Student Corner

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Restoration efforts respond to climate change conditions in the Duck Harbor Basin of the Herring River, Wellfleet, MA

Introduction

While once thought of as wastelands, climate change has highlighted the social and economic importance of resilient salt marshes. Healthy salt marshes function as natural barriers to sea-level rise and storm surges, store carbon, and offer recreational opportunities to the public. Across New England, there has been an increase in efforts to restore the hydrologic function in degraded salt marshes that have been physically impacted by freshwater impoundments such as historical dikes and dams. One of the largest restoration efforts in New England to revive an impaired tidal salt marsh takes place in the Herring River in Wellfleet, Massachusetts. The Herring River watershed is in the towns of Wellfleet and Truro, Massachusetts, and spans 1,100 acres inside and outside the boundaries of Cape Cod National Seashore.

The Herring River watershed is dynamic in nature and consists of an interconnected ecosystem that begins at the headwater freshwater kettle ponds to estuarine tributaries that eventually converge with the saline waters of Wellfleet Harbor. The diverse ecosystems within the Herring River watershed provide crucial habitat for diadromous fish species, like alewife (*Alosa pseudoharengus)* and American eel (*Anguilla rostrata*), that use the Herring River corridor to complete their life cycles.

In 1909, a dike was constructed across the main stem of the Herring River that muted saltwater exchange from Wellfleet Harbor into the upper reaches of the river (Figure 1). In effect, the tidal exchange has been reduced from 10.3 feet on the seaward side to 2.2 feet on the upstream side of the dike (Mullaney et al. 2020). In response to the limited pulsing of saltwater upstream, the once expansive salt marsh transitioned into freshwater wetland and coastal forest habitat and conditions slowly degraded. The restricted tidal flushing has had adverse impacts on the upper Herring River that include increased fecal coliform bacteria, decreased water quality, impaired conditions for fish passage, increased mosquito habitat, and altered watershed plant communities (Mullaney et al. 2020, Portnoy and Allen 2006). Since 2003, the Herring River has been officially designated by the Environmental Protection Agency as an "impaired" system under the Clean Water Act.

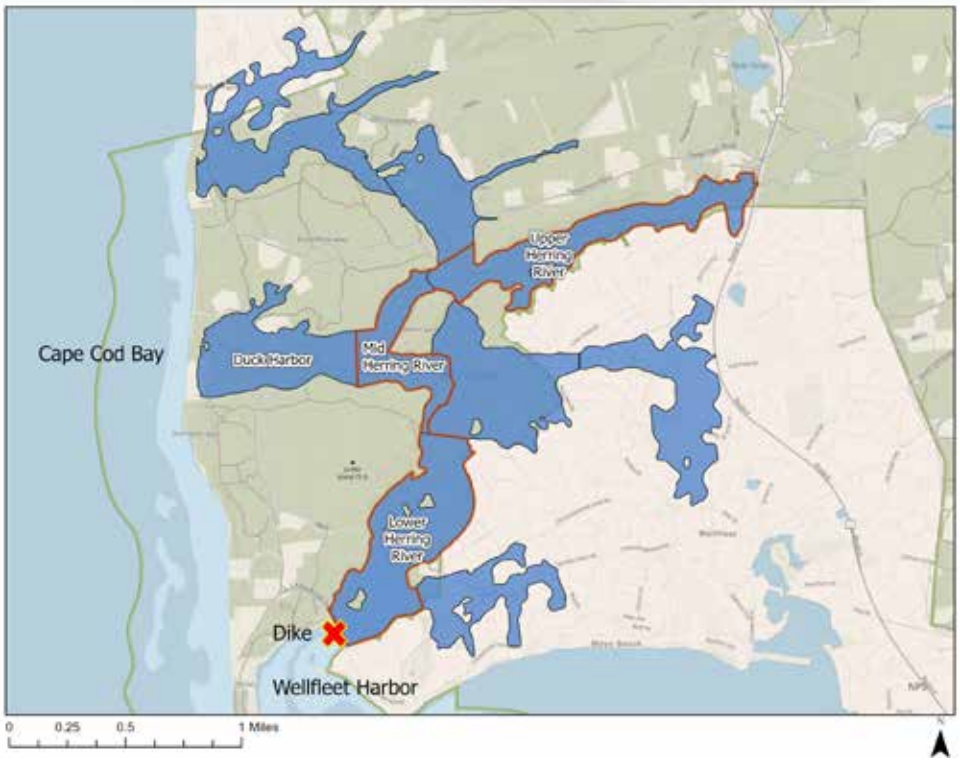

Figure 1. The 1,000-acre Herring River watershed was diked off from the Wellfleet Harbor in 1909 (blue). The red "X" represents the location at the mouth of the river where the historic dike currently exists. The main stem of the Herring River is outlined in orange. In addition to the main stem, the Herring River system contains several tributaries and sub-basins, including the Duck Harbor basin adjacent to Cape Cod Bay.

In response to the degraded ecological function of the watershed, Cape Cod National Seashore (National Park Service) issued a Final Environmental Impact Statement and Record of Decision in 2016 (National Park Service 2016) to implement the Herring River Restoration Project. The goal of the Herring River Restoration Project is to replace the historical dike with a new bridge equipped with adjustable tide gates to gradually reintroduce saltwater into the now freshwater portions of the estuary. The restored tidal exchange will revitalize the ecological functions of the Herring River, including the herring run it is named after, and create an opportunity for scientists to study the ecological

response of the watershed as conditions change.

The dynamics of Duck Harbor Beach, Wellfleet, MA

The Herring River watershed comprises multiple subbasins and includes the Duck Harbor Beach basin adjacent to Cape Cod Bay in Wellfleet, Massachusetts (Figure 1). As the name historically implies, Duck Harbor was once a harbor. Hand-drawn maps dating back to 1856 provide evidence that Duck Harbor was previously connected to Cape Cod Bay and included a tidal river system that traveled further landward (Baptista and Shumway 1998). Over time, the harbor mouth closed, and 3- to 5-meter-high dunes formed a protective barrier from Cape Cod Bay. As the barrier dunes developed, the low-lying basin behind the dunes transitioned from a salt marsh community to a mix of wetland shrubs and upland forest dominated by pitch pine (*Pinus rigida*).

In the fall of 2020, anecdotal reports of a tidal breach in the Duck Harbor dunes adjacent to Cape Cod Bay were reported and became evident by the winter of 2020 into 2021. As a result of rising sea levels in the adjacent Cape Cod Bay, the tidal breach allowed seawater from the bay to overwash and naturally inundate the low-lying wetland behind the dunes. Once the seawater overwashed into the Duck Harbor basin, the seawater flowed into the immediately adjacent freshwater portions of the Herring River through dilapidated mosquito ditches. The influx of seawater into the Herring River was detected on data loggers over a mile away from the breach and recorded the shift from oligohaline (0.5-5 ppt) to mesohaline (5- 18 ppt) and polyhaline (18-30 ppt) conditions (Figure 2). Since the initial breach reports, monthly higher high tides repeatedly overwash Duck Harbor beach and saltwater from Cape Cod Bay enters the upper Herring River and eventually exits out the dike.

Aside from instrumentation, the ecological response to saltwater pulsing became evident in the Duck Harbor vegetation composition. As the wetland shrubs and pitch pines were not able to recover from the repeated saline conditions, opportunistic salt marsh species began to colonize the basin

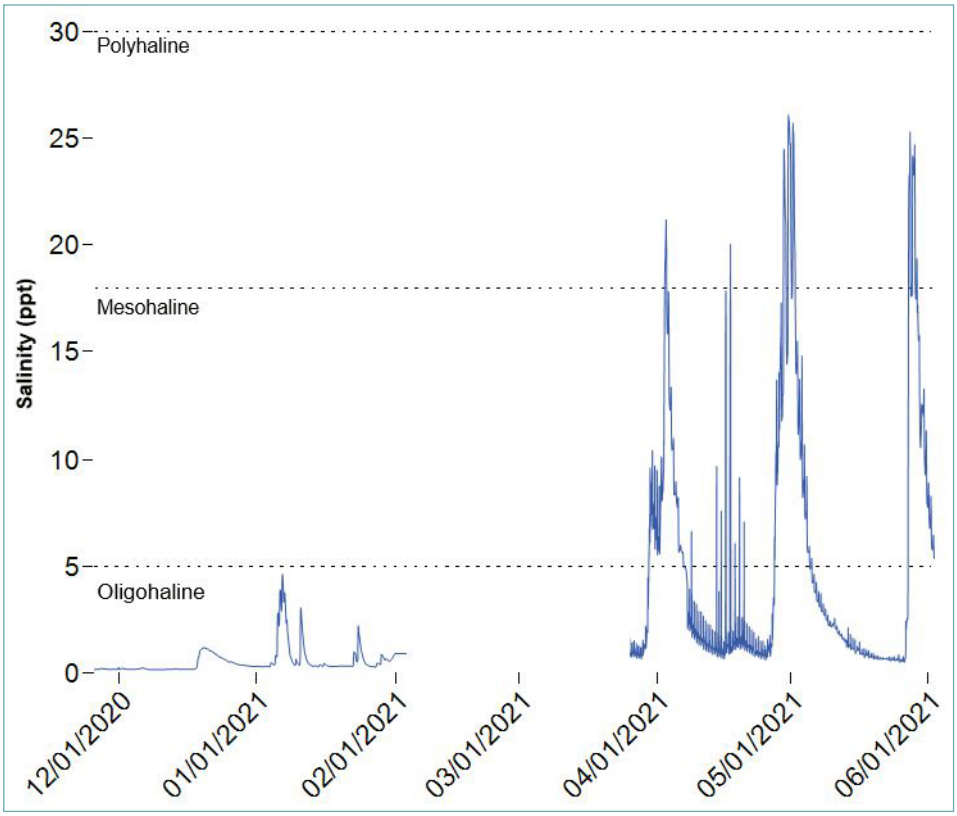

Figure 2. A continuous data logger within the Herring River initially detected the Duck Harbor tidal breach in December 2020 into February of 2021. In April 2021, the changes in salinity (ppt) from oligohaline to mesohaline and polyhaline during overwash events were evident within the Herring River Main stem.

beneath the remnants of the pitch pine forest. In a proactive effort to accelerate the recolonization of early successional salt marsh species in the basin, the dead standing pitch pines were manually cleared in the winter of 2023 and the wood chips were used as a substrate for the future marsh platform. Once light was able to penetrate the basin floor, early marsh colonizers, like sea blite (*Suaeda sp.)*, dominated the basin within the first growing season to begin the foundation for a hopeful trajectory toward self-sustaining salt marsh habitat (Figure 3). In addition to the immediate biological response of the plant community, American eels have been documented within the main marsh channel that transports seawater across the Duck Harbor basin.

Despite the introduction of saltwater from Duck Harbor into the Herring River, the overwash events are not associated with the Herring River Restoration Project. Instead, the Duck Harbor tidal breach creates a unique opportunity for scientists and collaborators to assess climate change impacts, such as sea level rise, on the Herring River system.

Macroinvertebrates as bioindicators

While the transition from a pitch pine forest to an early successional salt marsh is very visible to the naked eye, what happens to the communities that we cannot see such as benthic macroinvertebrates? Benthic macroinvertebrates are small aquatic organisms like worms, clams, and insect larvae that dwell on the river bottom. Macroinvertebrates are important because they play a key role in nutrient cycling, food web interactions, and can be used as bioindicators of water quality health. Although macroinvertebrates are widely used as bioindicators of water pollutants in streams, the impact of restored tidal flow on macroinvertebrates represents a gap in scientific literature.

Due to the importance of benthic macroinvertebrates in national water quality assessment standards, there is an

Figure 3. (Left) Low-lying wetland shrubs in the Duck Harbor basin in 2021 prior to the manual removal of trees. (Right) Early colonization of seablite in the first growing season in the Duck Harbor basin post manual removal of trees.

interest in the scientific community to determine the lethal and sublethal thresholds of saltwater influxes to freshwater macroinvertebrates. One challenge when assessing macroinvertebrates is the taxonomic level to which specimens are identified. In some instances, sensitive macroinvertebrate orders, such as mayfly larvae (Ephemeroptera), are known to include salt intolerant genera that may be missed when studies are identified to the higher order classification (Timpano et al. 2018). In further complexity, tolerance of taxa to saltwater can differ based on geographic region that speak to the need for macroinvertebrate studies in localized habitats such as the Herring River watershed.

Understanding the tolerance of taxa to saltwater intrusion is especially important in climate change scenarios where sea level rise and natural berm breaching can result in intrusion of saltwater into freshwater aquatic habitat. Sometimes this can unexpectedly precede planned management efforts. Climate change scenarios such as the tidal breach at Duck Harbor in Wellfleet, MA, create pertinent opportunities for scientists to better understand salinization impacts on freshwater macroinvertebrates, especially if baseline data already exist.

In anticipation of the ecological structure of the Herring River watershed changing, Cape Cod National Seashore implemented an adaptive management monitoring program in addition to hydrodynamic models to monitor baseline conditions in the system before and after the dike is removed and tidal flow is restored. The baseline monitoring occurred in 2013-2015 and included over 50 spatial locations located downstream of the dike that extended into the freshwater portion of the Herring River system. The purpose of this project was to document the spatial distribution of benthic macroinvertebrates, among other variables, within varying salinity gradients prior to restored tidal flow.

Future macroinvertebrate research in the Herring River

To better understand the recent impact of the Duck Harbor tidal breaches on the freshwater segments of the Herring River, a study is currently being undertaken to observe how intermittent fluxes of seawater affects the freshwater macroinvertebrate community in comparison to baseline data. In August of 2023 macroinvertebrates and water quality readings were collected at a subset of the baseline sampling locations at three salinity strata in the Herring River (Figure 4). The sampling locations were divided into three categories to include the Duck Harbor tidal breach impact zone, one marine reference zone, and one freshwater reference zone. The results from this project will provide insight on the biological response of

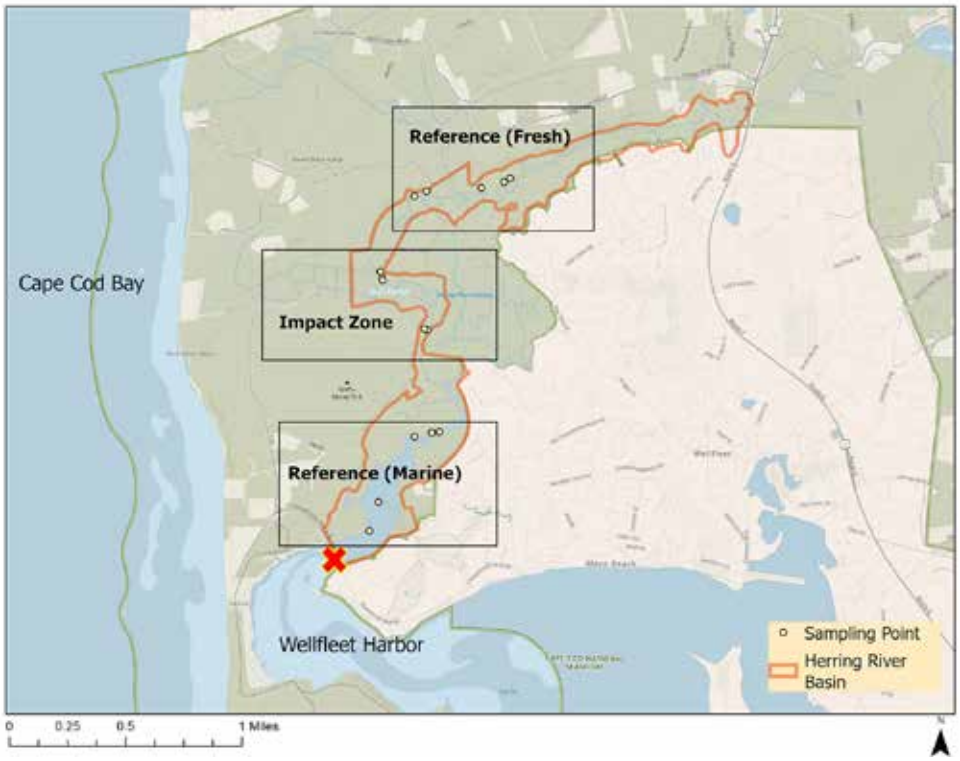

Figure 4. The location of 15 sampling points surveyed in August of 2023 for macroinvertebrate and water quality readings. The sampling locations were located throughout the marine reference zone, the Duck Harbor impact zone, and the freshwater reference zone.

macroinvertebrate community to partial tidal restoration as a result of the Duck Harbor tidal breach in the Herring River. On a larger scale, the results can inform the model and management on what to expect when the full tidal exchange is restored to remaining portions of the river.

Conclusions

In response to increased sea levels in Cape Cod Bay, a tidal breach formed at Duck Harbor Beach in Wellfleet, MA, in the winter of 2020/2021 that resulted in the intrusion of seawater into the low-lying basin and freshwater portions of the Herring River. Cape Cod National Seashore proactively responded to the repeated overwashes by manually removing salt-killed vegetation to accelerate the recolonization of early successional salt marsh species. The immediate response of the plant and biological community within the basin provides hope for the return of a functional salt marsh. Although the return of the salt marsh plant community allows the basin to appear as a salt marsh, how can we determine if the restored area will function like a salt marsh too? These functions can be measured by the chemical and physical response of the salt marsh that are imperative for ecological functions and long-term success in the Duck Harbor basin. The National Park Service has teamed up with U.S Geological Survey and local scientists to assess the cumulative responses and changes in the Duck Harbor system to include variables such as macroinvertebrate structure, nutrient loading, and geomorphology of the overwash. In effect, these successful partnerships create a unique opportunity to collect data at different scales and share research findings that can offer solutions in response to climate change impacts.

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Acknowledgements

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Kaitlyn Button is currently finishing her Master of Science degree innatural resource conservation at Paul Smith's College. In her most recent role as a biological science technician at Cape Cod National Seashore, she has monitored coastal aquatic resources, including the Herring River, for the past four years. She is interested in learning how climate change scenarios like increased water temperatures and sea level rise impact natural resources within the National Seashore and other protected lands. Her final master project focuses on the impact of saltwater intrusion on freshwater macroinvertebrates in the Herring River, Wellfleet, MA.