Leveraging Historical Cartography to Assess and Monitor the Geomorphologic Changes of the St. Augustine Inlet From 1589 – 2022

Presented by Thomas M. MacAvoy
My Work in St. Augustine and Relationship with the Study Area

I work at the St. Augustine Lighthouse and Maritime Museum (SALMM) as the GIS technician and spatial analyst for the Lighthouse Archaeological Maritime Program (LAMP).
The Lighthouse Archaeological Maritime Program (LAMP)

- They are a team of archaeologists, conservators, and researchers whose mission is to discover, preserve, and protect historical artifacts of North Florida’s Atlantic coast.

- Over 110 archaeological sites visited and thousands of individual artifacts discoveries.

Archaeological and Historic Value of the Inlet

- The coastline around the inlet estimated to have over 500 individual shipwrecks.
- Most of these wrecks are within 1 mile of the coastline.
- These wrecks are caused by:
  - Crazy banks and hidden shoals
  - Shifting sea-floor
  - Turbulent currents
  - Historically shallow point of entry
Shipwreck and archaeological sites worked on or discovered by the LAMP team as of 2022. Map: ESRI World Imagery, 2022, T. MacAvoy

Shipwreck and archaeological sites within the study area. Map: NAIP, 2022, T. MacAvoy
Shipwreck uncovered from the shoreline in Ponte Vedra, 2018. Photo courtesy of Chuck Miede, LAMP Director
The St. Augustine Inlet., NAIP (2021)

Approaching the inlet from the Atlantic, USCG (2020)

Birds-eye-view of the inlet. 90 USCG (2020)
Study Area Overview

- 25 square kilometers
- Consists of:
  - Littoral oceans
  - Lagoons
  - Sandy beaches
  - Saltmarshes
  - Developed urban areas
  - Maritime hammocks.

St. Augustine Inlet, 2022, T. MacAvoy
Factors Influencing the St. Augustine Inlet’s Geomorphology

- Climatic: Hurricanes, Nor’easters, and other strong storms
- Hydrologic: Drainage of the Tolomato and Matanzas Rivers
- Anthropogenic: Dredging, development, and dune renourishment efforts
The Moving Inlet

Left: St. Augustine Inlet, US Coastal Survey (1943) & Right: the present-day Inlet USGS (2020)
Problem Statement

- Despite its long history, no concise historical understanding of the inlet's geomorphology exists, which has generated considerable frustration and debate among local historians and maritime archaeologists (Miede, 2013; Budsburg, 2022).

Courtesy of the Library of Congress. Boazio, Sir Francis Drakes Raid of St. Augustine, 1585

Courtesy of the Special Collections Department, University of South Florida. Plano de la Ciudad y Puerto de San Agustín, Tomas Lopez, 1783

Courtesy of the Offices of Coastal Survey. St. Augustine Inlet to the Halifax river, B. Huger 1865
This Study Will…

- Create a historical cartographic record for the St. Augustine inlet and its surrounding area from 1589 to 2022. The resulting sequence of georeferenced maps will aid local, state, and national organizations to anticipate the discovery of archaeological and cultural assets and to plan for mitigation efforts in the event of climate change induced sea-level rise and the resulting erosion.
Previous Work

- In 2020, I produced a series of georeferenced coastal datasets from 1741 to the present as part of a NOAA grant to monitor archaeologically sensitive sites in St. Augustine.
Literature Review:

- Several recurring themes were present in the literature reviewed:
  - Historical research and reviews into the study areas.
  - Factors considered when selecting historic maps.
  - Georeferencing methodologies for historic coastal maps.
  - Specific concerns when dealing with bathymetry studies and sources of errors.
Theme 1: Extent and Factors Considered in Historical Research into a Study Area

- Providing a history of the study area provides valuable context to geomorphological phenomena. More intricate or complex projects typically included a proportionally larger historical review section. (Orman, Morang, & Larson, 1998)

- Factors include:
  - The geologic and hydrological nature of the study area (Zhang & Yang, 2006)
  - Demographic trends and human impacts (Capiella et al., 1999, and Foxgrover et al., 2004)
  - Socio-economic considerations
Determining which maps to use in a geomorphological study involves:

- Understanding a map’s spatiotemporal relevance.
- The availability to historical documents, (Fernández-Montblanc et al., 2007).
- Factoring for scale between each map dataset (Rumsey & Williams, 2002).
- The positional accuracy of one map in relation to the next in a sequence.
- Age of a map especially if it is made prior to the 1800s (van der Wal & Pye, 2003).
Theme 3: Methodologies Used to Georeference Historical Coastal Projects

- For long term sequential spatiotemporal change studies, it is ideal to have the following:
  - Several map samples of the study area
  - All maps be set to the same scale
  - Uniform coordinate system projection for local horizontal and vertical datums (Jakobbson et al., 2005)
  - That 3 to 10 control points are used for each time period
  - Regularly spaced intervals of time (i.e. every 20 years).
Theme 4: Specific Bathymetric Considerations and Sources of Errors.

Van der Wal & Pry identify several key considerations when looking at historical bathymetric cartographic elements:

- Dubious accuracy before the advent of sound distancing technology (sonar) that became widely used in 1930-1940s. (Rayner, 1993)
- Rectifying when soundings were taken during tidal phases for uniformity.
- Correcting mean sea level rise (SLR) in the study area.
- Identifying and confirming what is meant by the term “Coastline”.
- Converting units of measurements to a uniform standard.
- Ensuring uniform map projection and coordinate systems.

Examples of bathymetry recording devices. The earliest forms consisted of simplistic lead lines, it would not be until the 1890s that sonar would be invented, and it would take until 1930 before it was widely used. Today single and multi-beam sonars allow for more robust sea floor mapping.
A brief history of the St. Augustine inlet and its cartographic record can be broken down in the following time periods:

1. Pre-European Contact (40,000 B.C.E – 1513 C.E.)
2. First Spanish Period (1513 C.E. – 1763 C.E.)
3. British Period (1763 C.E. – 1783 C.E.)
4. Second Spanish Period (1784 C.E. – 1821 C.E.)
5. American Statehood and Civil War Period (1821 C.E. – 1865 C.E.)
6. Reconstruction and Resorts (1865 C.E. – 1920 C.E.)
Pre-European Contact: (40,000 BCE – 1513 AD)

- Pre-Columbian maps and records do not exist that describe the St. Augustine Inlet.
- The earliest account of the area around St. Augustine comes from the journal entries of a Franciscan friar named Harrera, who was with Juan Ponce de Leon in his exploration of “La Florida” in 1513. (Turner, 2006)
Modern replica of the Nina, a caravel used by Christopher Columbus. Photo Courtesy of: the Columbus Foundation.
Chief Sarouriona prepares for battle. Photo credit: The Florida Center for Instructional Technology, University of South Florida

Bringing crops to the public storehouse, la Moyne, Plate XXII. Photo credit: The Florida Center for Instructional Technology, University of South Florida

Chief Sarouriona prepares for battle. Photo credit: The Florida Center for Instructional Technology, University of South Florida
First Spanish Period (1513 - 1763)

This period is synonymous with the interactions of the Spanish empire’s first attempts to colonize the “New World”.

- First surveys of the region
- Early European and indigenous conflicts and negotiations
- Colonial settlement
Map of St. Augustine depicting the 1586 raid by Sir Francis Drakes English Forces. Produced by Boazio, Baptista, 1589. Note how the larger vessels of the English ships are anchored off the coastline, indicating that the inlet was not navigable by larger ships (drafts > 5ft).

Thomas Silver 1740 map depicting the English bombardment of St. Augustine. Source, the St. Augustine Historical Society.
British Period (1763 – 1783)

- Better map data produced a more defined route to enter the port.

- Maps begin to show the presence of large swaths of shallow shoals in the area that would go on to become the Anastasia State Park.

A reenactment of the British forces taking control of the Castillo de San Marcos. Photo courtesy of the Castillo de San Marcos
Plan of the town and Harbor of St. Augustine; Hurd, 1756-1773

Plan of the Town and Harbour of St. Augustine, 1762, William Roberts
Second Spanish Period (1784 – 1821)

- The second Spanish period was marked by sluggish economic development and little consideration by the empire. This regression is also reflected in the quality of maps and cartographic data.
- We can see in the Birch, 1812 map however that the shoals and coastline around the inlet continue to migrate south.
American Territory and Statehood Period (1821 – 1865)

- The first trigonometrically accurate pre-industrial revolution map of the inlet. Despite the greater of accuracy, surveyors continued to indicate the difficulty of crossing over the sand bars and shoals surrounding the inlet.

The first scientifically produced survey of the North Florida area. St. Augustine, FL; US Coastal Survey, 1861
Reconstruction and Resort Period (1865 -1920)

- The inlet continued to move to the south, and heavy boat activity was limited due to the shifting shallow shoals.
- The southern shoals begin to more consistently form into the sandy coastal islands known as Bird and Conch island.
Henry Morrison Flagler, Founder of the Florida East Coast Railway and developer of the majority of St. Augustine as it is today.
Florida Inland Navigation District & the Florida Intracoastal Waterway System
1890 US Coastal Survey, St. Augustine Inlet

1911 US Coastal Survey, St. Augustine Inlet
The Modern Industrial Period (1920 – 1960)

- This period also saw the most dramatic geomorphologic changes to the inlet in the form of the dredging of the inlet in 1943 by the USACE.
Present Day (1960 – 2022)

- Today the St. Augustine Inlet is a relatively safe commercial and recreational marine traffic lane. The inlet is characterized by routine dredging and beach restoration efforts that take place every 5 to 7 years.
The methodology used in this study reflects the processes employed in similar studies:

1. Gather Data
2. Georeference Historic Maps
3. Digitize Shoreline and Bathymetry Sounding Points or Contours
4. Generate TIN/Bathymetric grids (horizontal resolution 3 to 10 meters)
5. Convert TINs to Common Vertical Datum
6. Interpolate TIN Datasets to Elevation (Bathymetry) Rasters
7. Conduct Error Analysis For Years When Reasonable Data Exists
8. Conduct Change Analysis
9. Export Finished Maps to User Interface
Technology & Software Used

- This project will use a combination of computer software and web platforms
  - ArcGIS Pro
  - ArcGIS Online
  - Web applications
    - USGS Topo Map Viewer
    - Office of Coastal Survey Historical Maps Web Viewer
Methodology: Data Gathering and Georeferencing

<table>
<thead>
<tr>
<th>Control Point Name</th>
<th>Coordinates (Latitude, Longitude)</th>
<th>Date of Origin</th>
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<tbody>
<tr>
<td>Castillo de San Marcos</td>
<td>29.8964959 N, -81.3138931 W</td>
<td>1565*, 1672</td>
</tr>
<tr>
<td>Cathedral Basilica of St. Augustine</td>
<td>29.8921360 N, -81.3137017 W</td>
<td>1793</td>
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<tr>
<td>St. Augustine North Gate</td>
<td>29.8861250 N, -81.3429791 W</td>
<td>1808*</td>
</tr>
<tr>
<td>St. Francis Barracks</td>
<td>29.8329116 N, -81.3561607 W</td>
<td>Mid-1700s</td>
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<tr>
<td>Old St. Augustine Lighthouse</td>
<td>29.8463383 N, -81.3269041 W</td>
<td>1733</td>
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<tr>
<td>Modern St. Augustine Lighthouse</td>
<td>29.8473136 N, -81.3232015 W</td>
<td>1871</td>
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<tr>
<td>Governor’s House</td>
<td>29.8638086 N, -81.3346164 W</td>
<td>1598</td>
</tr>
<tr>
<td>Hotel Ponce de Leon (Flagler College)</td>
<td>29.8721146 N, -81.3417055 W</td>
<td>1888</td>
</tr>
</tbody>
</table>
The Old St. Augustine Lighthouse (1733 – 1880)

The Current St. Augustine Lighthouse (1874 – Present)

The St. Augustine Catholic Basilica (1793)

The Castillo de San Marcos (1565*, 1672)

St. Augustine North City Gate, (1808)

The Governor’s House (1598)

Hotel Ponce de Leon (Flagler College), (1888)

Southwest Fortification (1672)

Franciscan Barracks, (mid-1700s)
Methodology: Digitization of Coastlines and Bathymetry Soundings

- Coastlines will be uniformly determined using Mean Low Water (MLW) vertical datum.
- The bathymetry soundings will be used to create point datasets that reflect approximate depth.
- For bathymetry contours, these lines will be digitized and have their depth values applied to them.

Methodology: Point and Contour Lines to TIN and DEM Raster Datasets

- Sounding Points and Contour lines will be used to generate TIN files using the ArcPro 3D Analyst Toolbox.
- These TIN files will then be interpolated to form digital elevation map (DEM) rasters for the inlet's bathymetry, while the historically georeferenced coastlines will represent the areas above MLW or sea level.
Concerns & Considerations

- Incomplete bathymetry datasets
- Bathymetric sounding accuracy for earlier maps may be sub-par or nonexistent in some instances
- Irregularity with tidal datums
- The lack of control points in many of the older maps could produce errors or inaccuracies
Methodology: Export to Web Application

- Target users:
  - Archaeologists
  - Historians
  - Researchers
  - Local, state, and federal government agencies
  - The general public
<table>
<thead>
<tr>
<th>Time Frame</th>
<th>Tasks</th>
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<tbody>
<tr>
<td>March – April 2022</td>
<td>Literature Review and Capstone Project Proposal Development</td>
</tr>
<tr>
<td>April 2022</td>
<td>Additional Research and Literature Review, Prepare Project Proposal</td>
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<tr>
<td>May 2nd, 2022</td>
<td>Present Project Proposal</td>
</tr>
<tr>
<td>May – June 2022</td>
<td>Secure additional historic and modern navigational maps.</td>
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<tr>
<td></td>
<td>Begin the process of georeferencing historic maps</td>
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<tr>
<td>June – July 2022</td>
<td>Generate historic coastline shapefiles, contour bathymetry line shapefile, and sounding point datasets.</td>
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<tr>
<td>July – August 2022</td>
<td>Generate TIN layers and raster bathymetry detests to conduct spatial analysis for time periods.</td>
</tr>
<tr>
<td>August – September 2022</td>
<td>Review results and assess accuracy.</td>
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<tr>
<td>September – October 2022</td>
<td>Prepare web-viewer, slider tool, and other final product for release.</td>
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<tr>
<td>November 2022</td>
<td>Prepare official project paper.</td>
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<tr>
<td>December 2022</td>
<td>Present project and findings to capstone committee and separate scholarly organization.</td>
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</table>
Anticipated Results

- Greatest geomorphic variety will exist in time periods before the dredging operations of the 1940s.
- The location of the inlet throughout time will match with the presumed age of shipwrecks uncovered by LAMP.
- Some degree of sea level rise is likely to have taken place in the past 6 decades of the modern inlet.
- A publicly accessible time slider web application that will allow researchers and local stakeholders to understand the geomorphology of the inlet from the past 400 years.
Future Work

Matanzas Inlet

The southern entrance to the port of St. Augustine has similar hydrological characteristics. Similarly, it has also been the location of several LAMP shipwreck discoveries that could indicate the presence of additional wreck sites. This location however, has fewer historical maps and data available.
Thank you for your time and consideration
Questions or Comments
References:


- Budsburg, N. (2022, February 29). Personal communication [Personal interview].


References:


Perrault, P. H. (1830). Report to Andrew Jackson, President and J.H. Eaton. St. Augustine, FL; USA.


This study will utilize 19 historical and modern navigational maps, datasets, and charts of the area for georeferencing and addition written and records to help piece together the past 400 years of change in the inlet.

<table>
<thead>
<tr>
<th>Name</th>
<th>Date / Year</th>
<th>Source</th>
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<tr>
<td>Boazio 1585 Sir Francis Drakes Raid on St. Augustine Port and Town</td>
<td>1589</td>
<td>Library of Congress, Baptista Boazio</td>
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<tr>
<td>A View of the Town and Castle of St. Augustine and the English Camp</td>
<td>1740</td>
<td>Thomas Silver</td>
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<td>Before June 20, 1740</td>
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<td>Plan of the Town &amp; Harbour of Augustine</td>
<td>1756-1777</td>
<td>William Hurd</td>
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<td>Delineatio munimenti et Portus S. Augustini</td>
<td>1759</td>
<td>Homann</td>
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<td>Plan of the Town and Harbour of St. Augustine, 1762</td>
<td>1762</td>
<td>William Roberts</td>
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<td>St. Augustine Inlet and Town</td>
<td>1765 and 1766</td>
<td>W. Gerard DeBrahm, Esq.</td>
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<td>Plano de La Ciudad Y Puerto De San Augustin, De La Florida</td>
<td>1783</td>
<td>Tomas Lopez</td>
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<tr>
<td>Preliminary Chart of St. Augustine Harbor</td>
<td>1862</td>
<td>B. Huger Jr., &amp; F.W. Dorr</td>
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<tr>
<td>Preliminary Chart of St. Augustine Harbor Florida</td>
<td>1879</td>
<td>B. Huger Jr., &amp; F.W. Dorr</td>
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<td>St. Augustine Coastal Survey</td>
<td>1911</td>
<td>USGS</td>
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<td>Bird's -Eye View of Saint Augustine and Vicinity</td>
<td>1916</td>
<td>Unknown, Florida Memory State Library and</td>
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<td>Archives of Florida</td>
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<td>Florida Intracoastal Waterway St. Augustine To Titusville</td>
<td>1935</td>
<td>USGS</td>
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<td>Intracoastal Waterway Tolomato River to Palm Shores 1943</td>
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<td>Intracoastal Waterway Tolomato River to Palm Shores 2022</td>
<td>2022</td>
<td>USGS</td>
</tr>
</tbody>
</table>
Methodology: Data Sources

- Data was sourced depending on the type of map:
  - Historical Maps: 1585 - 1940
    - USGS Historical Map Archive
    - Library of Congress
    - National Archives
    - St. Augustine Historical Society
    - University of Florida’s Historic Map Library
    - University of Southern Florida’s Digital Map Library
    - LAMP’s Research Library
  - Modern Maps: 1940 – Present
    - United States Geologic Survey
    - United States Army Corps of Engineers
    - National Oceanic and Atmospheric Administration
  - Aerial and LiDAR Datasets
    - NOAA
    - USGS/NRCS
    - Florida Geospatial Open Data Portal