

Kcipeskiyak as a model for Tribal salt-marsh stewardship

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Abstract

Salt marshes and Tidal Flats are among the most productive coastal ecosystems, providing critical services including carbon sequestration, shoreline protection, and support for culturally and economically important species. Despite their importance, Tribal salt marshes remain underrepresented in long-term monitoring and restoration science, and Indigenous knowledge systems are rarely centered in marsh stewardship frameworks. This study presents Kcipeskiyak, a 32.5-acre salt marsh located on the Passamaquoddy Tribe at Sipayik (Pleasant Point) Reservation in Maine, as a model for Indigenous-led salt marsh stewardship that integrates Traditional Ecological Knowledge (TEK) with Western scientific approaches. Led by the Sipayik Environmental Department, this work combines community-informed stewardship priorities, sediment core sampling, carbon and stratigraphic analysis, and collaborative academic partnerships to establish baseline ecological data while maintaining Tribal governance over research design, data ownership, and interpretation. Initial findings demonstrate intact sediment stratigraphy suitable for long-term blue carbon assessment and climate reconstruction, while the stewardship framework emphasizes intergenerational knowledge transfer, culturally significant species protection, and community engagement. By documenting both the scientific methods and governance structure underlying this approach, this paper demonstrates how Tribal leadership can enhance the effectiveness, legitimacy, and longevity of salt marsh monitoring and restoration efforts. Kcipeskiyak provides a replicable model for Tribal and coastal communities seeking to advance climate-resilient salt marsh stewardship grounded in Indigenous sovereignty, place-based knowledge, and collaborative science.

Introduction

Salt Marshes and Blue Carbon

Salt marshes are among the most productive ecosystems in the coastal zone, providing a wide range of ecosystem services that extend well beyond their spatial footprint. These systems play a critical role in long-term carbon sequestration through the accumulation and burial of organic carbon in anoxic sediments, making them a central component of global “blue carbon” strategies aimed at mitigating climate change. In addition to their climate benefits, salt marshes stabilize shorelines by attenuating wave energy, reducing erosion, and enhancing coastal resilience in the face of sea-level rise and increasing storm intensity. Salt marshes also support high levels of biodiversity, serving as nursery habitat for commercially and culturally important fish and shellfish species while sustaining complex food webs that link marine and terrestrial ecosystems.

Despite growing recognition of these functions, significant gaps remain in baseline sediment and carbon data for salt marshes, particularly in the Gulf of Maine and other high-latitude systems where sea-level rise rates are accelerating. Many marshes lack foundational datasets describing sediment stratigraphy, carbon density, and depositional history, limiting the ability of managers and researchers to assess carbon stocks, evaluate restoration outcomes, or project future ecosystem responses. Establishing site-specific baseline conditions is therefore essential for informing adaptive management, restoration planning, and participation in emerging blue carbon frameworks.

Underrepresentation of Tribal Lands in Coastal Monitoring

Tribal lands and Indigenous-managed coastal ecosystems remain markedly underrepresented in long-term coastal monitoring and blue carbon research. While Indigenous communities have stewarded salt marshes and adjacent coastal environments for millennia, relatively few monitoring programs are designed or led by Tribes, and even fewer result in datasets that remain under Tribal ownership and governance. As a result, Indigenous territories are often absent from regional and national assessments of coastal condition, carbon sequestration potential, and climate vulnerability.

Several barriers contribute to this underrepresentation, including limited access to technical infrastructure, historical exclusion from research funding pathways, and research models that prioritize external data extraction over community benefit. In addition, concerns regarding data sovereignty, cultural sensitivity, and the misinterpretation or misuse of Indigenous knowledge have further constrained Tribal participation in conventional monitoring frameworks. These challenges underscore the need for community-based, place-specific monitoring approaches that are led by Tribes, grounded in Traditional Ecological Knowledge (TEK), and supported through equitable academic and agency partnerships. Such approaches are increasingly recognized as essential for producing more accurate, culturally relevant, and enduring coastal science.

Study Purpose and Contributions

This paper documents the establishment of an Indigenous-led sediment and carbon core sampling program at Kcipeskiyak, a 32.5-acre salt marsh located on the Passamaquoddy Tribe at Sipayik (Pleasant Point) Reservation in Maine through partnership with Bates College's Professor Beverly Johnson, PHD, UMASS's Professor Jon Woodruff, PHD in collaboration with Sipayik Environmental Department, this effort integrates Traditional Ecological Knowledge with Western sedimentological methods to develop field protocols, laboratory workflows, and baseline sediment characterization for a culturally and ecologically significant marsh system.

Specifically, this study (1) describes the creation of a Tribal sediment and carbon core laboratory, (2) presents Indigenous-led field and laboratory protocols for salt marsh sediment sampling and analysis, and (3) provides initial baseline observations of sediment stratigraphy relevant to long-term blue carbon assessment(4)Provides an overall health assessment of Kcipeskiyak(5)Provides the Tribe with Historical Data so as to return to Precolonial Capacity. A central contribution of this work is the documentation of the first Indigenous-owned and operated sediment and carbon core laboratory in the United States, established to support Tribal stewardship priorities and climate research.

Beyond local application, this program is designed as a regional capacity-building model, providing training opportunities and laboratory access for other Wabanaki Tribes seeking to develop their own sediment and carbon monitoring programs. By centering Tribal leadership, data sovereignty, and intergenerational knowledge transfer, this study demonstrates how Indigenous-led science can strengthen salt marsh stewardship, advance blue carbon research, and offer a replicable framework for Tribal and coastal communities throughout the Gulf of Maine and beyond.

Study Area

Kcipeskiyak a Terraformed Salt Marsh

Kcipeskiyak is a 32.5-acre salt marsh located on the Passamaquoddy Tribe at Sipayik (Pleasant Point) Reservation along the eastern Maine coast, within the Passamaquoddy Bay region of the Gulf of Maine. The marsh is currently in a state of disfunction due to Colonial Practices and Terraforming. The marsh occupies a low-lying coastal setting influenced by large semidiurnal tides characteristic of the Bay of Fundy system, which produces some of the highest tidal ranges in the world. These tidal dynamics, even though now blocked from a raised bike path to the north and the addition of County Road to the South have slowed active sediment exchange, periodic inundation, and the development of vertically accreting marsh platforms typical of high-energy, macrotidal environments.

The marsh was historically hydrologically connected to adjacent coastal waters through a network of tidal channels and creeks that facilitate sediment deposition and organic matter

accumulation. Historical vegetation and Micro Organism assemblages are characteristic of northern New England salt marshes, as well as some currently existing vegetation and include low- and high-marsh zones structured by tidal elevation and salinity gradients. The marsh functions as an important transitional ecosystem linking upland, freshwater, and marine environments within the broader Passamaquoddy Bay watershed.

Cultural and Ecological Significance

Kcipeskiyak holds long-standing cultural importance for the Passamaquoddy people, serving as a source of culturally significant plants, medicines, and materials, including sweetgrass (*Muhlenbergia* spp.), as well as habitat for fish and invertebrate species that support subsistence and small-scale fisheries. The marsh is understood within Passamaquoddy Traditional Ecological Knowledge as a living landscape shaped by reciprocal relationships among water, sediment, plants, animals, and people.

Ecologically, the marsh provides essential habitat for a range of species, functioning as a nursery and refuge for finfish, shellfish, and migratory birds, while supporting benthic and invertebrate communities that underpin coastal food webs. These ecological functions are closely aligned with cultural values emphasizing stewardship, seasonal observation, and intergenerational knowledge transfer. Community observations of vegetation change, sediment movement, and tidal patterns have informed stewardship priorities and guided site selection for sediment core sampling.

Historical Context and Restoration Setting

Like many salt marshes in the northeastern United States, Kcipeskiyak has experienced historical modifications associated with regional land-use practices, hydrologic alteration, and coastal development. Past activities, including ditching and changes to tidal flow via the addition of a main road to the south and a bike path to the north, have altered marsh hydrology and sediment dynamics, contributing to concerns regarding marsh resilience under accelerating sea-level rise.

In response, the Passamaquoddy Tribe, through the Sipayik Environmental Department, has prioritized Kcipeskiyak for long-term stewardship, monitoring, and restoration planning. Current efforts emphasize understanding baseline sediment conditions, restoring natural hydrologic connectivity where feasible, and establishing monitoring frameworks capable of tracking ecological change over time. The development of a Tribal sediment and carbon core sampling program at Kcipeskiyak is intended to support these goals by generating foundational data necessary for informed decision-making and adaptive management in a rapidly changing coastal environment.

Methods

Indigenous-Led Research Framework and Governance

This study was designed and implemented under the leadership of the Passamaquoddy Tribe at Sipayik through the Sipayik Environmental Department. Research priorities, site selection, field protocols, and data governance were established by Tribal staff in consultation with community knowledge holders and academic collaborators. Traditional Ecological Knowledge (TEK), including long-term observations of tidal patterns, vegetation change, sediment movement, and marsh use, informed both the spatial focus of the study and the interpretation of observed sediment characteristics.

All data generated through this project are governed by Tribal data sovereignty principles. The Passamaquoddy Tribe retains ownership of samples, analytical results, and derived datasets, with data sharing conducted through collaborative agreements that prioritize Tribal consent, appropriate attribution, and community benefit. Academic partnerships were structured to support capacity building, training, and technical exchange while maintaining Indigenous leadership over research direction and outcomes.

Site Selection and Sampling Design

Sediment core sampling locations within Kcipeskiyak were selected using a combination of field reconnaissance, TEK-informed observations, and geomorphic assessment of marsh elevation and hydrologic connectivity. Sampling sites were chosen to represent intact marsh platform areas with minimal visible disturbance and consistent vegetation cover, thereby maximizing the likelihood of preserved stratigraphy suitable for long-term sediment and carbon analysis.

At each selected location, sediment cores were collected to capture vertical profiles spanning recent and historical marsh deposition. Geographic coordinates were recorded using handheld GPS units to ensure repeatability and facilitate future resampling. Field notes documented vegetation type, surface conditions, tidal stage, and any evidence of disturbance at the time of sampling.

Sediment Core Collection

Sediment cores were collected using manual coring techniques appropriate for fine-grained salt marsh sediments. Coring equipment included hand-driven push corers and peat corers capable of recovering continuous sediment profiles while minimizing compaction and disturbance. Core lengths varied depending on sediment resistance and site conditions but were sufficient to capture multiple stratigraphic layers relevant to marsh development and carbon accumulation.

Following extraction, cores were capped, labeled, and transported to the Sipayik Environmental Department's Tribal sediment and carbon core laboratory for processing. Care was taken to maintain core orientation and integrity during transport and storage. Field protocols emphasized consistency across sampling locations to support comparative analysis and long-term monitoring.

Laboratory Processing and Stratigraphic Analysis

Upon arrival at the laboratory, sediment cores were refrigerated prior to processing. Cores were split longitudinally, photographed, and described following standard sedimentological

procedures. Visual descriptions included color, texture, organic content, presence of root material, and identifiable stratigraphic boundaries.

Subsampling intervals were established based on observed stratigraphy and analytical needs. Sediment samples were collected for determination of bulk density, organic matter content, and carbon concentration using established laboratory methods. Where applicable, subsamples were retained for future analyses, including radiometric dating and additional geochemical characterization, as analytical capacity expands.

All laboratory procedures were conducted by trained Tribal staff, with technical guidance and quality-control support provided through academic partnerships. Laboratory protocols were documented to ensure reproducibility and facilitate training of additional personnel.

Capacity Building and Training

A central component of this project was the development of Tribal capacity for independent sediment and carbon analysis. Tribal staff received hands-on training in field coring techniques, laboratory processing, data documentation, and sample management. Training was conducted collaboratively with academic partners from regional universities and emphasized skill transfer, protocol development, and long-term sustainability of monitoring efforts.

The Tribal sediment and carbon core laboratory was established not only to support research at Kcipeskiyak, but also as a regional resource for other Wabanaki Tribes. The laboratory framework includes provisions for future training workshops, shared access to analytical equipment, and collaborative research initiatives designed to expand Indigenous participation in coastal monitoring and blue carbon research across the Gulf of Maine.

Ethical Considerations

This research was conducted in accordance with Tribal research protocols and ethical standards emphasizing respect, reciprocity, and responsibility. Community engagement and transparency were prioritized throughout project development and implementation. The integration of TEK was undertaken with care to avoid misrepresentation or extraction of culturally sensitive knowledge, ensuring that Indigenous knowledge holders maintain control over how their knowledge is shared and applied.

Results

Sediment Core Recovery and Integrity

Sediment cores were successfully recovered from all selected sampling locations within Kcipeskiyak. Core lengths varied among sites based on local sediment conditions and resistance, but all cores retained sufficient length and structural integrity for stratigraphic description and laboratory processing. Minimal compaction and disturbance were observed during core extraction, and continuous vertical profiles were preserved across sampling depths.

Core recovery was consistent across marsh platform locations characterized by intact vegetation cover and regular tidal inundation. Visual inspection during field collection and laboratory processing indicated that the coring methods employed were effective in capturing representative sediment profiles suitable for baseline characterization and future analytical work.

Stratigraphic Characteristics

Visual stratigraphic analysis of split cores revealed distinct sediment layering typical of northern New England salt marsh environments. Sediments were predominantly fine-grained, with alternating layers of organic-rich material and mineral sediments. Root structures were present throughout much of the core profiles, indicating sustained vegetative growth and in situ organic matter accumulation over time.

Color variation and textural changes were observed within and among cores, suggesting shifts in depositional conditions consistent with tidal influence and marsh development processes. Stratigraphic boundaries were generally well-defined, allowing for clear identification of depositional units and supporting the suitability of the cores for subsequent subsampling and chronological analysis.

Organic Matter and Carbon-Relevant Indicators

Sediment characteristics indicative of organic matter accumulation were observed across all cores. Organic-rich horizons were present at multiple depths, with visible plant material and root matter contributing to sediment structure. These features are consistent with conditions favorable for long-term carbon burial in salt marsh systems.

Bulk sediment texture and preservation of organic material suggest low-oxygen depositional environments typical of salt marsh settings, which are conducive to the retention of organic carbon. While full quantitative carbon analyses are ongoing, the observed sediment properties indicate that Kcipeskiyak contains stratigraphic sequences appropriate for assessing blue carbon storage and accumulation through future analytical work.

Suitability for Long-Term Monitoring and Analysis

The integrity and stratigraphic clarity of the recovered cores demonstrate the suitability of Kcipeskiyak for long-term sediment and carbon monitoring. Core preservation supports future analyses including bulk density determination, organic carbon quantification, and radiometric dating to establish sediment accumulation rates and carbon sequestration timelines.

The successful recovery and processing of sediment cores also validate the effectiveness of Indigenous-led field and laboratory protocols developed through this project. These results establish a foundational dataset for ongoing monitoring at Kcipeskiyak and provide a methodological baseline that can be applied in other Tribal salt marsh systems across the region.

Baseline Dataset Establishment

The sediment cores and associated field and laboratory documentation generated through this study constitute the first baseline sediment dataset for Kcipeskiyak. These baseline observations provide a reference point against which future environmental change, restoration actions, and climate-driven impacts can be evaluated. The establishment of this dataset represents a critical step toward long-term, Tribe-led stewardship and adaptive management of the marsh.

Discussion

Implications for Salt Marsh Stewardship and Blue Carbon Research

The baseline sediment characteristics observed at Kcipeskiyak are consistent with those reported for intact salt marshes in the Gulf of Maine and other macrotidal systems, indicating conditions favorable for long-term sediment accretion and organic carbon burial. The presence of well-preserved stratigraphy and organic-rich horizons suggests that Kcipeskiyak has the capacity to store carbon over decadal to centennial timescales, reinforcing the importance of including Tribal salt marshes in regional blue carbon assessments.

While comprehensive carbon quantification and sediment accumulation rates are beyond the scope of this initial study, the establishment of baseline sediment conditions is a critical prerequisite for future blue carbon research. Without such baseline data, it is difficult to evaluate the effectiveness of restoration actions, assess vulnerability to sea-level rise, or integrate Tribal marshes into climate mitigation frameworks. The results presented here demonstrate that Indigenous-led monitoring programs can generate scientifically robust baseline data essential for advancing salt marsh and blue carbon science.

Integrating Traditional Ecological Knowledge and Western Science

A defining feature of this study is the intentional integration of Traditional Ecological Knowledge (TEK) with Western scientific methods throughout the research process. TEK informed site selection, sampling priorities, and contextual interpretation of sediment characteristics, drawing on long-term community observations of marsh dynamics, vegetation change, and tidal behavior. These knowledge systems complemented sedimentological analyses by providing temporal depth and place-based understanding that are often absent from short-term scientific datasets.

Rather than treating TEK as supplementary or anecdotal, this project positioned Indigenous knowledge as foundational to research design and stewardship decision-making. This approach enhanced the relevance and applicability of the monitoring framework, ensuring that scientific

outputs align with community priorities and lived experience. The integration of TEK and Western science demonstrated here offers a model for more holistic and culturally grounded salt marsh research that strengthens both scientific rigor and stewardship outcomes.

Indigenous Ownership of Monitoring Infrastructure and Data Sovereignty

The establishment of an Indigenous-owned and operated sediment and carbon core laboratory represents a significant shift in how coastal monitoring is conducted on Tribal lands. Ownership of laboratory infrastructure enables Tribes to control research timelines, analytical priorities, and data use, reducing reliance on external institutions and mitigating the risk of data extraction without community benefit. This model directly addresses longstanding barriers to Tribal participation in coastal science, including limited access to analytical facilities and concerns over data sovereignty.

By retaining governance over samples and datasets, the Passamaquoddy Tribe ensures that research outcomes support Tribal stewardship goals, regulatory needs, and intergenerational knowledge transfer. This approach also fosters continuity in long-term monitoring, which is essential for detecting gradual environmental change in salt marsh systems. The results of this study demonstrate that Tribal ownership of monitoring infrastructure is not only feasible but also enhances the quality, relevance, and durability of coastal research.

Capacity Building and Replicability for Other Tribal Communities

Beyond site-specific findings, this project was explicitly designed as a capacity-building initiative with regional applicability. Training Tribal staff in field coring, laboratory processing, and data management established local expertise that can support ongoing monitoring at Kcipeskiyak and beyond. The laboratory framework also provides a pathway for other Wabanaki Tribes to access sediment and carbon analysis while developing their own monitoring programs.

The methods and governance structures documented in this study are intentionally replicable, offering a scalable model for Indigenous-led salt marsh stewardship across diverse coastal settings. By emphasizing training, protocol transparency, and collaborative partnerships, this approach can be adapted by other Tribal and community-based organizations seeking to build long-term monitoring capacity grounded in local knowledge and sovereignty.

Management and Policy Relevance

The integration of Indigenous-led monitoring into salt marsh stewardship has direct implications for coastal management and climate policy. Baseline sediment and carbon data generated through Tribal programs can inform restoration planning, support climate resilience strategies, and contribute to regional and national assessments of blue carbon potential. Importantly, recognizing and supporting Tribal-led science aligns with growing calls from federal agencies to advance equity, co-production of knowledge, and community-based adaptation in environmental decision-making.

The Kcipeskiyak case study illustrates how Tribal leadership can strengthen the scientific foundation of salt marsh management while advancing culturally grounded stewardship. Incorporating Indigenous-led monitoring frameworks into agency partnerships and funding programs has the potential to expand the geographic and cultural scope of coastal science, resulting in more inclusive and effective responses to climate change.

Conclusions

This study documents the establishment of an Indigenous-led sediment and carbon core sampling program at Kcipeskiyak, a culturally and ecologically significant salt marsh on the Passamaquoddy Tribe at Sipayik Reservation in Maine. By integrating Traditional Ecological Knowledge with Western sedimentological methods, this work provides a foundational framework for long-term salt marsh stewardship grounded in Tribal leadership, scientific rigor, and data sovereignty.

The successful recovery of intact sediment cores and the identification of preserved stratigraphic sequences demonstrate the suitability of Kcipeskiyak for future blue carbon assessment and climate-related research. While this study focuses on baseline conditions rather than comprehensive carbon quantification, it establishes the critical groundwork necessary for evaluating marsh resilience, guiding restoration actions, and supporting adaptive management in a rapidly changing coastal environment.

Beyond site-specific findings, the development of an Indigenous-owned and operated sediment and carbon core laboratory represents a significant advancement in Tribal capacity for coastal monitoring. This model addresses longstanding gaps in the inclusion of Tribal lands in regional datasets and offers a replicable approach for other Wabanaki Tribes and coastal communities seeking to develop their own monitoring infrastructure.

Collectively, this work highlights the value of Indigenous-led science in strengthening salt marsh research and stewardship. By centering Tribal governance, intergenerational knowledge transfer, and collaborative partnerships, Kcipeskiyak serves as a model for advancing climate-resilient salt marsh stewardship that is both scientifically robust and culturally grounded.

Data Availability Statement

Data generated through this study, including sediment cores, laboratory analyses, and associated metadata, are governed by the Passamaquoddy Tribe at Sipayik under Tribal data sovereignty protocols. Due to the cultural significance of the study area and the Tribe's stewardship responsibilities, datasets are not publicly archived. Data may be made available upon reasonable request and subject to Tribal approval and data-sharing agreements that ensure appropriate use, attribution, and community benefit.

Author Contributions Statement

Bruce P. Doughty(Sipayik Environmental Dept.) led project conceptualization, study design, field sampling, laboratory development, data interpretation, and manuscript preparation.

Kyle Francis(Sipayik Environmental Dept.) contributed to field data collection, laboratory processing, protocol development, and community engagement.

Beverly Johnson PHD(Bates College) and Jon Woodruff PHD(UMASS) were **Academic collaborators** provided technical guidance, methodological support, training in sediment core analysis, and contributed to manuscript review and refinement.

All authors reviewed and approved the final manuscript.

Ethics Statement

This research was conducted under the authority of the Passamaquoddy Tribe at Sipayik and in accordance with Tribal research protocols and ethical standards. The study design, field activities, and data governance framework were led by the Sipayik Environmental Department and guided by principles of respect, reciprocity, and responsibility. Traditional Ecological Knowledge was incorporated with the consent and oversight of community knowledge holders, and care was taken to ensure that culturally sensitive information was not disclosed or misrepresented. All data generated through this work are governed by Tribal data sovereignty principles, and research outcomes are intended to directly support Tribal stewardship priorities and community benefit.

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