

Building Coastal Resilience at the Gay Head Cliffs

Integrating Tribal Knowledge, Monitoring, and Modeling to Support Long-Term Stewardship

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Sponsor:



PROBLEM STATEMENT

The Gay Head Cliffs are culturally significant, physically dynamic, and exposed to erosion-driving climate stressors like storms and groundwater processes

PROJECT GOAL

Integrate community knowledge, longitudinal data, and slope stability modeling to support WTGHA-led stewardship and resilience planning

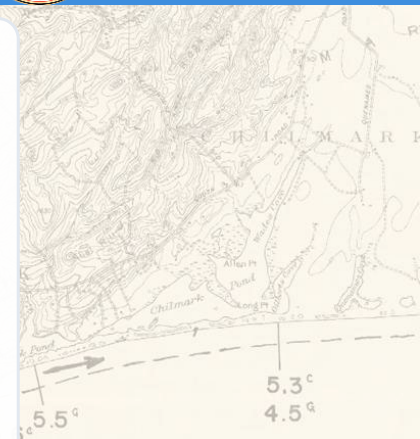
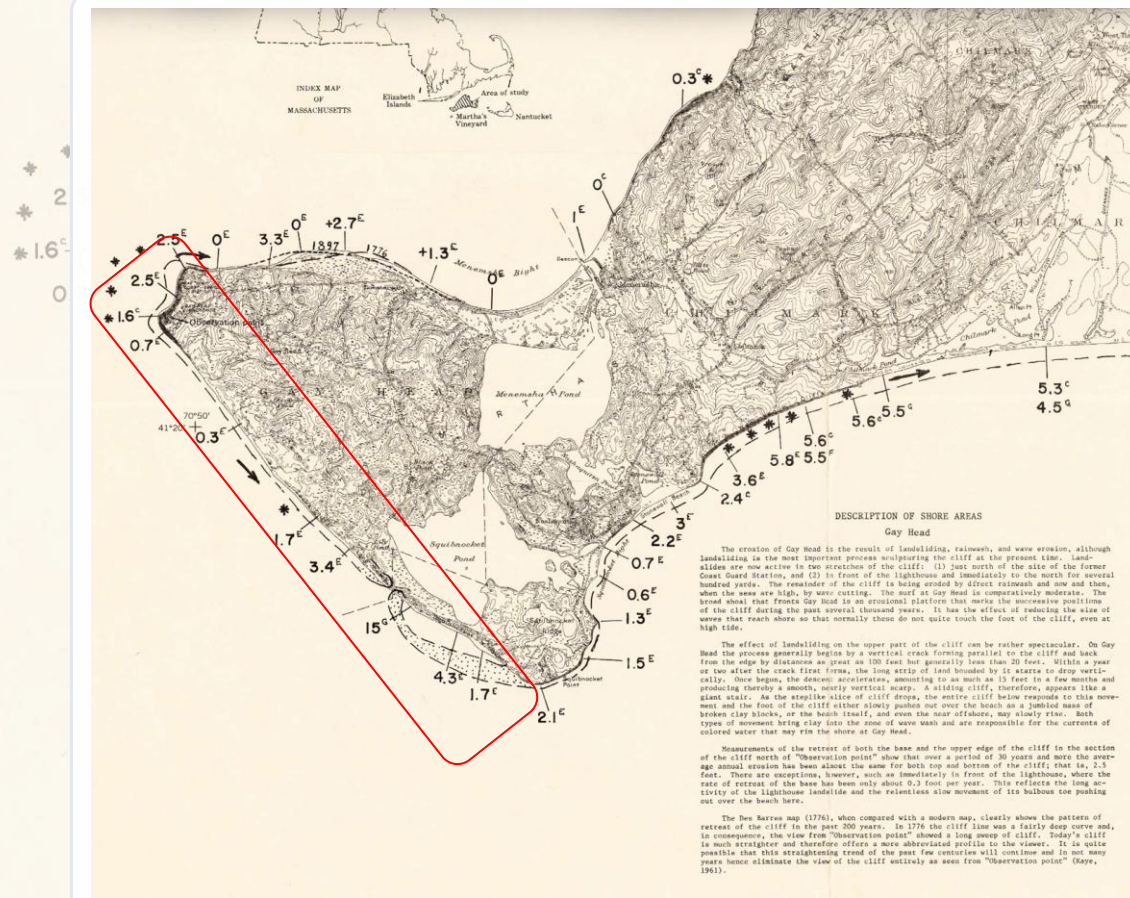
KEY OBJECTIVES

01

Establish a robust foundation for understanding this complex, evolving coastal system

02

Develop a portfolio of interventions to support the long-term resilience and stewardship of the Cliffs by combining community priorities with advanced modeling tools

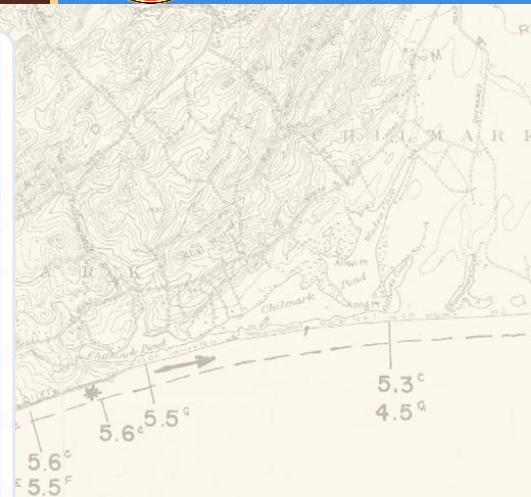


the base and the upper edge of the cliff in the section " show that over a period of 30 years and more the average same for both top and bottom of the cliff; that is, 2.5





Recent Evolution: 15-Year Time Series



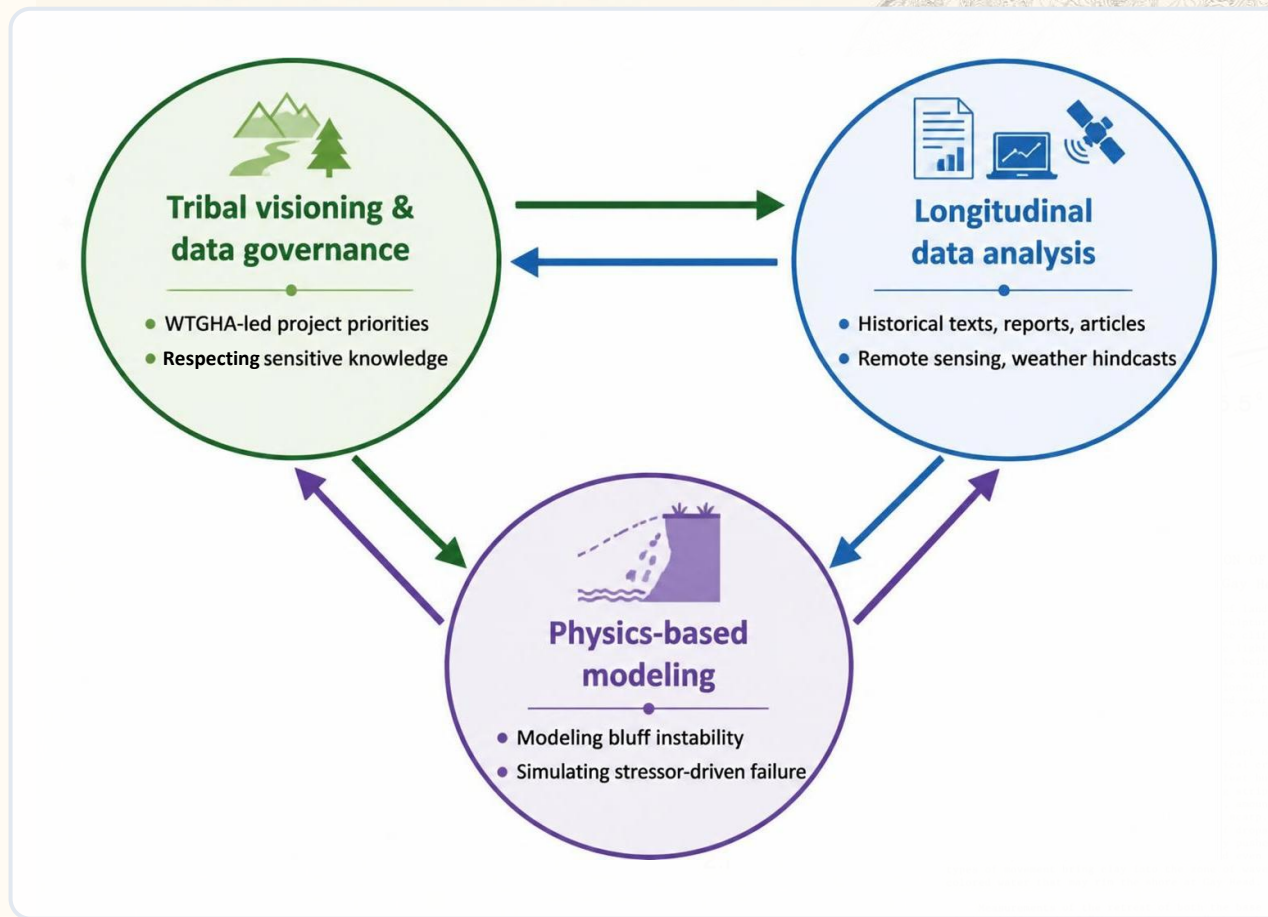
DESCRIPTION OF SHORE AREAS Gay Head

Gay Head is the result of landsliding, rainwash, and wave erosion, although the important process sculpturing the cliff at the present time. Landslides occur in two stretches of the cliff: (1) just north of the site of the former lighthouse and (2) in front of the lighthouse and immediately to the north for several hundred yards. The main body of the cliff is being eroded by direct rainwash and now and then, by wave cutting. The surf at Gay Head is comparatively moderate. The Gay Head is an erosional platform that marks the successive positions of the cliff over a past several thousand years. It has the effect of reducing the size of the cliff so that normally these do not quite touch the foot of the cliff, even at high tide. Landsliding on the upper part of the cliff can be rather spectacular. On Gay Head it usually begins by a vertical crack forming parallel to the cliff and back to the beach as great as 100 feet but generally less than 20 feet. Within a year or two the first forms, the long strip of land bounded by it starts to drop vertically and descend; accelerates, amounting to as much as 15 feet in a few months and then, nearly vertical scarp. A sliding cliff, therefore, appears like a repulsive slice of cliff drops, the entire cliff below responds to this movement. The cliff either slowly pushes out over the beach as a jumbled mass of rock and debris, and even the near offshore, may slowly rise. Both the beach and the zone of wave wash and are responsible for the currents of the surf on the shore at Gay Head.

The retreat of both the base and the upper edge of the cliff in the section of the cliff north of "Observation point" show that over a period of 30 years and more the average annual erosion has been almost the same for both top and bottom of the cliff; that is, 2.5



Interconnected Work Streams





Tribal Visioning & Data Governance



Four-Tier Data-Access Structure

- **Tier 1:** Highly restricted identifiable data (protected knowledge).
- **Tier 2:** De-identified analytical data for authorized research access.
- **Tier 3:** Aggregated project findings and synthesized insights.
- **Tier 4:** WTGHA-approved public products and open reports.

Community Engagement

- Ongoing monthly meetings with island and Tribal team members
- On- and off-island group discussions with Tribe members
- Targeted surveys & focus groups within Aquinnah

Reflecting on the Aquinnah Cliffs

This survey is part of a research partnership between WTGHA and Tufts University about the Aquinnah Cliffs. Participation is voluntary. The survey may take 5-10 minutes. Your responses will help us understand community memories of the Cliffs and potential ways to help protect them. You may skip questions or stop at any time. By responding to these questions, you are providing your consent to participate in this survey.



Before beginning, please confirm:

- ☐ I have read the information above, I am at least 18 years old, and I voluntarily agree to participate in this survey.
- ☐ I am an enrolled member of the Wampanoag Tribe of Gay Head/Aquinnah

Thank you for sharing your memories and ideas about the Aquinnah/GayHead Cliffs. Please share as much or as little as you wish. You may skip any question.

1. How have you experienced the Aquinnah Cliffs in your life, such as in your childhood? Please select any/all that apply.

- ☐ I have lived near the Cliffs and/or have spent/spend time there regularly
- ☐ I have visited the Cliffs when I visit Aquinnah
- ☐ I have rarely or did not interact with the Cliffs
- ☐ I experienced the Cliffs in a different way _____

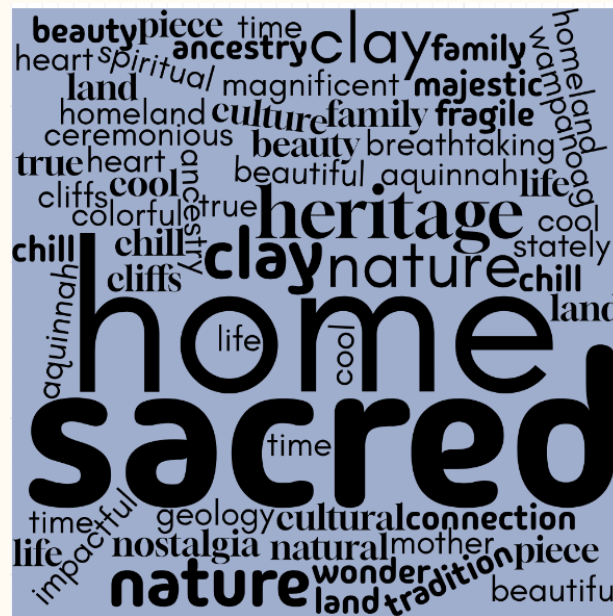
2. What one word best describes what the Cliffs mean to you? _____

3. Is there a story you were told about the Cliffs that you would like to share? _____



2026 WTGHA Powwow

Celebrating Wampanoag culture, identity, and community



- ✓ Ongoing meetings, discussions & engagements with Tribe
- ✓ Tribal knowledge & priorities inform the technical approach and ultimately drive the adaptation portfolio





Longitudinal Data Analysis



Historical Data Compilation - More than 60 references spanning all aspects of the Cliffs

Reviewing books, white papers, local articles, maps, parcel assessments, engineering reports, etc.

- ✓ Environmental & Geophysical
- ✓ Ecological
- ✓ Cultural and Historical
- ✓ Climate & Future Scenarios
- ✓ Economic & Infrastructure
- ✓ Governance & Policy
- ✓ Social & Community
- ✓ Participatory & Visual

1. Introduction

The Aquinnah Cliffs, also referred to as the Gay Head Cliffs, are among the most geologically, culturally, and historically significant coastal landscapes in Massachusetts. Located on the western end of Noepe (Martha's Vineyard), the Cliffs hold deep importance to the Wampanoag Tribe of Gay Head (Aquinnah) [WTGHA] and have long been recognized for their distinctive exposed clay formations, dynamic coastal processes, ecological features, and enduring role in island life. Over centuries, the Cliffs and surrounding shoreline have experienced continual change through erosion, landsliding, sediment transport, wave action, groundwater processes, storms, and long-term coastal evolution. These processes have drawn scientific, governmental, and community attention as concerns surrounding sea-level rise, shoreline retreat and intensified storms continue to grow.

This Historical Data Compilation (HDC) was developed as part of the broader WTGHA and Tufts University collaborative project focused on understanding the past, present, and potential future changes affecting the Cliffs. The purpose of this document is to compile and synthesize existing information relevant to the Cliffs and surrounding landscape, drawing from archival materials, scientific literature, government reports, maps, imagery, observational records, and other available sources. It aims to provide a non-exhaustive but thorough background resource to support and inform ongoing and upcoming project activities, including a values assessment, remote sensing analysis, bluff stability modeling, and bluff resilience planning.

The report is organized around a series of thematic categories that together help contextualize the Aquinnah Cliffs within broader environmental, historical, ecological, cultural, social, and infrastructural systems. These categories include environmental and geophysical conditions, ecological systems, community and cultural information, governance and economic context, and climate and future scenarios. We do not attempt to provide a complete or final interpretation of community perspectives or Cliff processes. Rather, the HDC serves as a structured compilation of existing knowledge and observed change across multiple timescales and disciplines.

The HDC also contributes to the ongoing development of a repository of information concerning the Aquinnah Cliffs for WTGHA educational, archival, and planning purposes. As described throughout this report, information related to the Cliffs exists in many forms, including published scientific studies, historical maps, photographs, oral histories, community observations, environmental monitoring, and cultural documentation. Some materials referenced in this report are publicly available, while others may remain private or restricted at the direction of WTGHA in accordance with Tribal data governance priorities.

Ultimately, this document establishes a baseline understanding of the Cliffs and surrounding environment by folding diverse forms of historical and contemporary information into a single synthesized reference document. In doing so, the HDC supports future phases of the WTGHA-Tufts project while simultaneously documenting environmental and cultural context for a landscape of great significance to the WTGHA and the greater coastal region.

4.5 Climate & Future Scenarios

Relative to other parts of the country, the northeastern United States has experienced unusually strong coastal warming. Karmaliuk and Horton (2021) identify the coastal northeastern United States and the adjacent Northwest Atlantic Shelf as warming hotspots. Their analysis found that coastal northeastern surface air temperature warming since 1902 has been exceptional at both continental and hemispheric scales, with some coastal areas experiencing more than 2°C of warming. Unlike many mid-latitude regions, where winter warming dominates annual trends, the coastal northeast has experienced strong warming in summer as well as winter. The study links this enhanced coastal warming to two related drivers: sea-surface temperature warming on the Northwest Atlantic Shelf associated with weakening Atlantic Meridional Overturning Circulation, and atmospheric circulation patterns associated with a more persistent positive North Atlantic Oscillation (Karmaliuk and Horton, 2021). These findings are significant for Martha's Vineyard because the island lies within the coastal northeastern region where land and ocean warming are closely connected. The adjacent Northwest Atlantic Shelf has warmed rapidly in recent decades, and the shelf's warming pattern is spatially linked to the coastal air-temperature pattern observed over land. This means that future climate conditions on Martha's Vineyard should not be understood only through inland air-temperature projections, but also through changes in nearby ocean conditions and large-scale atmospheric circulation.

Regional ocean warming is also uneven at finer spatial scales. Yu and Yang (2022) examined sea-surface temperature trends in Cape Cod waters and found that the New England Continental Shelf has warmed at a rate two to three times faster than the global open ocean in recent decades. The broader warming trend varies seasonally and peaks in late summer, with reported warming near 1.0°C per decade in July through September and a lengthening of the summer season by approximately 0.6 to 1.8 days per year (Yu and Yang, 2022). These broad shelf trends provide regional context for Martha's Vineyard, but the study also shows that waters near the Cape and Islands do not warm uniformly. Using a fine-resolution sea-surface temperature product, they also identified both a "warm spot" and a "cold spot" in nearby waters. The warm spot occurs in Nantucket Sound, sheltered by Martha's Vineyard and Nantucket, where summer sea-surface temperature maxima increased by 3.1 ± 1.0°C and the summer season lengthened by 20 ± 7 days over the 2006-2020 study period. In contrast, the cold spot occurs over Nantucket Shoals, where strong tidal mixing is associated with cooling during June through August, reducing summer sea-surface temperature maxima by 2.5 ± 1.2°C and shortening the warm season by 32 ± 11 days. Away from these localized features, the broader shelf warming was associated with a forward shift in the annual temperature cycle, especially from August through November, delaying the onset of fall by 13 ± 6 days.

This spatial variability is important because Martha's Vineyard sits between multiple marine environments with different thermal behavior: Nantucket Sound, Vineyard Sound, Nantucket Shoals, and the open shelf do not respond identically to climate forcing. The presence of both strong warming and localized cooling near the Cape and Islands suggests that future marine conditions may be highly place-specific, influenced by tidal mixing, wind forcing, and



Remote Sensing Establishes a Baseline for Bluff Deformation from 2015–2026

- **Sentinel-1 SAR Data:** The analysis utilizes Synthetic Aperture Radar data from ascending and descending geometries, coregistered at a spatial resolution of $\sim 3 \times 10$ meters.
- **TerraSAR-X Constraints:** The methodology incorporates constraints from TerraSAR-X observations to resolve line-of-sight displacement into slope-parallel and slope-perpendicular ground motion.
- **Hotspot Identification:** Spatially detailed time series identify localized deformation hotspots and areas showing persistent or accelerating motion to evaluate potential slope instability.



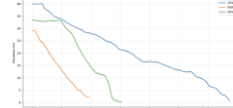
01. Identify Loss Rates

Line of sight velocity via remote sensing



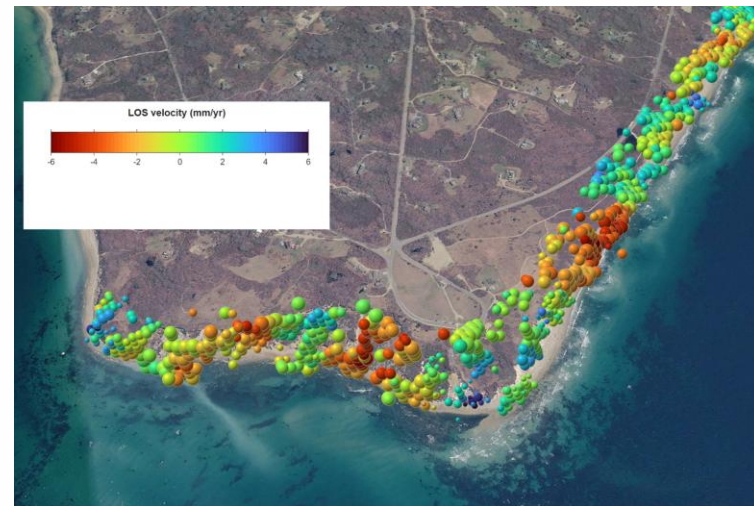
02. Slice DEM Profile

Import coordinates to slice 2D profile of DEM



03. Trace Bluff Slope

Trace slope from behind crest to beyond toe

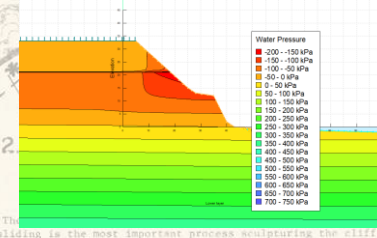


Line-of-sight (LOS) velocity in mm/year. Larger bubble = lower uncertainty

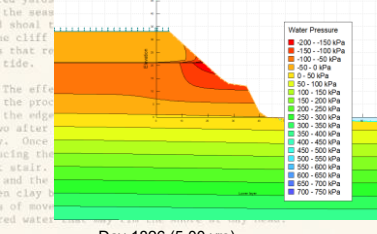


- **Transient Hydrodynamics:** Seepage and slope stability models simulate pore-water pressure variations and infiltration dynamics driven by long-term transient environmental forcing.

5.3^C
4.5^G



Day 727 (1.99 yrs)

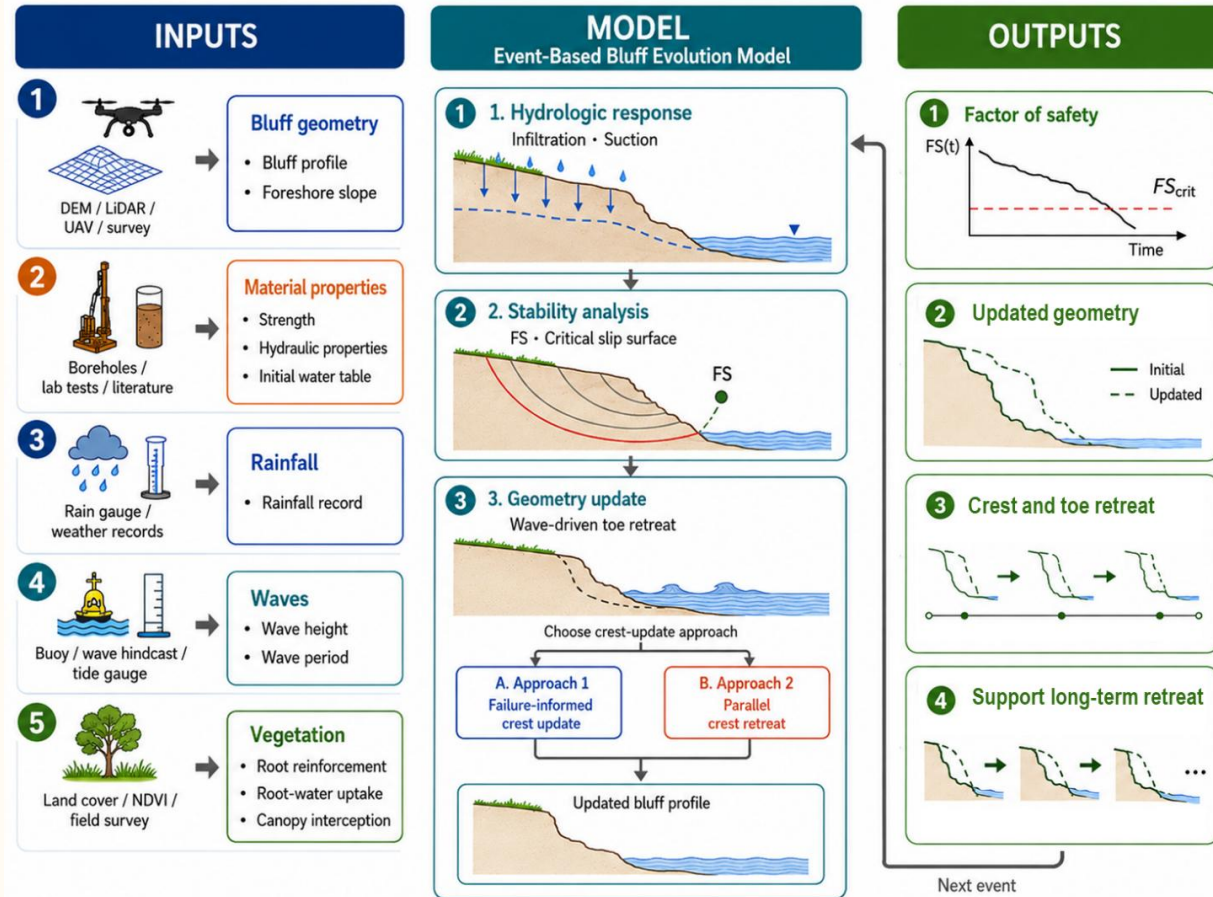


Day 1462 (4.01 yrs)

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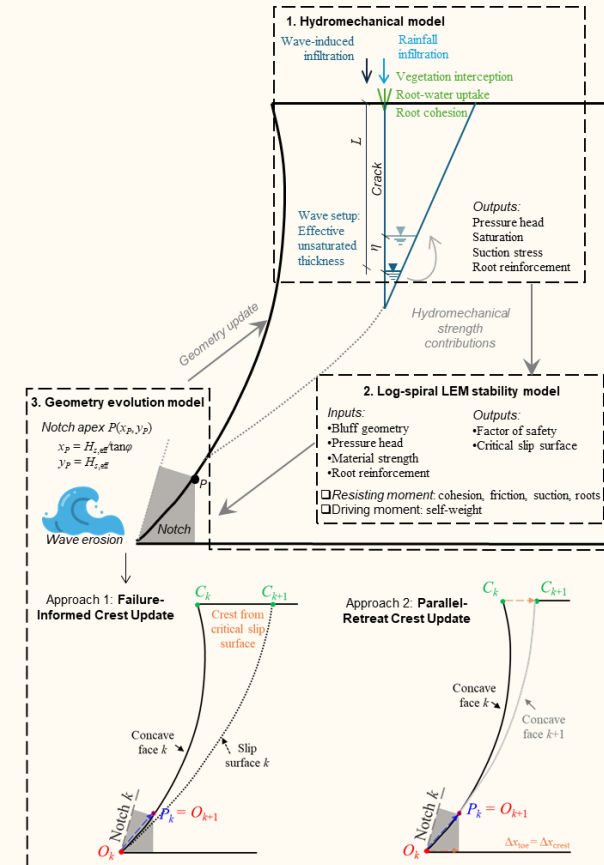
Physics-Based Modeling





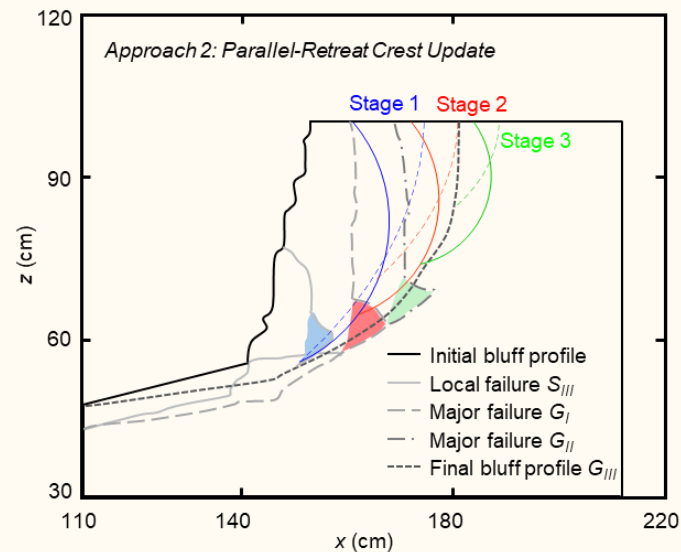
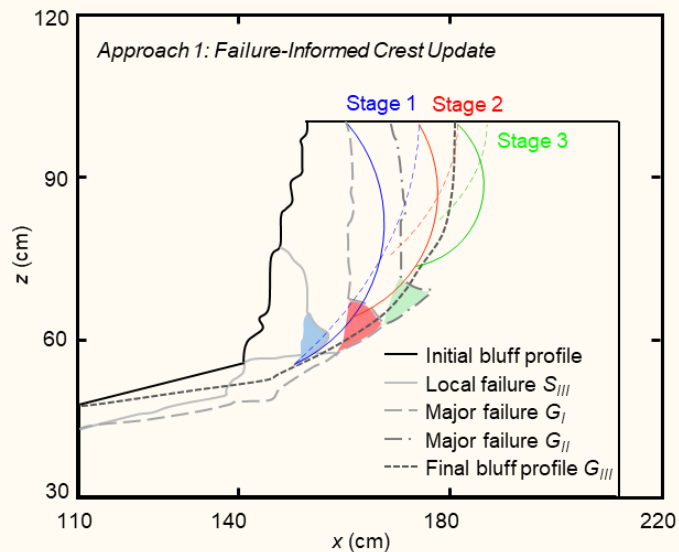
Stability & Reduced-Order Modeling

- **Long-Term Evolution:** A parallel reduced-order model simulates overall coastal bluff retreat and profile transformation across decadal and centennial timescales.
- **Nested Dual Time-Scale Configuration:** Effectively couples continuous, gradual bluff evolution with episodic, event-driven erosion caused by major storm surges and rainfall triggers.





Physics-Based Modeling



Wave-flume experiment observations:

- | | |
|-------------------------------------|---------------|
| — Initial bluff profile | Failure wedge |
| — Local failure S_{III} | Stage 1 |
| - - - Major failure G_I | Stage 2 |
| - · - Major failure G_{II} | Stage 3 |
| ····· Final bluff profile G_{III} | |

Model results:

- | | |
|--------------|-------------------------|
| Concave face | Log-spiral slip surface |
| — Stage 1 | - - - Stage 1 |
| — Stage 2 | - - - Stage 2 |
| — Stage 3 | - - - Stage 3 |



Integrated Modeling and Monitoring Support Long-Term Coastal Resilience Pathways

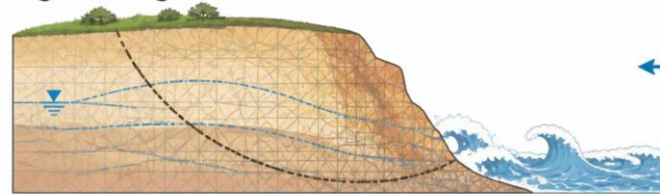
Building Toward Actionable Strategies

Baseline analyses and physics-based models provide the foundation for evaluating long-term coastal resilience strategies for the Gay Head Cliffs.

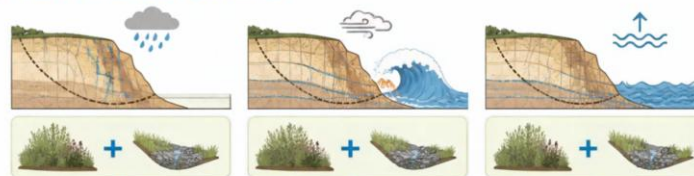
Next Steps:

- Scenario Pathways Development
- Comprehensive Risk Assessment
- Adaptation and Nature-Based Solutions Portfolio

1 Engineering Models



2 Test Future Scenarios



3 Mitigation Portfolio



~ Informed by Tribal priorities. ~

Types of movement bring clay into the zone of wave wash and are responsible for the currents of colored water that may rim the shore at Gay Head.

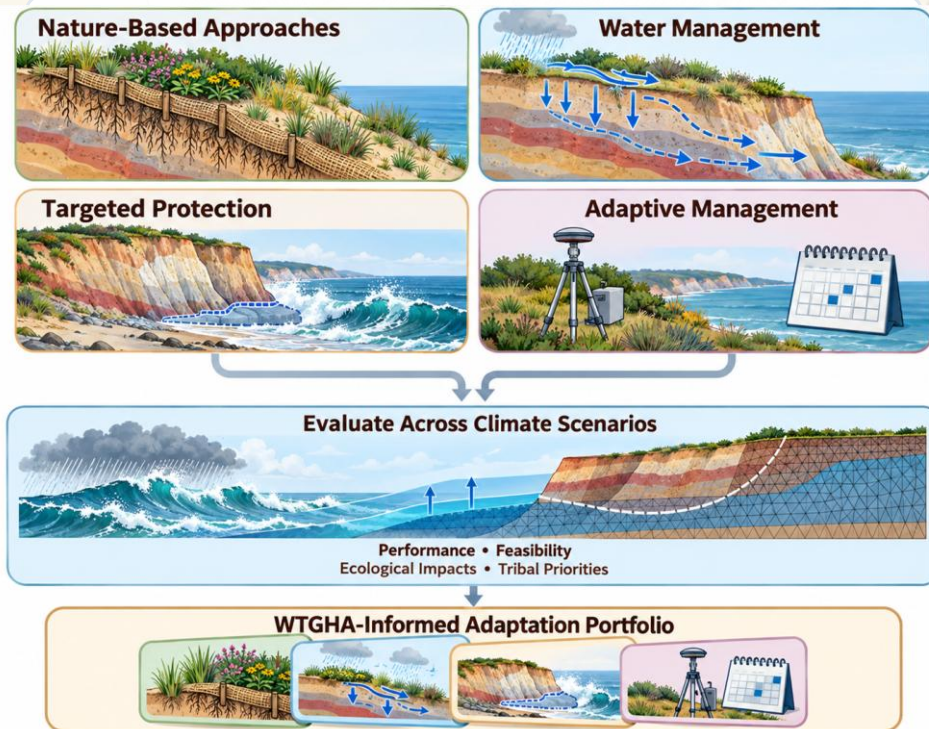
Measurements of the retreat of both the base and the upper edge of the cliff in the section of the cliff north of "Observation point" show that over a period of 30 years and more the average annual erosion has been almost the same for both top and bottom of the cliff; that is, 2.5



Evaluating a Range of Adaptation Measures to Support WTGHA-Led Stewardship

Potential Measures to Evaluate

- *Nature-based approaches*: Native vegetation, habitat restoration, and erosion control.
- *Water management*: Surface runoff and groundwater management.
- *Targeted protection*: Site-specific measures to address wave attack and toe erosion.
- *Adaptive management*: Monitoring, intervention triggers, and phased implementation.



colored water that may rim the shore at Jay Head.

Measurements of the retreat of both the base and the upper edge of the cliff in the section of the cliff north of "Observation point" show that over a period of 30 years and more the average annual erosion has been almost the same for both top and bottom of the cliff; that is, 2.5



The funding changed; the partnership and shared commitment continued

Early 2024 Partnership begins

Tufts reaches out to WTGHA to partner on a NASA proposal on equitable resilience to geohazards.

Apr. 2025 Unexpected setback

NASA project is terminated following changes in federal priorities.

Late 2025 A new opportunity

WTGHA leads a new proposal to Massachusetts CZM, with Tufts as a technical partner.

Aug. 2024 NASA project funded

A multidisciplinary team begins the work with a shared vision and strong momentum.

2025 Partnership continues

WTGHA and Tufts keep the collaboration moving forward using internal resources.

Today A stronger partnership

Community knowledge, monitoring, modeling, and adaptation planning now come together.

A project about resilience has itself had to be resilient

Resilience is not only about coastlines and infrastructure - it is also about relationships



Thank you - Questions?



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