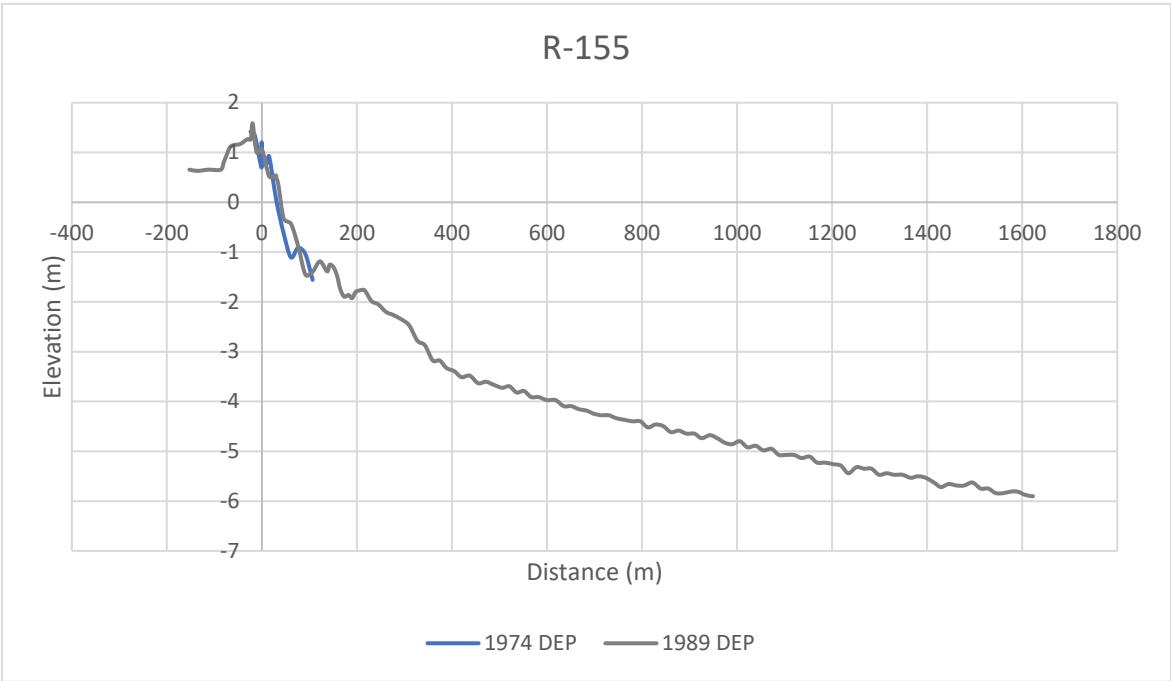

Figure A2.72. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-155.

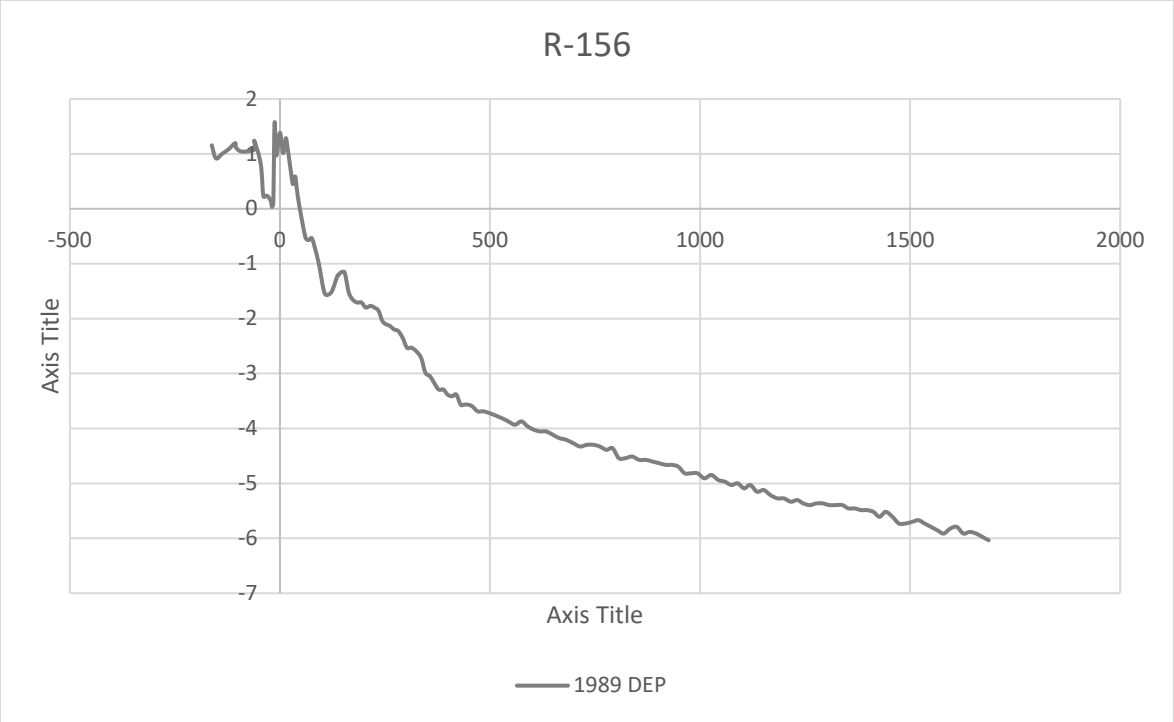

Figure A2.73. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-156.

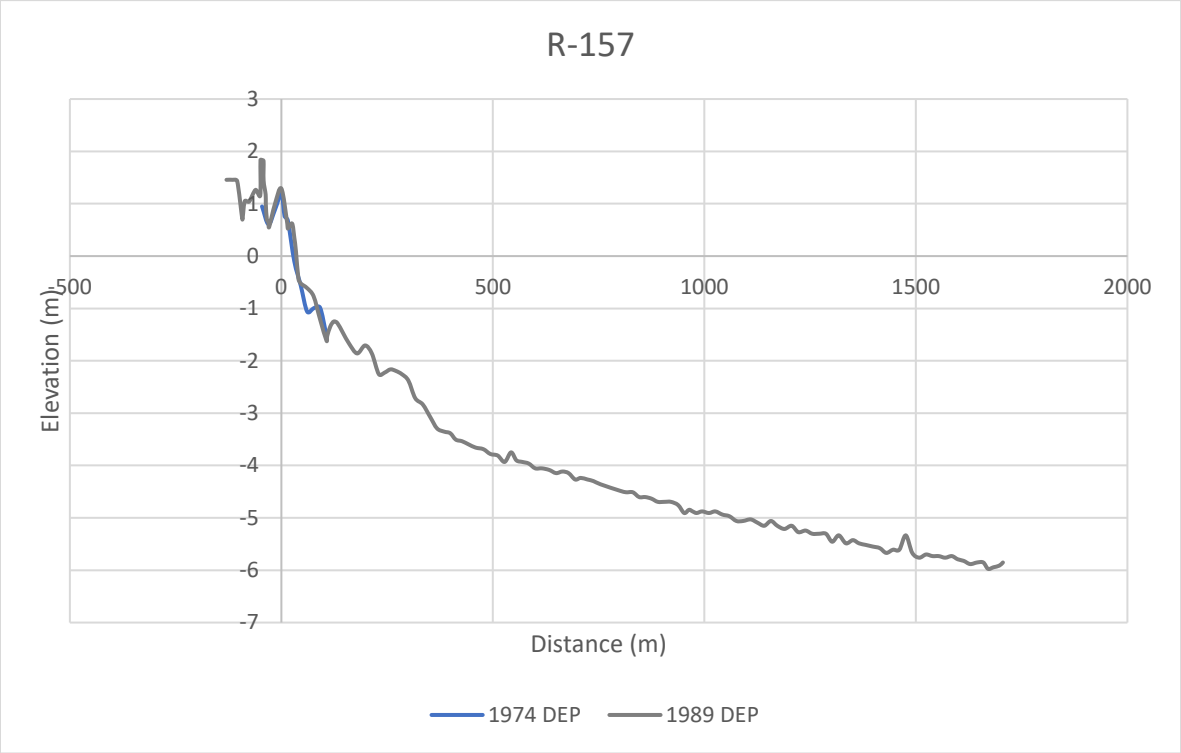

Figure A2.74. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-157.

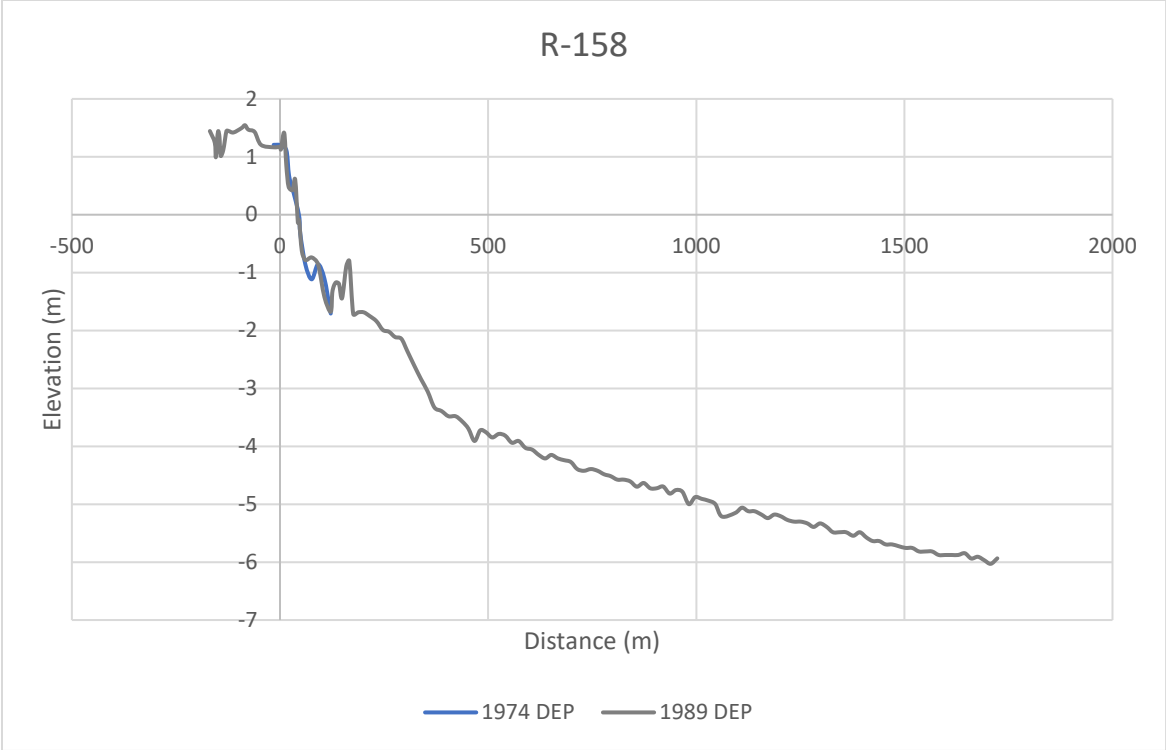

Figure A2.75. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-158.

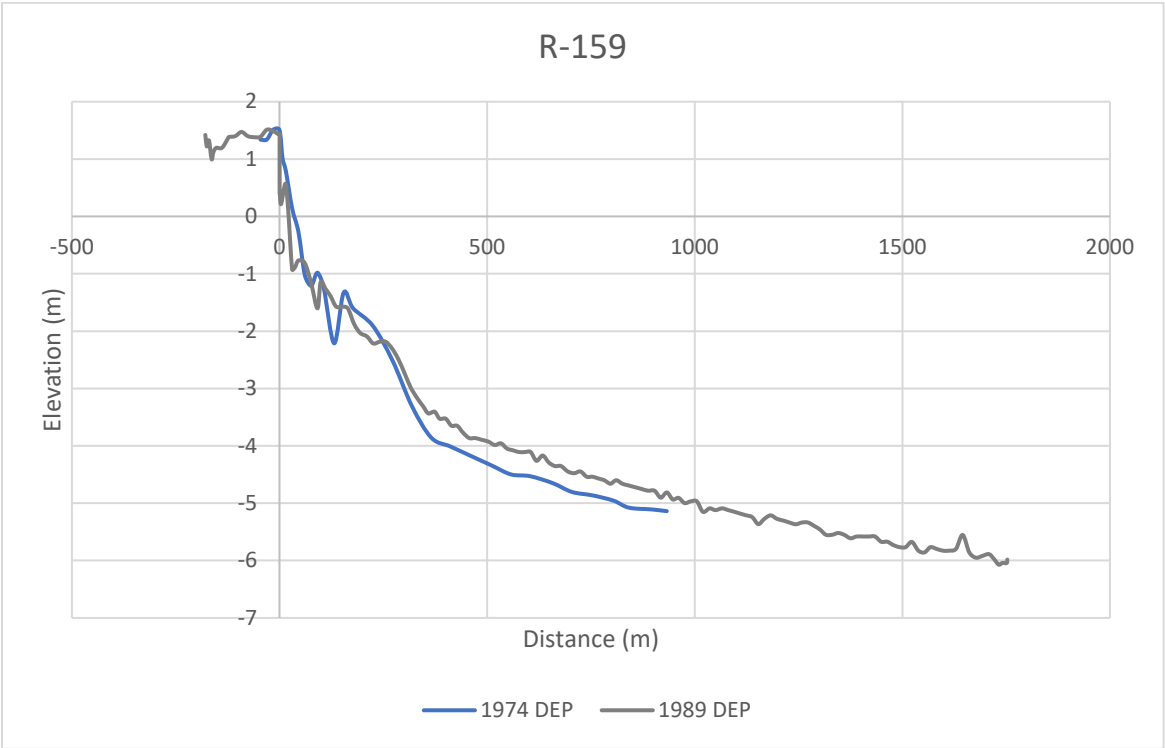

Figure A2.76. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-159.

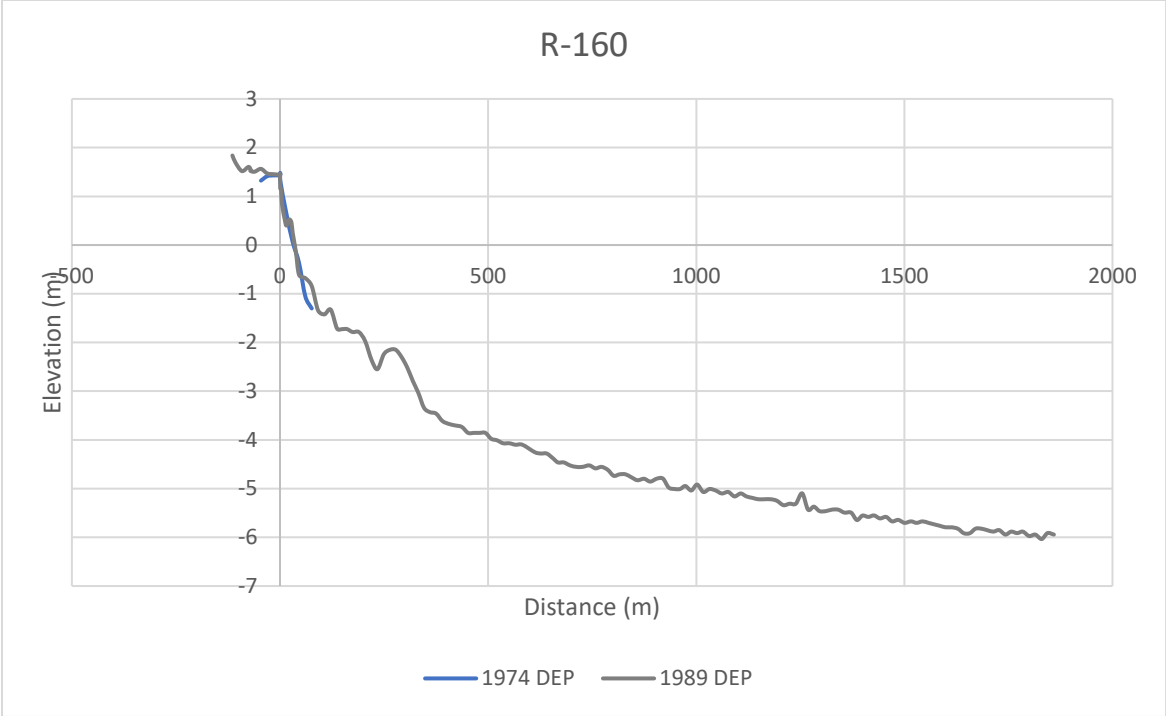

Figure A2.77. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-160.

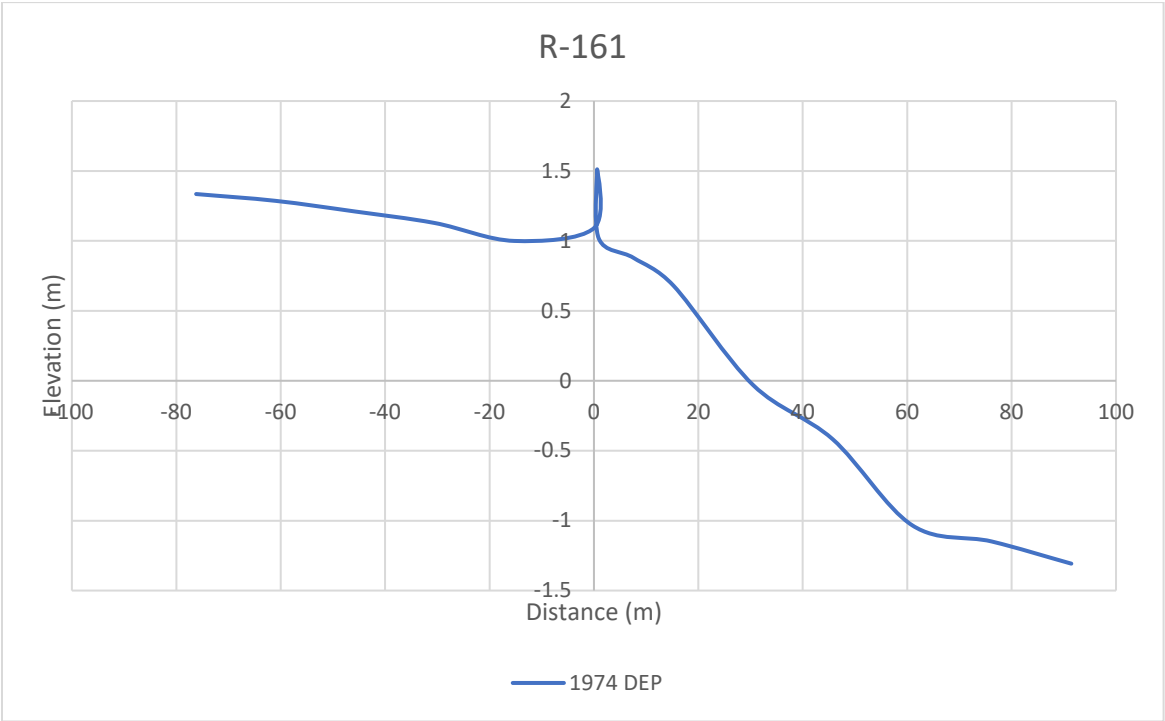

Figure A2.78. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-161.

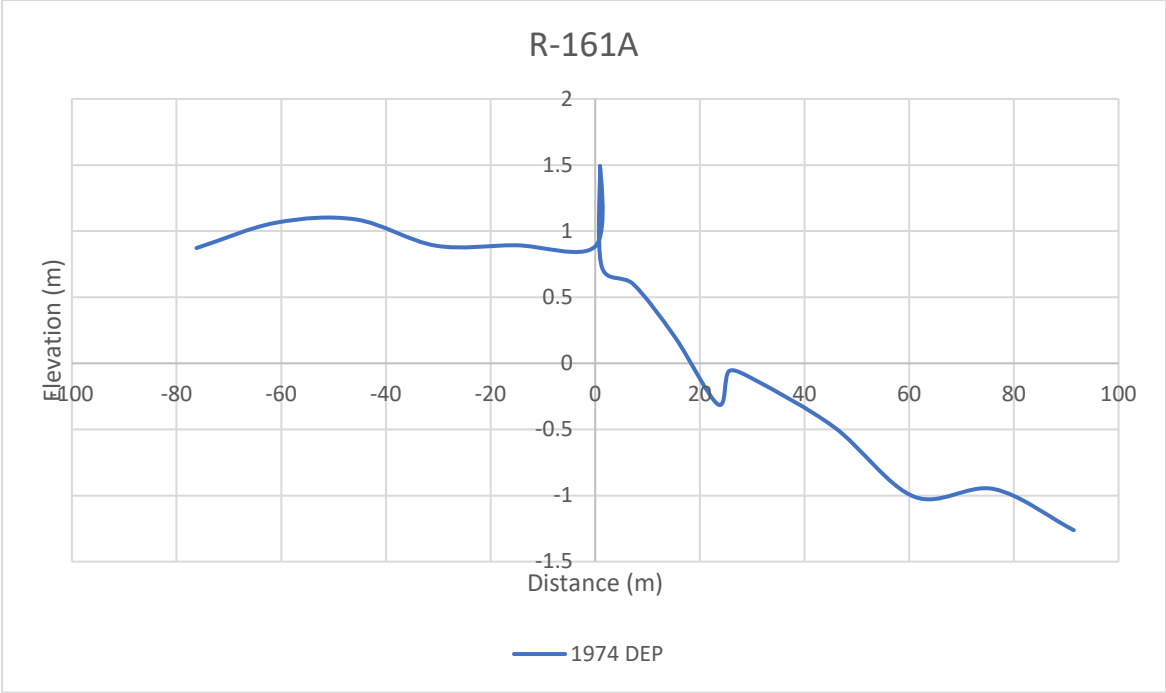

Figure A2.79. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-161A.

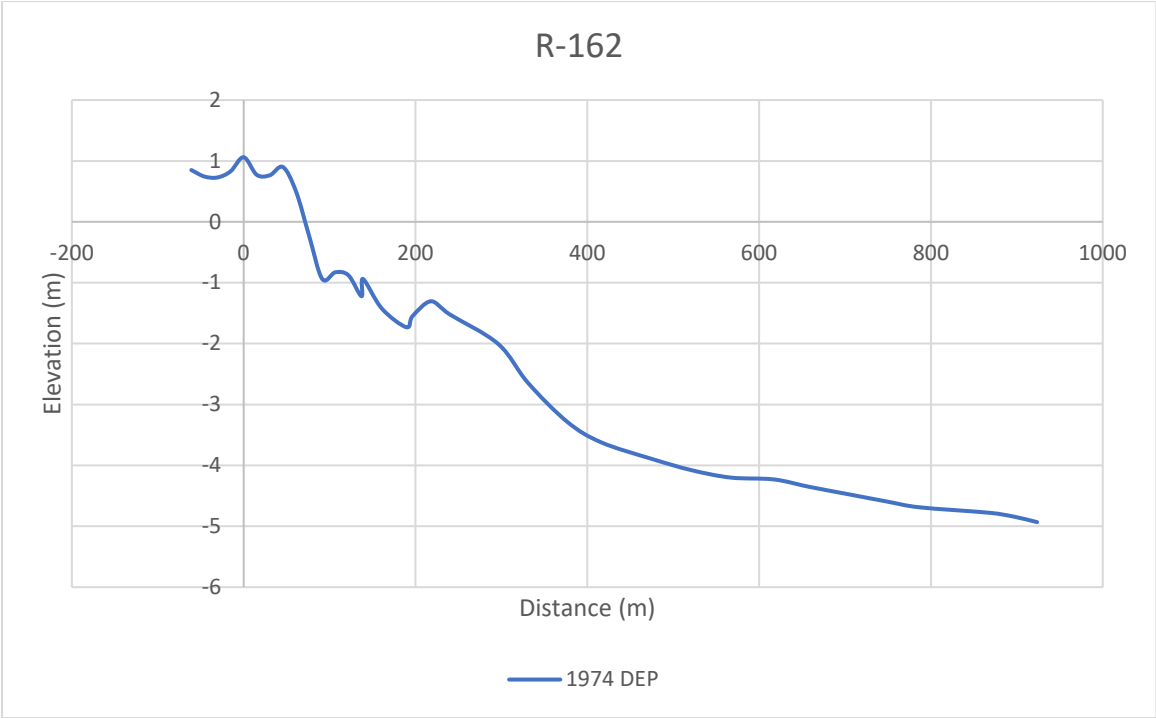

Figure A2.80. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-162.

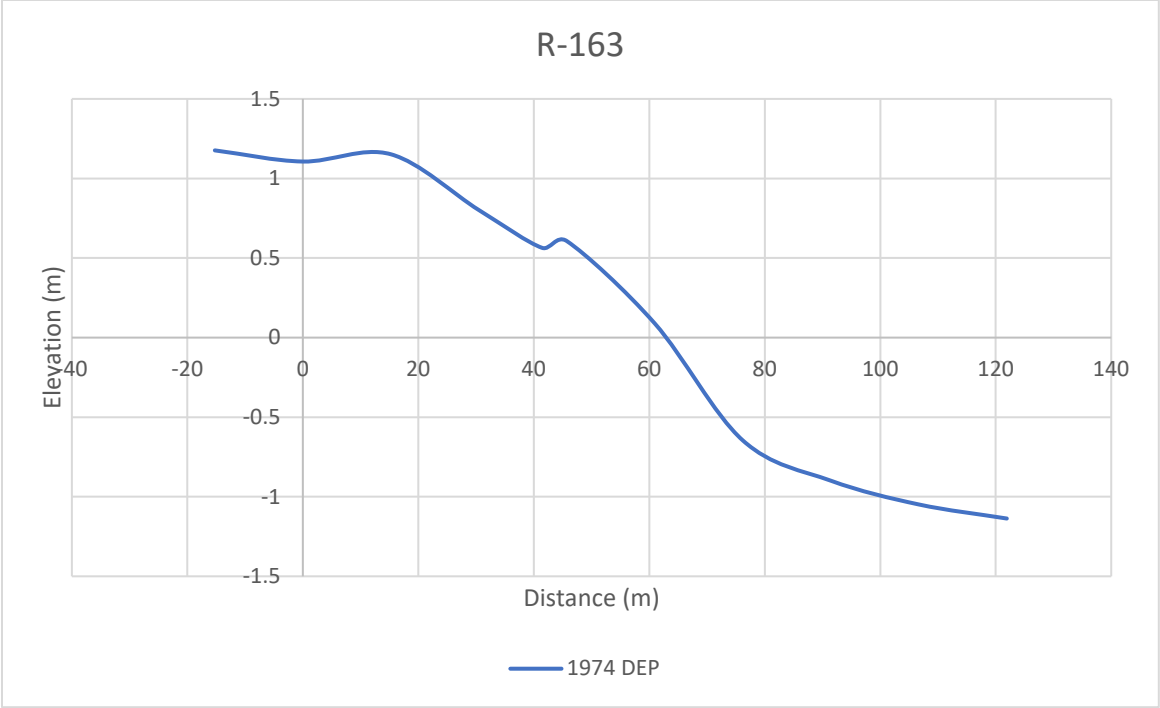

Figure A2.81. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-163.

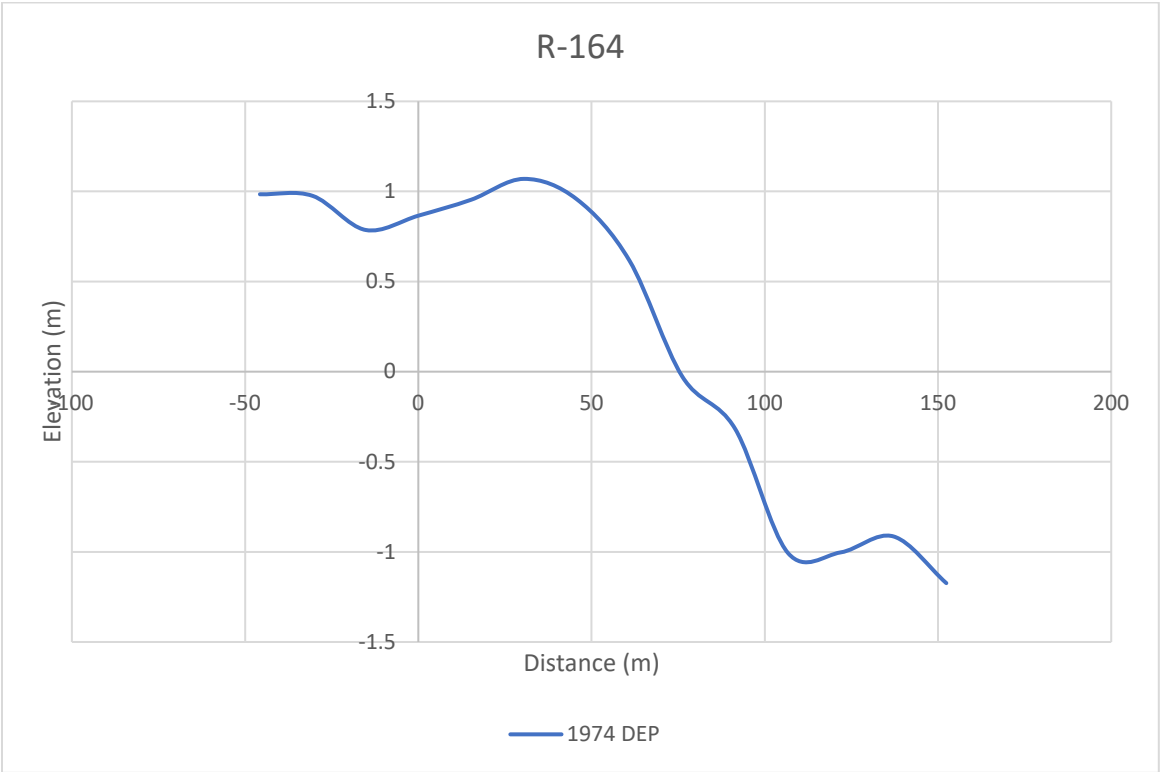

Figure A2.82. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-164.

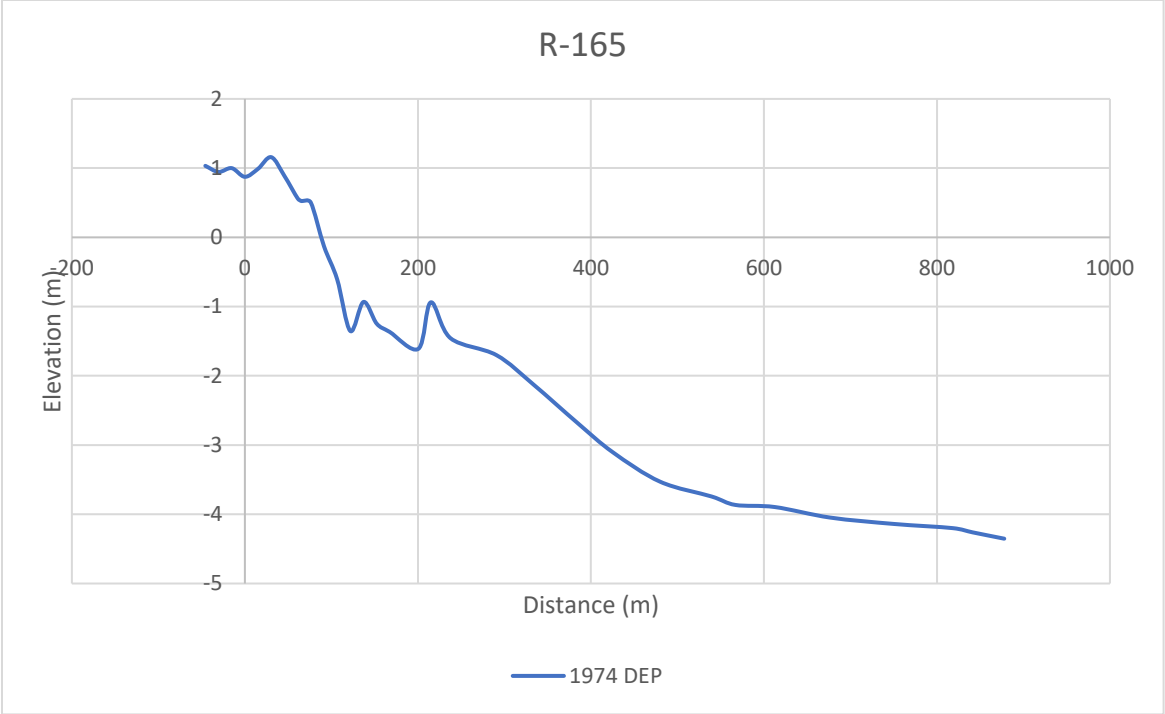

Figure A2.83. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-165.

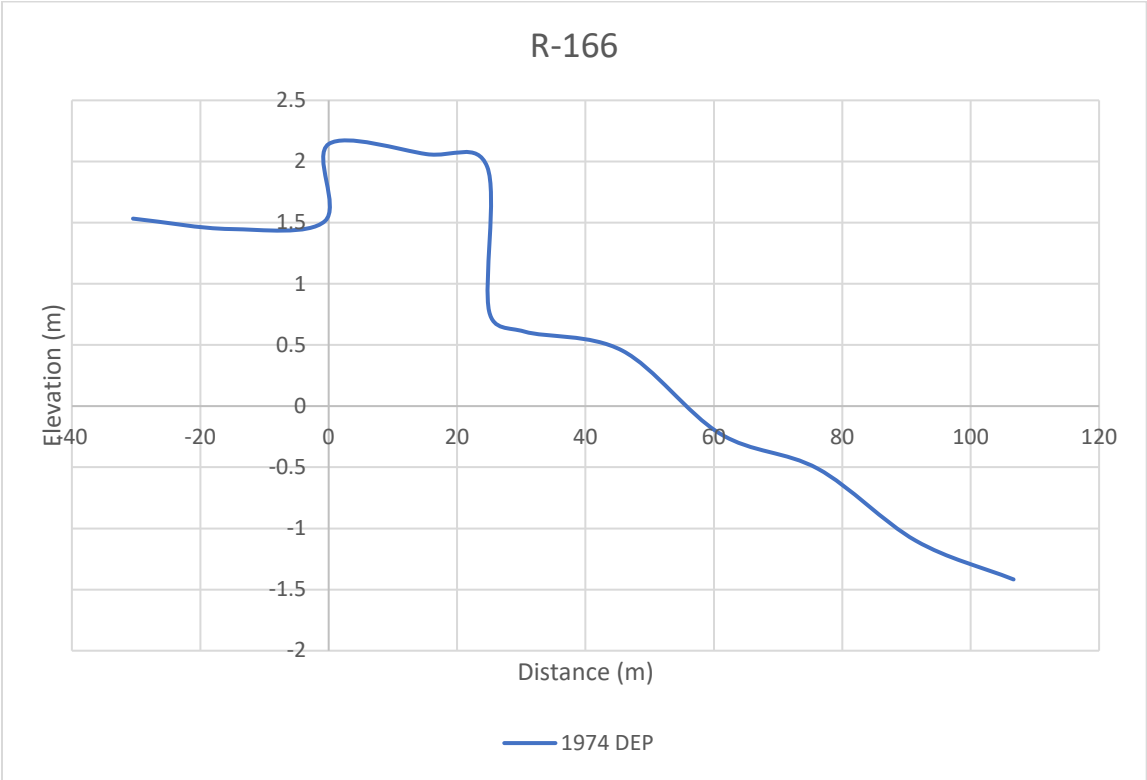

Figure A2.84. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-166.

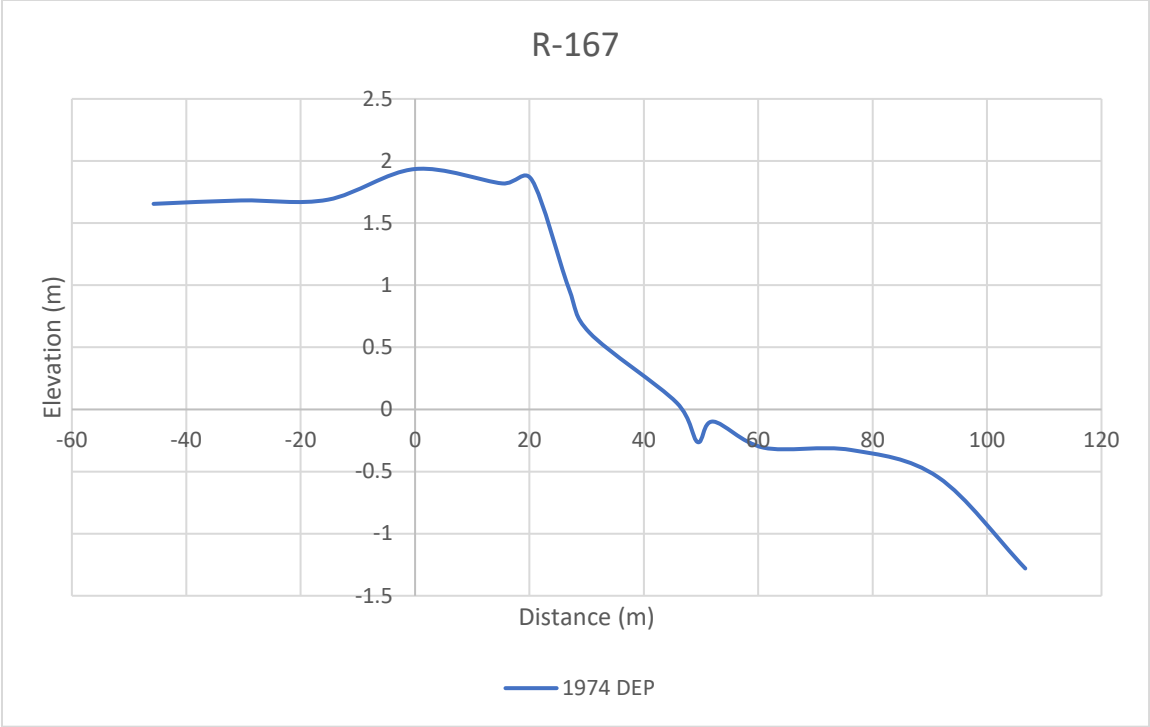

Figure A2.85. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-167.

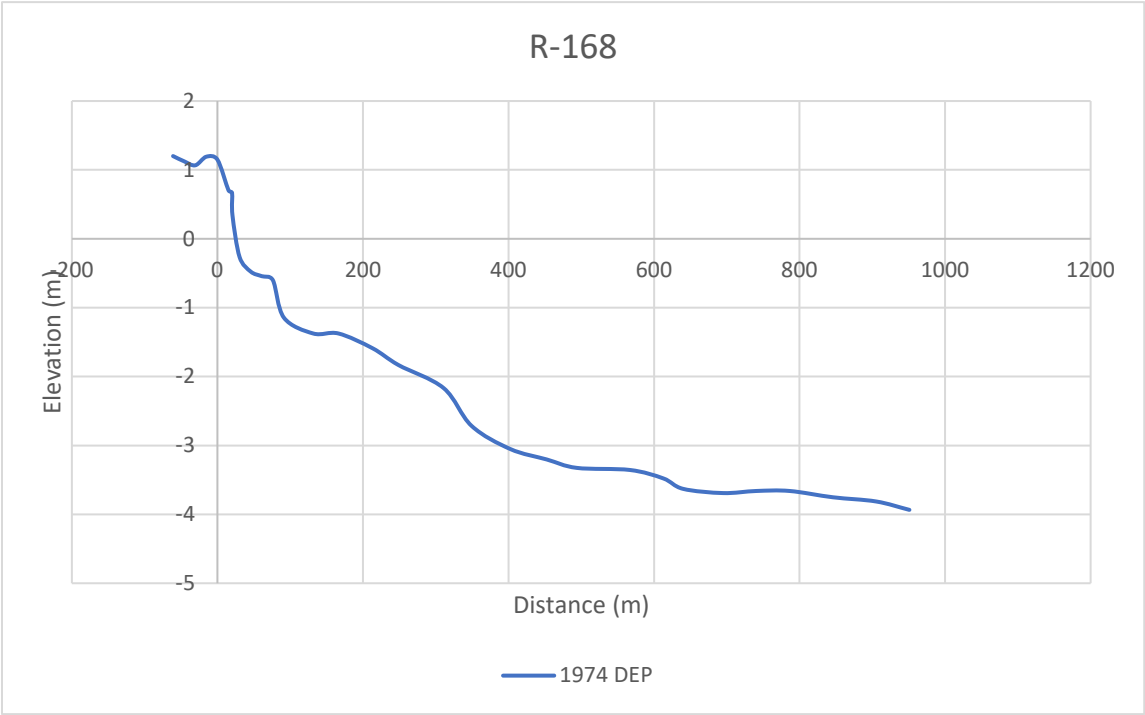

Figure A2.86. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-168.

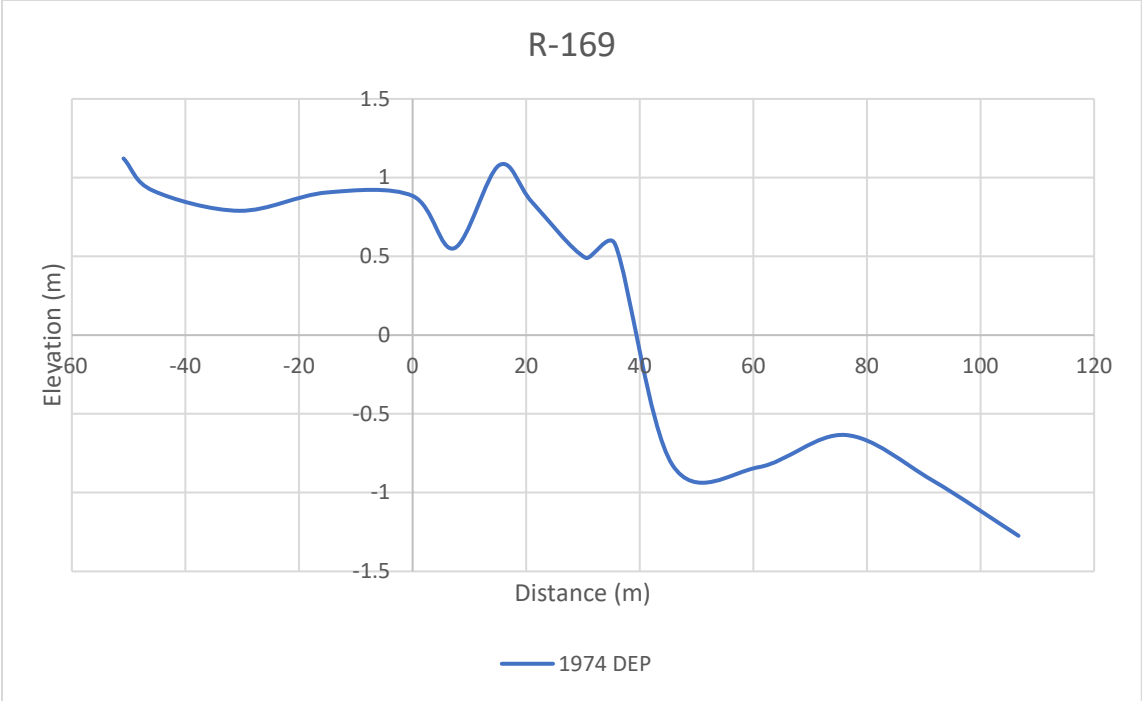

Figure A2.87. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-169.

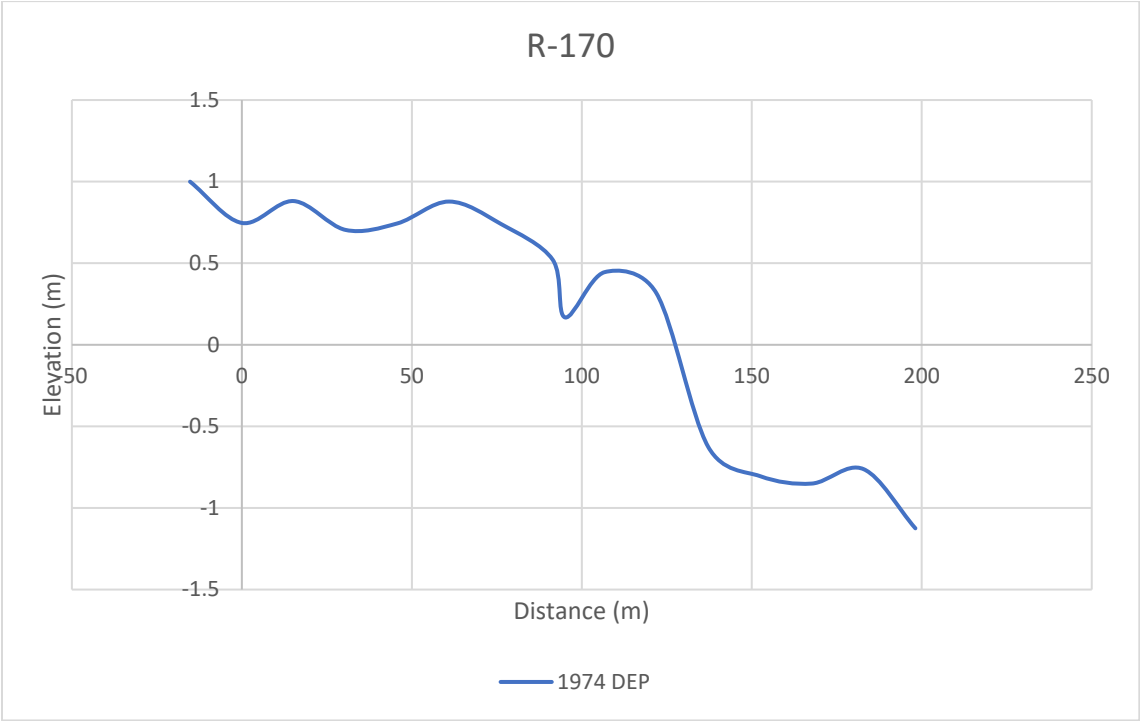

Figure A2.88. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-170.

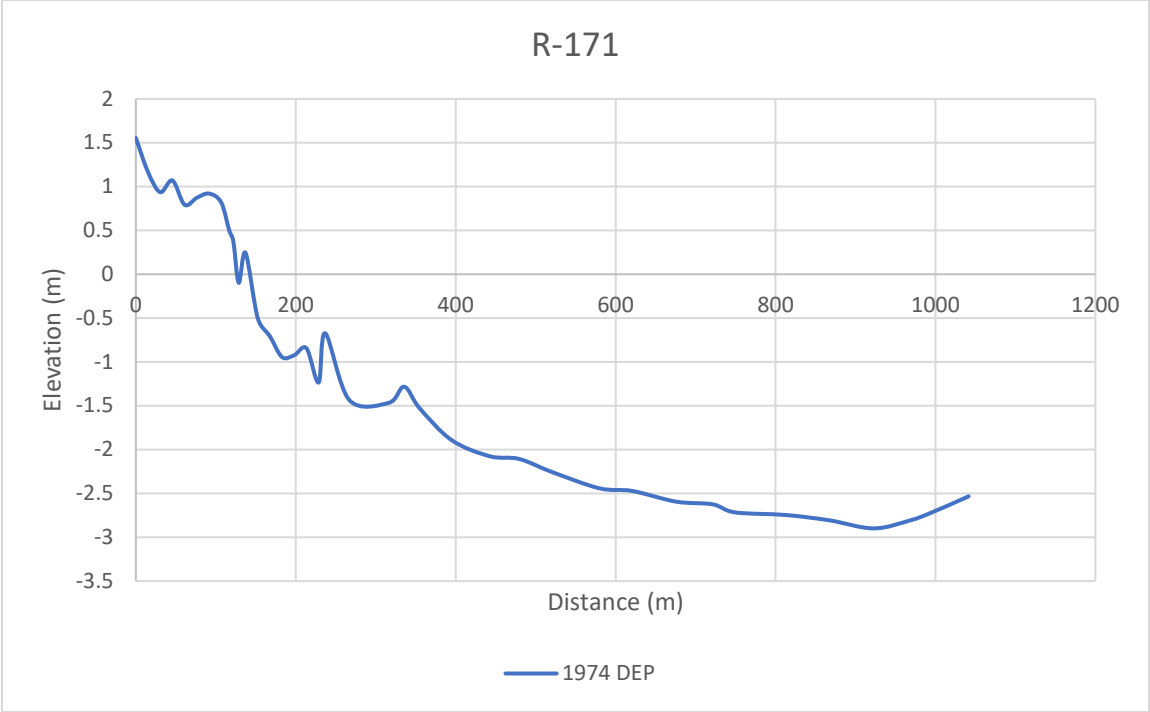

Figure A2.89. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-171.

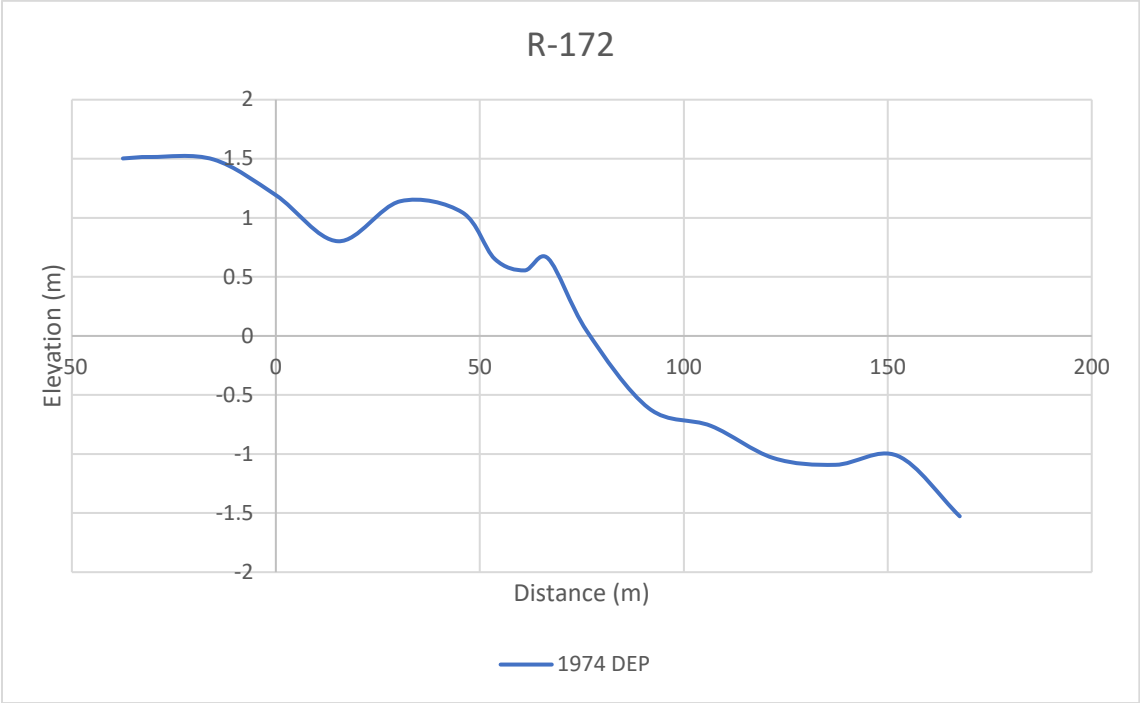

Figure A2.90. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-172.

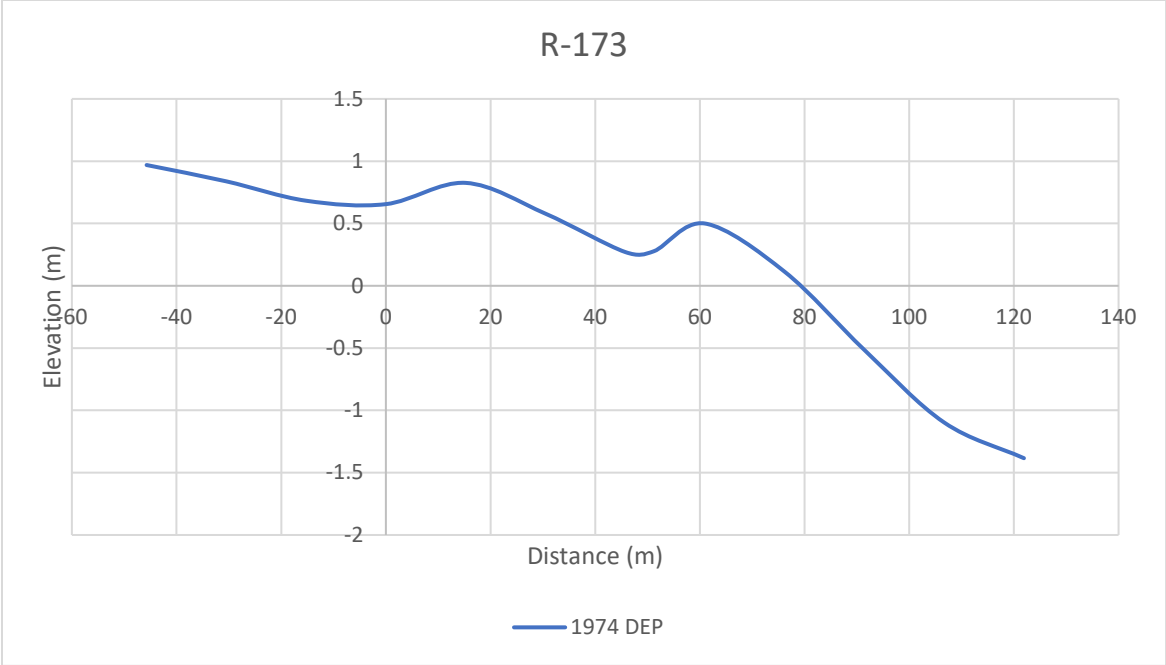

Figure A2.91. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-173.

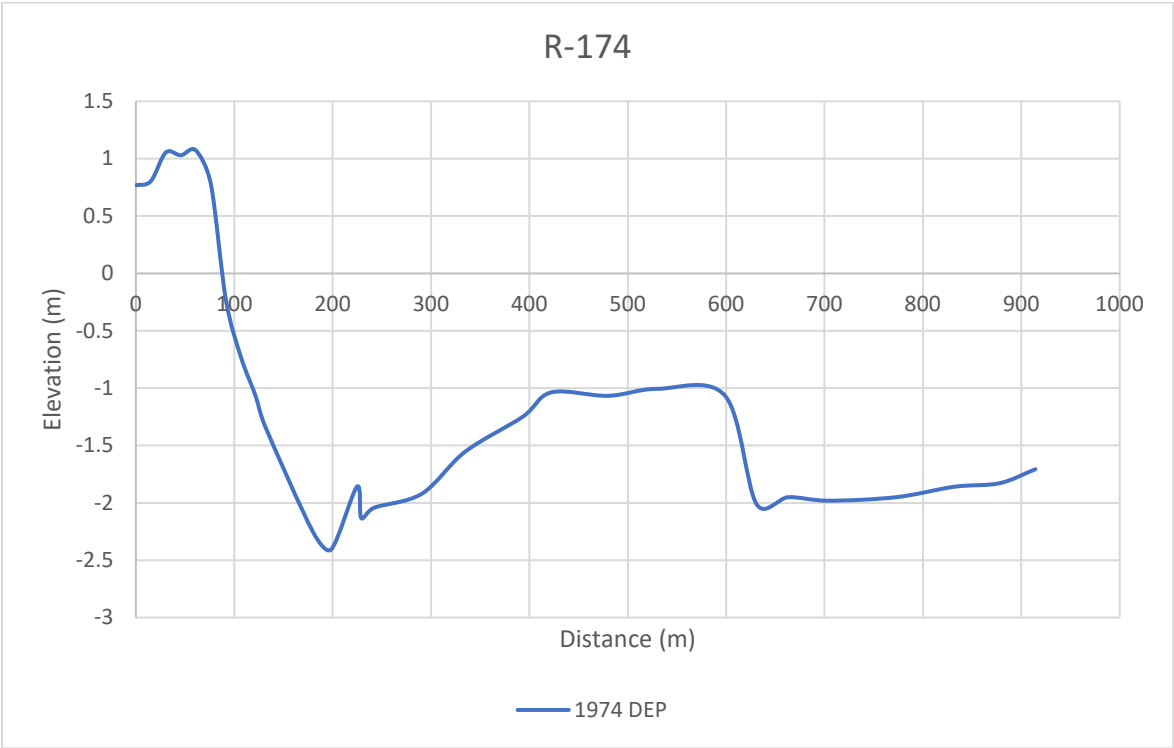

Figure A2.92. Beach profiles from pre-LiDAR surveys with respect to NAVD88 at R-174.

Appendix III

This collection of tables displays sediment budget data for each of the 10 sectors spanning the length of Captiva and Sanibel Islands. Sediment volume change, in meters cubed and in percent change, is shown for the following time intervals: (1) 2004 – 2005, (2) 2005 – 2006, (3) 2006 – 2010, and (4) 2010 – 2015. Values are shown for each pair of neighboring R monuments and then summed for each sector. Average, minimum, and maximum percent volume change are also shown for each sector. Regions of the beach experiencing appreciable erosion are color-coded red; moderate erosion pink; no significant change gray; moderate deposition light blue; and appreciable deposition blue. Negative values represent erosion, positive values deposition. Volume was calculated using the software package SANDS by interpolating the sediment surface between neighboring profiles and measuring the surface depth above the "master profile", an arbitrary depth which serves as a datum. A length of 40 m was used for budgeting for all sectors but 5 and 10. 200 m lengths were used for sectors 5 and 10 because of the extraordinary width of the strandplains here.

Changes Between Locations		Sector 1 - Volume Changes Above MP							
		2004 to 2005		2005 to 2006		2006 to 2010		2010 to 2015	
Location 1	Location 2	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change
R-084	R-085	-4356.7	-8.08	38147.07	76.99	-12593.99	-14.36	-2446.93	-3.26
R-085	R-086	44.95	0.13	21204.72	59.58	-7799.8	-13.73	-724.65	-1.48
R-086	R-087	-623.11	-1.11	15639	28.17	-1663.78	-2.34	-386.8	-0.56
R-087	R-088	-113.39	-0.2	8790.89	15.79	2074.47	3.22	-784.89	-1.18
R-088	R-089	872.13	1.49	10367.7	17.4	710.69	1.02	-1272.48	-1.8
R-089	R-090	1072.03	2.15	11360.66	22.27	302.7	0.49	-940.88	-1.5
R-090	R-091	1820.23	3.26	12621.61	21.9	-169.58	-0.24	122.7	0.18
R-091	R-092	792.7	1.27	15371.93	24.31	-490.97	-0.62	1630.12	2.09
R-092	R-093	322.89	0.59	11252.56	20.38	696.08	1.05	39.64	0.06
		-168.27	Av=-0.06%	144756.14	Av=31.87%	-18934.18	Av=-2.83%	-4764.17	Av=-0.83%
			Min=-8.08%		Min=15.79%		Min=-14.36%		Min=-3.26%
			Max=3.26%		Max=76.99%		Max=3.22%		Max=2.09%

Table A3.1. Sediment budget data for Sector 1. Profile lengths of 40 m were used to calculate volumetric change.

Changes Between Locations		Sector 2 - Volume Changes Above MP							
		2004 to 2005		2005 to 2006		2006 to 2010		2010 to 2015	
Location 1	Location 2	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change
R-093	R-094	198.79	0.17	20420.52	17.76	-476.5	-0.35	2598.04	1.93
R-094	R-095	-368.44	-0.56	13348.77	20.25	-481.7	-0.61	3249.83	4.13
R-095	R-096	259.55	0.34	15122.07	19.76	-1559.13	-1.7	1954.4	2.17
R-096	R-097	80.6	0.12	14999.75	22.28	-3800.92	-4.62	1835.7	2.34
R-097	R-098	730.82	0.91	13354.26	16.5	-1753.89	-1.86	429.58	0.46
R-098	R-099	1193.96	1.54	7112.6	9.05	1172.63	1.37	-561.39	-0.65
R-099	R-100	953.25	1.15	6385.71	7.59	2049.42	2.26	269.11	0.29
R-100	R-101	1070.11	1.37	6770.86	8.53	3077.95	3.57	-582.55	-0.65
R-101	R-102	1385.63	1.48	8390.42	8.82	2273.59	2.2	-1732.55	-1.64
		5504.27	Av=0.72%	105904.96	Av=14.50%	501.45	Av=0.03%	7460.17	Av=0.93%
			Min=-0.56%		Min=7.59%		Min=-4.62%		Min=-1.64%
			Max=1.54%		Max=22.28%		Max=3.57%		Max=4.13%

Table A3.2. Sediment budget data for Sector 2. Profile lengths of 40 m were used to calculate volumetric change.

Changes Between Locations		Sector 3 - Volume Changes Above MP							
		2004 to 2005		2005 to 2006		2006 to 2010		2010 to 2015	
Location 1	Location 2	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change
R-102	R-103	1772.4	2.48	4701.31	6.43	1121.75	1.44	-1227.62	-1.55
R-103	R-104	2802.39	3.19	4878.68	5.39	1669.38	1.75	-1647.01	-1.7
R-104	R-105	3673.69	3.91	6665.15	6.82	1951.37	1.87	-2463.11	-2.32
R-105	R-106	2733.94	3.96	15256.75	21.24	1640.05	1.88	-636.64	-0.72
R-106	R-107	-1790.76	-2.55	22998.73	33.63	2462.21	2.69	566.74	0.6
R-107	R-108	-2029.6	-2.01	18927.16	19.18	4301.8	3.66	-1504.2	-1.23
R-108	R-109	1011.95	1.41	8294.71	11.39	-1549.83	-1.91	-3295.58	-4.14
R-109	R-110	434.94	1.19	2638.2	7.14	-2899.65	-7.33	-6039.92	-16.47
R-110	R-111	144.06	0.17	5479.15	6.64	-3491.51	-3.97	-19751.94	-23.39
		8753.01	Av=1.31%	89839.84	Av=13.10%	5205.57	Av=0.01%	-35999.28	Av=-5.66%
			Min=-2.55%		Min=5.39%		Min=-7.33%		Min=-23.39%
			Max=3.96%		Max=33.63%		Max=3.66%		Max=0.60%

Table A3.3. Sediment budget data for Sector 3. Profile lengths of 40 m were used to calculate volumetric change.

Changes Between Locations		Sector 4 - Volume Changes Above MP					
		2004 to 2005		2005 to 2010		2010 to 2015	
Location 1	Location 2	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change
R-111	R-112	17.52	0.03	4722.77	7.63	-9232.16	-13.86
R-112	R-113	2659.19	2.9	3466.06	3.67	-5427.75	-5.54
R-113	R-114	3514.13	5.94	3819.41	6.09	-8720.63	-13.11
R-114	R-115	17928.41	25.27	493.69	0.56	-15521.34	-17.37
R-115	R-116	19883.63	38.56	2998.37	4.2	1564.56	2.1
R-116	R-117	-1155.49	-2.22	19906.61	39.14	8407.93	11.88
R-117	R-118	-9160.01	-15.84	26599.55	54.65	8358.76	11.1
R-118	R-119	-1203.51	-1.96	12869.86	21.37	5083.33	6.95
R-119	R-120	1562.64	1.98	3756.77	4.66	-1476.39	-1.75
		34046.51	Av=6.07%	78633.09	Av=15.77%	-16963.69	Av=-2.18%
			Min=-15.84%		Min=0.56%		Min=-17.37%
			Max=38.56%		Max=54.65%		Max=11.88%

Table A3.4. Sediment budget data for Sector 4. Profile lengths of 40 m were used to calculate volumetric change.

Changes Between Locations		Sector 5 - Volume Changes Above MP					
		2004 to 2005		2005 to 2010		2010 to 2015	
Location 1	Location 2	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change
R-120	R-121	-1868.36	-0.66	28070.19	10.03	-9714.04	-3.15
R-121	R-122	-4025.39	-1.47	16016.6	5.95	4940.24	1.73
R-122	R-123	-5266.74	-1.59	11361.36	3.48	7123.8	2.11
R-123	R-124	-3367.66	-1.1	12864.71	4.24	14053.42	4.44
R-124	R-125	-5083.54	-1.39	33985.58	9.42	21058.1	5.34
R-125	R-126	-4805.16	-1.69	40292.02	14.44	13791.49	4.32
R-126	R-127	-4249.98	-1.26	65422.17	19.69	18034.74	4.54
R-127	R-128	-6452.99	-1.94	87369.87	26.72	3087.83	0.75
R-128	R-129	-10459.95	-4.76	67728.81	32.33	-14309.48	-5.16
		-45579.77	Av=-1.76%	363111.31	Av=14.03%	58066.1	Av=1.66%
			Min=-4.76%		Min=3.48%		Min=-5.16%
			Max=-0.66%		Max=32.33%		Max=5.34%

Table A3.5. Sediment budget data for Sector 5. Profile lengths of 200 m were used to calculate volumetric change.

Changes Between Locations		Sector 6 - Volume Changes Above MP					
		2004 to 2005		2005 to 2010		2010 to 2015	
Location 1	Location 2	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change
R-129	R-130	1099.43	1.49	15828.93	21.21	-937.05	-1.04
R-130	R-131	2164.54	3.83	10557.86	17.97	1188.9	1.72
R-131	R-132	592.46	0.92	1422.15	2.18	7068.41	10.6
R-132	R-133	-388.79	-0.63	1373.03	2.25	6561.49	10.52
R-133	R-134	646.95	0.98	5635.79	8.49	3577.85	4.97
R-134	R-135	2079.58	3.2	6956.94	10.37	1598.72	2.16
R-135	R-136	1886.02	2.99	9236.5	14.22	-888.65	-1.2
R-136	R-137	1576.53	1.95	9123.21	11.07	-1133.03	-1.24
R-137	R-138	194.75	0.31	4875.41	7.76	-472.95	-0.7
		9851.47	Av=1.67%	65009.82	Av=10.61%	16563.69	Av=2.87%
			Min=-0.63%		Min=2.18%		Min=-1.24%
			Max=3.83%		Max=21.21%		Max=10.60%

Table A3.6. Sediment budget data for Sector 6. Profile lengths of 40 m were used to calculate volumetric change.

Changes Between Locations		Sector 7 - Volume Changes Above MP					
		2004 to 2005		2005 to 2010		2010 to 2015	
Location 1	Location 2	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change
R-138	R-139	-1030.52	-1.28	9644.69	12.13	-259.8	-0.29
R-139	R-140	496.27	0.8	8109.36	12.92	382.52	0.54
R-140	R-141	1319.09	1.79	6468.55	8.61	-770.2	-0.94
R-141	R-142	-279.33	-0.35	5539.42	6.93	-3072.1	-3.59
R-142	R-144	-1664.07	-1.14	8722.99	6.06	-7397.25	-4.84
R-144	R-145	-426.6	-0.56	6045.82	8.03	-5180.89	-6.37
R-145	R-146	438.33	0.58	8075.24	10.62	-3740.26	-4.45
R-146	R-147	-176.51	-0.23	8331.17	10.76	-573.76	-0.67
R-147	R-148	-1061.27	-1.5	10021.21	14.41	710.96	0.89
		-2384.61	Av=-0.21%	70958.45	Av=10.05%	-19900.78	Av=-2.19%
			Min=-1.50%		Min=6.06%		Min=-6.37%
			Max=1.79%		Max=14.41%		Max=0.89%

Table A3.7. Sediment budget data for Sector 7. Profile lengths of 40 m were used to calculate volumetric change.

Changes Between Locations		Sector 8 - Volume Changes Above MP					
		2004 to 2005		2005 to 2010		2010 to 2015	
Location 1	Location 2	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change
R-148	R-149	-852.93	-1.2	7652.57	10.92	-34.95	-0.04
R-149	R-150	21.68	0.03	3263.38	4.68	-855.78	-1.17
R-150	R-151	383.98	0.48	6887.82	8.59	147.09	0.17
R-151	R-152	548.55	0.92	5571.82	9.28	-808.14	-1.23
R-152	R-153	640.36	0.77	5190.04	6.2	-163.11	-0.18
R-153	R-154	580.78	0.85	4459.96	6.45	951.51	1.29
R-154	R-155	167.6	0.24	6687.26	9.61	-415.1	-0.54
R-155	R-156	-514.03	-0.73	7294.99	10.48	-65.91	-0.09
R-156	R-157	-199.17	-0.29	5971.31	8.64	-985.49	-1.31
		776.82	Av=0.12%	52979.15	Av=8.32%	-2229.88	Av=-0.34%
			Min=-1.20%		Min=4.68%		Min=-1.31%
			Max=0.92%		Max=10.92%		Max=1.29%

Table A3.8. Sediment budget data for Sector 8. Profile lengths of 40 m were used to calculate volumetric change.

Changes Between Locations		Sector 9 - Volume Changes Above MP					
		2004 to 2005		2005 to 2010		2010 to 2015	
Location 1	Location 2	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change
R-157	R-158	-218.88	-0.32	5720.46	8.47	872.57	1.19
R-158	R-159	9.42	0.01	7548.63	11.15	2265.7	3.01
R-159	R-160	-172.17	-0.29	8127.72	13.75	-663.31	-0.99
R-160	R-161	942.26	1.3	8963.79	12.24	-3390.69	-4.13
R-161	R-161A	2628.54	3.8	7075.7	9.87	-4767.56	-6.05
R-161A	R-162	566.48	0.93	5189.38	8.48	-3871.16	-5.83
R-162	R-163	-237.93	-0.28	6707.93	7.85	-3946.54	-4.28
R-163	R-164	1399.25	2.68	3791.31	7.08	-2064.87	-3.6
R-164	R-165	2296.09	2.54	5126.38	5.54	-3022.5	-3.09
		7213.06	Av=1.15%	58251.3	Av=9.38%	-18588.36	Av=-2.64%
			Min=-0.32%		Min=5.54%		Min=-6.05%
			Max=3.80%		Max=13.75%		Max=3.01%

Table A3.9. Sediment budget data for Sector 9. Profile lengths of 40 m were used to calculate volumetric change.

Changes Between Locations		Sector 10 - Volume Changes Above MP					
		2004 to 2005		2005 to 2010		2010 to 2015	
Location 1	Location 2	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change	Vol Diff (m3)	% Change
R-165	R-166	6891.79	2.42	21416.78	7.35	-1920.59	-0.61
R-166	R-167	2246.56	0.85	24794.8	9.28	-3448.86	-1.18
R-167	R-168	1695.39	0.59	29944.76	10.45	-3491.41	-1.1
R-168	R-169	3181.54	1.03	27010.04	8.67	-2745.87	-0.81
R-169	R-170	3844.07	1.47	18812.02	7.09	1801.83	0.63
R-170	R-171	7791.71	2.72	12314.59	4.18	5514.34	1.8
R-171	R-172	4579.61	1.94	5515.05	2.29	4676	1.9
R-172	R-173	40637.23	15.91	20175.32	6.81	-6684.61	-2.11
R-173	R-174	46497.51	38.4	6617.53	3.95	-2506.71	-1.44
		117365.41	Av=7.26%	166600.89	Av=6.67%	-8805.88	Av=-0.32%
			Min=0.59%		Min=2.29%		Min=-2.11%
			Max=38.40%		Max=10.45%		Max=1.90%

Table A3.10. Sediment budget data for Sector 10. Profile lengths of 200 m were used to calculate volumetric change.