Participatory Science in Boston Harbor: Bridging Research and Outreach

Anne E. O'Connell

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PARTICIPATORY SCIENCE IN BOSTON HARBOR:
BRIDGING RESEARCH AND OUTREACH

A Thesis Presented
by
ANNE E. O’CONNELL

Submitted to the Office of Graduate Studies,
University of Massachusetts Boston,
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
August 2022

Environmental Sciences Program
PARTICIPATORY SCIENCE IN BOSTON HARBOR: 
BRIDGING RESEARCH AND OUTREACH

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by
ANNE E. O’CONNELL

Approved as to style and content by:

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Chairperson of Committee

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Mark Borrelli, Senior Research Fellow
Member

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Robert Stevenson, Associate Professor
Member

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Crystal Schaaf, Graduate Program Director
Environmental Sciences Program

_____________________________
Robert F. Chen, Interim Dean
School for the Environment
ABSTRACT

PARTICIPATORY SCIENCE IN BOSTON HARBOR:
BRIDGING RESEARCH AND OUTREACH

August 2022

Anne E. O’Connell, B.S., Boston College
M.S., University of Massachusetts Boston

Directed by Professor Robert F. Chen

Participatory science programs are becoming effective mechanisms to provide members of the public opportunities to be involved in scientific research worldwide. In the city of Boston, coastal resilience research is of particular interest to researchers, policy makers, and members of the public due to the threat of up to two meters of sea level rise by the year 2100. As part of the outreach and education initiative at the Stone Living Lab, community members were trained to use the Emery method of beach profiling and conducted measurements at twelve different sites around Boston harbor. The sites were visited during the period of April through December of 2021 to initiate a record of beach elevation change around greater Boston Harbor. The results of this yearlong project reveal that participants successfully used the Emery method to measure beach profiles at multiple sites. These data
are useful to delineate wave energy levels of beach sites, characterize seasonal trends, and assess individual storm impacts. The results of the project have been useful both in terms of collecting scientific beach elevation data, broadening the number of shoreline change measurements than what was possible for the Stone Living Lab core research team alone, building a network of community members interested in the future of our shorelines, and engaging thirty-five participants in authentic, meaningful coastal research. Successes and suggestions for improvements of future participatory science efforts are discussed.
ACKNOWLEDGEMENTS

This project would not have been possible without the dedication of our volunteers Chris Mancini, Ed Dobbins, Wendy Fox, Heidi Baker, Roseann Trionfi-Mazzuchelli, Kathleen Kennedy, Amina Miliani, Jeremy Reger, Yue Ma, Monica Peng, Maria Lyons, Judy O’Leary, Gwendolyn Tisch, Lunci Valentine, Peter MacLean, Gwen MacLean, Joyce Pun-Flynn, Sara Grady, Julianne Sullivan, Jacquelyn Devin, Deedy Wyman, Calista Wyan, Jason McCann, and more! Further support from Bob Chen, Mark Borrelli, Bryan McCormack, Rebecca Shoer, and Kayla Bradley with the Stone Living Lab made this project a big success.
# TABLE OF CONTENTS

ACKNOWLEDGEMENTS ........................................................................................................ vi

LIST OF FIGURES ................................................................................................................ viii

LIST OF TABLES .................................................................................................................... x

CHAPTER

| I. INTRODUCTION AND CONTEXT ................................................................. | 1 |
| II. BEACH PROFILING – THE PROJECT ......................................................... | 7 |
| II.A - Project Overview ................................................................. | 7 |
| II.B - Project Timeline ................................................................. | 8 |
| II.C – Methodology ................................................................. | 9 |
| II.D - Research Questions ................................................................. | 13 |
| II.D.1 - Evaluating Profiling Methods– RTK-GPS vs. Emery ............... | 13 |
| II.D.2 – Inner Harbor vs. Outer Harbor Sites ....................................... | 25 |
| II.D.3 - Case Study: Wollaston Beach ...................................................... | 35 |
| II.E - Conclusions and Further Exploration ........................................... | 47 |
| III. PARTICIPATORY SCIENCE – THE PROGRAM ......................................... | 49 |
| III.A – Perspective Importance .......................................................... | 49 |
| III.B – Research Questions ................................................................. | 50 |
| III.B.1 – Program Participants ............................................................... | 51 |
| III.B.2 – Continued Engagement ............................................................ | 54 |
| III.B.3 – Volunteer-inspired Improvements ............................................... | 59 |
| III.D – Program Success Summary ......................................................... | 63 |
| IV. SUMMARY ................................................................................................. | 67 |

REFERENCE LIST .............................................................................................................. 71
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1: Volunteers profiling at Nahant Beach, May 2021</td>
<td>5</td>
</tr>
<tr>
<td>Figure 2: Timeline of SLL Beach Profiling Project</td>
<td>9</td>
</tr>
<tr>
<td>Figure 3: Schematic of Emery Method Use</td>
<td>10</td>
</tr>
<tr>
<td>Figure 4: Example of RTK-GPS Tagged Benchmarks on Wollaston Beach</td>
<td>11</td>
</tr>
<tr>
<td>Figure 5: Contents of Stone Living Lab Beach Profiling Kit</td>
<td>12</td>
</tr>
<tr>
<td>Figure 6: Overhead view of 3 transects profiled with RTK and Emery methods on 5/23/22</td>
<td>15</td>
</tr>
<tr>
<td>Figure 7: Method Comparison (Emery vs. RTK-GPS) Along Wollaston Transect 1</td>
<td>16</td>
</tr>
<tr>
<td>Figure 8: Method Comparison (Emery vs. RTK-GPS) Along Wollaston Transect 2</td>
<td>16</td>
</tr>
<tr>
<td>Figure 9: Method Comparison (Emery vs. RTK-GPS) Along Wollaston Transect 3 (5.23.22)</td>
<td>16</td>
</tr>
<tr>
<td>Figure 10: 5-foot Mark Correction applied at Revere Beach (4&quot; removed from each elevation)</td>
<td>22</td>
</tr>
<tr>
<td>Figure 11: Sources of Error - 5-foot mark correction for Revere Beach Profile</td>
<td>23</td>
</tr>
<tr>
<td>Figure 12: Beach Study Site Map</td>
<td>26</td>
</tr>
<tr>
<td>Figure 13: Wave Model Results for Project Sites (Source: Kirshen et al., 2018)</td>
<td>28</td>
</tr>
<tr>
<td>Figure 14: Wollaston Beach Profile Envelope and Max Beach Elevation Spread</td>
<td>30</td>
</tr>
<tr>
<td>Figure 15: NWS Wave Heights (Source: National Weather Service, Pulled 6/17/22)</td>
<td>31</td>
</tr>
<tr>
<td>Figure 16: Observed lower (&lt;2 ft elevation range) and higher (&gt;2 ft range) beach sites</td>
<td>32</td>
</tr>
<tr>
<td>Figure 17: Graph of Modeled Storm Wave Height &amp; Max Observed Profile Difference</td>
<td>33</td>
</tr>
<tr>
<td>Figure</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>Figure 18: Wollaston Beach Complete Beach Profile Envelope</td>
<td>38</td>
</tr>
<tr>
<td>Figure 19: Wollaston Average Area Under Profiles (Elevations over NAVD88, Along Transect 2)</td>
<td>38</td>
</tr>
<tr>
<td>Figure 20: Pre-and post-July storm transects on Wollaston Beach for A) Transect 1, B) Transect 2, and C) Transect 3</td>
<td>41</td>
</tr>
<tr>
<td>Figure 21: All Transects Along Wollaston Beach A) Pre-Storm (7/6/21) and B) Post-Storm (7/16/21)</td>
<td>42</td>
</tr>
<tr>
<td>Figure 22: Wollaston Transects 1-3 and Groins</td>
<td>43</td>
</tr>
<tr>
<td>Figure 23: pre-and post-October storm transects on Wollaston Beach for A) Transect 1, B) Transect 2, and C) Transect 3</td>
<td>45</td>
</tr>
<tr>
<td>Figure 24: All transects along Wollaston Beach A) Pre-storm (10/14/21) and B) Post-storm (10/28/21)</td>
<td>46</td>
</tr>
<tr>
<td>Figure 25: Wollaston Beach Photos Pre- and Post- Nor’easter</td>
<td>47</td>
</tr>
<tr>
<td>Figure 26: Timeline of beach site visits April-December of 2021</td>
<td>51</td>
</tr>
<tr>
<td>Figure 27: Site selection category and continued SLL engagement</td>
<td>55</td>
</tr>
<tr>
<td>Figure 28: Beach Profiling Time Commitment and Continued Engagement</td>
<td>56</td>
</tr>
<tr>
<td>Figure 29: Volunteer perception of value of beach profile vs. comfortability communicating project with others</td>
<td>65</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1: Differences in RTK-Emery Method for Transects 1, 2, and 3</td>
<td>17</td>
</tr>
<tr>
<td>Table 2: Differences in RTK-Emery Methods for Different Portions of Profiles</td>
<td>19</td>
</tr>
<tr>
<td>Table 3: Comparison of Emery Error Range Estimates</td>
<td>20</td>
</tr>
<tr>
<td>Table 4: Max Modeled Nor'easter Wave Height vs. Max Observed Range in Profile Elevation</td>
<td>32</td>
</tr>
<tr>
<td>Table 5: Precipitation Data from Hingham COOP Station (NOAA), wind and wave data from Massachusetts Bay Buoy (NOAA, Station 44013 (LLNR 420))</td>
<td>39</td>
</tr>
<tr>
<td>Table 6: Volumetric Analysis for July and October storms</td>
<td>43</td>
</tr>
<tr>
<td>Table 7: Estimated time spent by project participants March - December of 2022</td>
<td>52</td>
</tr>
<tr>
<td>Table 8: Volunteer Continued Engagement</td>
<td>58</td>
</tr>
</tbody>
</table>
CHAPTER I
INTRODUCTION AND CONTEXT

Participatory science programs provide opportunities for members of the public to take part in and contribute to ongoing scientific research. The field of participatory science is incredibly broad and can follow many different models (US EPA, 2022). Universities, non-profit organizations, and government agencies alike run programs designed to invite members of various stakeholder groups to engage with their own scientific initiatives. Though the protocols followed by participants in these programs are designed to be simple and accessible, the information gathered by these individuals is not trivial. As participants in a well-designed program, members of the public gather high quality data that is very useful for researchers, educators, planners, and other decision makers (Guerrini et al., 2018). Well-designed programs also allow for participants to have an input into what, how, and where research is conducted, a practice than can ensure meaningful project outcomes for both participants and researchers. A network of many participatory scientists allows for much more information to be gathered than by a small group of researchers, which makes these program an invaluable tool (Balazs & Morello-Frosch, 2013; Guerrini et al., 2018; Jakositz et
This is especially true for research in the marine research field, and programs that engage members of the public could become a major component of research in the next few critical decades due to their unique capability to expand the scope of research investigations (Thiel et al., 2014).

These types of programs are often also referred to as citizen science, crowd science, or simply volunteer monitoring. Involving members of the public in scientific investigation has existed for a long time (Eitzel et al., 2017), but the term Citizen Science was first coined by researchers in the 1990s (Irwin, 1995; Bonney, 1996). The popularity of the practice has increased since then, and the citizen science is the most commonly used terminology in the literature. Resources such as the journal Citizen Science: Theory and Practice (https://theoryandpractice.citizenscienceassociation.org) and the Federal Crowdsourcing and Citizen Science Toolkit (https://citizenscience.gov) use the term citizen science as an umbrella term for different structures of research that involves members of the public (Eitzel et al., 2017).

In recent years, many organizations have chosen to phase out the term citizen science in favor of community science to ensure that non-citizens are included and feel comfortable engaging in these types of projects. However, it should be noted that the term community science originated in reference to grassroots scientific initiatives spearheaded by community members that help drive the objectives of the research. (Cooper et al., 2021). Most recently, the US EPA has settled on the term participatory science in an effort to delineate their public participation programs from research efforts that originate in communities (US EPA, 2022). The ongoing conversation regarding the best terminology to use when describing these
programs will continue, but the term participatory science captures the values of inclusivity and accessibility that is at the heart of these types of programs without overstepping into true community originated science research efforts (US EPA, 2022).

In Boston, a city with 47 miles of coastline, participatory science efforts focused on coastal resiliency research are of particular interest. Given the accelerating rate of sea level rise paired with the increase in frequency and intensity of extreme precipitation events, Boston’s shores are at the forefront of many policy makers (Douglas & Kirshen, 2022). A recent report by the Greater Boston Research Advisory Group estimated that sea levels in Boston could rise anywhere from 35 centimeters to 2 meters in Boston by 2100, depending on the projection model used. Many parts of the city already experience coastal flooding during especially high tides (City of Boston, 2016), but this is rapidly becoming an issue that will impact more and more residents.

Partnerships between non-profits, government organizations, academic institutions, and community members can play a role in the ongoing and upcoming conversations about coastal resilience decisions (Nichols et al., 2019). The Stone Living Lab, a new collaborative initiative seeks to do just that by utilizing Boston Harbor as a dynamic outdoor laboratory for both research and education (www.stonelivinglab.org). The main objective of the lab’s core research is to help increase the tools available for people like developers and regulators so they can make decisions that prepare Boston’s shorelines for a sustainable future in the best way possible. An important component of this work is to engage a wide range of perspectives in contributing to our sustainable future. Participatory science is a great way to involve members of the public in active areas of scientific research in a hands-on way. Once trained,
volunteers can reliably collect valuable data that can be used to inform ongoing studies and refine new research questions (Slovinsky & Dickson, 2019; Ward et al., 2021).

Examples of these programs in the greater Boston area include gathering monthly water samples to be tested for water quality (Neponset River Watershed Association), counting fireflies in your backyard (Mass Audubon), or mapping urban heat islands using equipment on loan from the Museum of Science (Wicked Hot Boston, 2019). Some programs do not even require leaving home – you can count herring passing by an underwater webcam (Mystic River Watershed Association), or help classify kelp forests for UMass Boston researchers who have partnered with NASA (Floating Forests).

Typically, participatory science programs operate with an indefinite timeline – the goals are to continue to have the most up to date information, like with the Neponset River Watershed Association water quality monitoring program, or to build a long-term record of data like the beach profiling programs in New Hampshire and Southern Maine. Rather than choosing one research area to focus a participatory science program on, the Stone Living Lab has adopted an annual model where the project and research focus will change each year. This allows different lead scientists to have the opportunity to utilize the participatory science model to complement their own research as part of the lab.

The first program ran from April – December of 2021 and focused on beach profiling. This was designed as a complimentary research venture to Dr. Mark Borrelli’s island sedimentation, sea level rise, and coastal resiliency research efforts out on the Boston Harbor Islands. The Stone Living Lab began recruiting volunteers to participate in the community science program in early 2021, and the network has continued to grow since then. Volunteers
were trained to use the Emery method of beach profiling to track monthly elevation change at
twelve different beach sites around Boston harbor (Figure 1). This method was developed in
the 1970s by oceanographer K.O. Emery (Emery, 1971), and remains a low cost but effective
and reliable method to measure beach profiles. The long-term goals of the Stone Living Lab
participatory science program are to continue to gather meaningful scientific quality
information that can complement the core research being done around Boston Harbor, but
also to build a community and increase engagement over time.

Figure 1: Volunteers profiling at Nahant Beach, May 2021
The framework of the Stone Living Lab’s participatory science program lies somewhere between researcher-led and community-led scientific inquiries. The lab provides training, technology, analysis of results, and access to academic researchers that members of the public typically would not have. The community participants drive their own experiences by choosing their location based on personal interest, importance, or ease of access. They are also encouraged to ask researchers questions and report any interesting observations that could drive future research projects.

The five key steps to developing a successful participatory science project laid out in the Citizen Science Toolkit (CitizenScience.Gov) are 1) scope your problem, 2) design a project, 3) build a community, 4) manage your data, and 5) sustain and improve your project. These steps were adapted from a 2009 paper published by Rick Bonney (Bonney et al., 2009), one of the original users of the term citizen science and a very respected figure in the field. This thesis seeks to evaluate the benefits and usefulness of the data gathered during this annual short-term participatory science model after the first year of the program by considering each step of this process. Research questions that emphasize both scientific and social program benefits help focus the evaluation on the strengths of this model.
II.A - Project Overview

The shores of greater Boston Harbor are home to several beaches that serve as special places for recreation, exercise, and relaxation for residents of the city and surrounding towns. With sea levels rising and intense storms becoming more frequent due to climate change (City of Boston, 2016, Douglas & Kirshen, 2022), the future of many of these sites is uncertain. This uncertainty for the future of greater Boston Harbor’s beaches provides the scope of the problem for this participatory science project (Step 1, Citizen Science Toolkit).

Beaches are highly dynamic environments that are constantly in flux (Kennedy et al., 2019). Occasional beachgoers may not realize how much change is happening, but more frequent visitors know how different beaches can look at different times year. Wind, waves, and tidal action work together to constantly change the profiles of beaches. This is most noticeable during intense storms, when coastal cliffs can suddenly be washed away (erosion), or huge amounts of sediment can wash over the beach (Webb, 2021).
Beach profile changes can also happen more gradually on a seasonal basis (McPherran, 2017; Kennedy et al., 2019). During the winter, intense storms like Nor’easters pummel the shores and strip away sand from beaches over the course of a few months and stores it in offshore sand bars. Once the summer rolls around and the weather becomes calmer, the beach has a chance to accumulate sand again (accretion). Seasonal patterns are not necessarily seen every year. If there is a mild winter, there may not be as big of a seasonal change. In the event of an intense storm, that reservoir of offshore sand could be moved, and the beach will not be replenished that year. Measuring the profile of a beach on frequently or on a regular basis can tell us how the beach is responding to seasonal variations in weather and storms (Webb, 2021).

As part of the Stone Living Lab’s inaugural participatory science project, volunteers were trained to use a simple but effective technique called the Emery method (Emery, 1961) to measure beach profiles. The data produced using this method can be of high quality, similar to that or much more technically advanced methods such as Real-time Kinetic Global Positioning System or LIDAR measurements (Ferreira et al., 2012). Different beaches were visited from April to December of 2021 to help document profile changes happening on a monthly basis.

II.B - Project Timeline

The timeline of this beach profiling project is shown below (Figure 2).

- February 2021 – Core research and outreach team held meetings to compile volunteer materials and recruit volunteers
- March 2021 – Virtual Volunteer Training Held
• April 2021 – Completed Site Visits and used RTK-GPS to tag benchmarks at majority of the sites
• May 2021 – Trained Volunteers
• June – December 2021 – Volunteers collected monthly beach profiles, as well as occasional pre- and post- storm profiles.
• September 2021 – Virtual Volunteer Meeting Held with preliminary results
• February 2022 – Volunteer Appreciation Dinner held, and short report distributed to volunteers
• May 2022 – Wollaston Beach visited with RTK GPS to establish error of Emery Method
• June 2022 and Beyond – A handful of sites will continue to measure profiles on a seasonal basis (about once every 3 months)

**Figure 2: Timeline of SLL Beach Profiling Project**

**II.C – Methodology**

The project design (Step 2 – Citizen Science Toolkit) was modeled after nearby programs such as the New Hampshire Volunteer Beach Profile Monitoring Program (Eberhardt et al., 2022) and the Southern Maine Volunteer Beach Profile Monitoring Program (Slovinsky & Dickson, 2019). Beach profiling in general works well in this research framework because nothing permanent needs to be installed at study sites besides occasional
removable nails. Getting adequate permitting for more robust or permanent fixtures can be very difficult and time consuming and may adversely affect the environment, so this is an important consideration when choosing a project that will be able to get up and running quickly. The Emery method also lends itself to participatory science because of the relatively inexpensive cost of assembling a profiling kit as well as the simplicity of the profiling protocol.

The method works by using two poles attached by a rope to take incremental measurements of elevation change starting at the top of the beach and working down towards the water line (Figure 3). The horizon serves at a point of reference to use while measuring elevation change. Our rods were separated by a 6-foot rope so that volunteers could maintain a safe social distance during the height of COVID-19, but any known distance between the two poles will work.

![Figure 3: Schematic of Emery Method Use](image)

Each of the twelve beach sites were set up with three benchmarks – known locations from which to begin profile transects (Figure 4). At sites where easily recognizable
permanent structures were convenient, items or markings on these were used and recorded. At other sites, we installed small nails for volunteers to use as starting points. These benchmarks at most sites were geotagged using a Real Time Kinematic GPS (RTK-GPS). The RTK-GPS used was a Trimble® R10 Rover that utilizes a proprietary Virtual Reference System (VRS) via KeyNetGPS® that allows for the collection of RTK-GPS data points without needing a nearby known benchmark. This system has been shown to have centimeter level positional accuracy (Folta, 2015; Alkan et al., 2017). Sites without RTK-GPS tagged benchmarks still have physical benchmarks in place and will be visited in the coming months with an instrument so their absolute elevation is known.

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>Transect 1</th>
<th>Transect 2</th>
<th>Transect 3</th>
</tr>
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<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
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<td>42.27734</td>
<td>42.27663</td>
</tr>
<tr>
<td>Longitude</td>
<td>-71.0116</td>
<td>-71.01107</td>
<td>-71.00892</td>
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*Figure 4: Example of RTK-GPS Tagged Benchmarks on Wollaston Beach*

After attending a virtual training session, our volunteers were provided with a beach profiling “kit” including everything needed to perform beach profiling (Figure 5). They were met at their sites to perform the first measurements alongside researchers and given
instructions on how to submit data going forward. They were also provided with online resources such as instructional videos, written step-by-step protocols, and FAQ sheets to help them along with the process. Our volunteers were instructed to take these measurements once per month at a low tide that was convenient for them. We also sent out weather alerts via email to volunteers when there was a storm coming so that they could take pre- and post-storm profiles at their sites as their schedules allowed.

Figure 5: Contents of Stone Living Lab Beach Profiling Kit
II.D - Research Questions

To help evaluate the success of this model of a one-year limited participatory science program, several research questions were addressed. These evaluate the usefulness of the profile data gathered during this project from a scientific perspective (Step 4 – Citizen Science Toolkit).

1. Research Question 1: How accurate were measurements taken by participants using the Emery method?
2. Research Question 2: Did the inner harbor and outer harbor beach sites behave as expected?
3. Research Question 3: What ways can a short-term beach profile record be used?

II.D.1 - Evaluating Profiling Methods– RTK-GPS vs. Emery

Research Question 1: How accurate were measurements taken by participants using the Emery method?

Data collected using the Emery method are generally considered to be precise and accurate (Krause, 2004; Eberhardt et al., 2022). Ward et al. (2021) recently published a paper on a very similar beach profiling study and reaffirmed that the Emery method can yield repeatable (precise) results when measured along the same transect by two different volunteer groups. Less information is available about the actual accuracy of beach elevation profiles taken with the Emery method. Ideally, to estimate error concurrent profiles should be measured with the Emery method and compared to elevation measurements taken with an
instrument with established high accuracy, like the Trimble® R10 Rover used to establish benchmarks at the beach sites.

On May 23, 2022, Wollaston Beach was visited by volunteers equipped with their Emery Rod beach profiling kit and researchers with a high-tech Real-Time Kinematic GPS (RTK-GPS) instrument. Profiles with both methods were taken along three transects, starting at known benchmarks (Figure 6). A different model RTK-GPS called the Emlid Reach RS2 GNSS Receiver was used for this comparison. This model is a less expensive RTK-GPS option that works the same way as the Trimble® R10 Rover. It is advertised as having centimeter accuracy for lengths of up to 60 km (Reach RS2 Manual by Emlid), and a study has verified its accuracy within 5-centimeters (Hill et al., 2019). Concurrent profiles were taken so that each incremental elevation change measured by volunteers with the Emery method had a corresponding RTK-GPS point. Elevation measurements for the RTK-GPS are reported in meters above the NAVD88 vertical datum and converted to decimal feet for this comparison (National Geodetic Survey). The NAD83 (2011) datum is used for horizontal reference (Datums - National Geodetic Survey, n.d.). Because of the established accuracy of the Emlid Reach RS2 GNSS Receiver, elevation measurements taken with the RTK-GPS were considered the true elevations within the scope of this project. Elevation measurements taken with the Emery method were compared those taken with the RTK-GPS to establish an error range.
II.D.1.a – Results

For each transect measured at Wollaston beach on 5/23/22, the profiles generated using both the Emery and RTK-GPS methods were plotted (Figure 7, Figure 8, Figure 9). Visually, the profiles for both methods along Transects 2 and 3 were very close. The profiles taken along Transect 1 had a larger difference between the elevations measured with the different methods.
Figure 7: Method Comparison (Emery vs. RTK-GPS) Along Wollaston Transect 1

Figure 8: Method Comparison (Emery vs. RTK-GPS) Along Wollaston Transect 2

Figure 9: Method Comparison (Emery vs. RTK-GPS) Along Wollaston Transect 3 (5.23.22)
II.D.1.b – Error Range

In total, across all three profiles, 136 paired elevation measurements were generated. The difference in elevation for each point measured with the RTK GPS method and the Emery method was calculated. From there, the standard deviation and error of this difference was calculated to estimate a range of the differences between the two methods (Table 1).

When all three transects are considered, the mean difference between the RTK GPS and Emery methods was -0.191 feet, meaning that volunteers using the method were likely to come up with an elevation reading about 2.3 inches above the actual elevation level for each point along the transect. The standard deviation of 0.584 feet puts the range of the majority of possible values somewhere between 0.392 feet below the actual elevation and 0.772 feet above the true elevation.

<table>
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<th>STD Error</th>
<th>High Estimate</th>
<th>Low Estimate</th>
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<td>0.209</td>
<td>0.0312</td>
<td>0.112</td>
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<td>0.190</td>
<td>0.0283</td>
<td>0.513</td>
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<td>0.289</td>
<td>0.0295</td>
<td>0.413</td>
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<td>All Transects</td>
<td>-0.191</td>
<td>0.584</td>
<td>0.0497</td>
<td>0.392</td>
<td>-0.775</td>
</tr>
</tbody>
</table>

Table 1: Differences in RTK-Emery Method for Transects 1, 2, and 3

The two methods were much closer for transects 2 and 3. When only those two are considered, the mean difference between the RTK GPS method and Emery method was 0.124, meaning that elevation measurements taken with the Emery method were likely to be
about 1.5 inches above the “true” elevation as measured with the RTK GPS. The smaller standard deviation of 0.289 feet puts the range of values measured with the Emery method between 0.413 feet below the RTK-GPS measured elevation and 0.165 feet above.

**II.D.1.c – Cumulative Error**

As elevation measurements using the Emery method are taken along a transect, points recorded further away from the benchmark are more likely to be further from the “true” elevation measured using the RTK-GPS. This is because if the user of the Emery rods is making the same slight error each time, and the offset from the true elevation will increase with each point. This explains why the Emery profile for Transect 1 starts off closely fitting the RTK GPS profile but moves further away from it as the profile progresses.

When the three profiles are split into halves – a front 50% of point elevation readings and a back 50% - the front half has a mean difference of -0.0803 feet (and standard deviation of 0.373 ft), while the back half has a mean difference of -0.292 (standard deviation of 0.708 ft). The difference is further exaggerated when the profiles are split into quarters – the first quarter of the profiles have a mean difference of -0.0528 feet (standard deviation of 0.142). This increases through the second and third quarters and is highest within the fourth quarter at -0.405 feet (standard deviation of 0.696 ft) (Table 2).
II.D.1.e – Literature Comparison

In meters, the mean vertical deviation across all three transects converts to -0.05 meters with a standard error of 0.18 m. Recent evaluations of the Emery method in the literature support this observed range of error (Table 3). A 2016 paper evaluated 80 different Emery method profiles taken in Australia with concurrent RTK-GPS measurements and found that vertical deviations were approximately normally distributed with a mean of -0.03 meters and a standard deviation of 0.13 meters (Turner et al., 2016). Ward et al. (2021) did not attempt to assign exact error estimates to the profiles taken with the Emery method because they did not have concurrent profiles taken by volunteers and with an instrument using Global Navigation Satellite System (GNSS) positioning available to researchers. However, they did have measurements within a reasonably close timeframe for several beach sites that they used to estimate error. Based on comparisons of these profiles, they settled on a conservative approximation of an error of +/- 0.2 meters, giving an estimated error range of

<table>
<thead>
<tr>
<th>Profile Portion</th>
<th>Mean Difference (RTK - Emery)</th>
<th>STD Deviation from Mean</th>
<th>STD Error</th>
<th>High Estimate</th>
<th>Low Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Q</td>
<td>-0.0528</td>
<td>0.142</td>
<td>0.0259</td>
<td>0.0893</td>
<td>-0.195</td>
</tr>
<tr>
<td>2nd Q</td>
<td>-0.141</td>
<td>0.440</td>
<td>0.0791</td>
<td>0.299</td>
<td>-0.582</td>
</tr>
<tr>
<td>3rd Q</td>
<td>-0.174</td>
<td>0.712</td>
<td>0.117</td>
<td>0.537</td>
<td>-0.886</td>
</tr>
<tr>
<td>4th Q</td>
<td>-0.405</td>
<td>0.696</td>
<td>0.113</td>
<td>0.537</td>
<td>-1.100</td>
</tr>
<tr>
<td>Front Half</td>
<td>-0.0803</td>
<td>0.373</td>
<td>0.0459</td>
<td>0.293</td>
<td>-0.453</td>
</tr>
<tr>
<td>Back Half</td>
<td>-0.292</td>
<td>0.708</td>
<td>0.0829</td>
<td>0.417</td>
<td>-1.000</td>
</tr>
</tbody>
</table>

*Table 2: Differences in RTK-Emery Methods for Different Portions of Profiles*
-0.2 to 0.2 meters. These ranges are all close to one another, but the range from this study does exceed the Turner et al. (2016) and the lower bound of the Ward et al. (2021) estimation by a few centimeters. If another comparative profile outing were to be completed, more paired elevation data points would help constrain the standard deviation and tighten the range.

Table 3: Comparison of Emery Error Range Estimates

<table>
<thead>
<tr>
<th>Source</th>
<th>Mean Vertical Deviation</th>
<th>STD Deviation</th>
<th>Range (68% of points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLL Study</td>
<td>-0.05 m</td>
<td>0.18 m</td>
<td>-0.23 – 0.13 m</td>
</tr>
<tr>
<td>Turner et al., 2016</td>
<td>-0.03 m</td>
<td>0.13 m</td>
<td>-0.16 – 0.1 m</td>
</tr>
<tr>
<td>Ward et al., 2021</td>
<td>n/a</td>
<td>n/a</td>
<td>-0.2 – 0.2 m (est.)</td>
</tr>
</tbody>
</table>

Ward et al. (2021) also noted that error increased as elevation points taken with the Emery method approached the water line. This is consistent with the cumulative error that was observed on Wollaston Beach, especially noticeable in Transect 3. This phenomenon is further supported by the assertion that the Emery method is particularly sensitive to systematic errors which influence each point along a profile uniformly and end up skewing the overall elevation change at the seaward side of the profile (Krause, 2004).

II.D.1.f – Sources of Error

All three profiles were taken on the same day by the same volunteers, but the values from the Emery method recorded along Transect 1 were farther off from the RTK GPS values than along Transect 2 and 3. This is puzzling, but points to variation in accurate use of
this specific set of Emery rods, even within one site visit. Had points along only Transects 2 and 3 been evaluated, it may have appeared that the Emery elevation values were always closer to the “true” elevation values than the difference between the three different transects reveals.

There are several possible sources of error when using the Emery rods. First, we chose to use a telescoping pole for our unmarked reference rod so that it could collapse and be stored with the marked stadia rod (Figure 5). This makes it easier for transporting the rods, especially for volunteers who may have been using public transportation to get to their beach sites. However, in expanding and compacting the rods, there could be slight variations in height that could impact the overall accuracy of a profile. There are marked lines on the telescoping rod to help set the 5-foot mark at the correct height, but if these are not exactly matched up or they slip, the 5-foot mark could move. This could result in a positive or negative error relative to the true elevation.

Another source of error is the 5-foot mark itself. On the unmarked rods in our Emery Rod set, we included a phone holder attachment so that volunteers could use their smartphones to take pictures of the beach from the same height and location each visit. This led to some confusion with where the 5-foot mark was, because the two parts of the rod looked similar. We ran into this at Revere Beach, where the raw reported data appeared to be gaining elevation moving away from the benchmark and towards the water line (Figure 10). Knowing this was not possible, we talked to the volunteers, and they confirmed they had mistakenly been looking at the top of the phone holder attachment base, not the 5-foot line. Since they were consistently using the top of the pole, it was simple to correct the data by
subtracting the 4” (0.33 ft) difference from the elevation readings. After that, the beach profile looked much more reasonable. This specific error resulted in a very obvious positive skew from what the true elevation change would be.

Other possible sources of error include the unmarked rod making a deep depression in the sand that could skew the profile negatively and the levels on the rods and rope not being centered before taking a measurement. Krause (2004) found that the method works best on firm ground and introduced a footing pad to their rods to allow the rod to “float” on the sand and get more accurate results.

It seems most likely that in the case of Transect 1 on 5/23/22, the height of the 5-foot mark could have been mistakenly set slightly higher while adjusting the telescoping unmarked rod. Transect 1 was also the last profile done by volunteers during this outing, so fatigue or hurriedness could have been setting in. Adjusting the raw elevation change values

Figure 10: 5-foot Mark Correction applied at Revere Beach (4” removed from each elevation)
given by the volunteers by only 0.05 feet down yielded a profile that matched the RTK GPS method profile very neatly (Figure 11). It seems most likely this is useful information for two key reasons. First, it shows that even though there was an offset between the profile derived from the Emery method and the RTK GPS method, since the same error seems to have been repeated for each profile point, the basic morphology of the beach is still captured by the profile. Seeing how the shape of the beach changes from month to month is very useful to researchers, even if with the profile elevation errors, we saw in the comparison of the two methods. Secondly, it demonstrates how error when using the Emery method is cumulative. Systematic errors involved in the profiling process will impact each individual elevation point measured and create a larger margin of error towards the end of a profile. If you can isolate the error offset, you can correct the profile.

Figure 11: Sources of Error - 5-foot mark correction for Revere Beach Profile
II.D.1.g – Conclusions

Volunteers and researchers were able to combine efforts to produce an error analysis that can be applied to the larger dataset collected throughout this project. The average vertical error was found to be -0.05 meters with a standard deviation of 0.18m, which is close to values found in literature (Turner et al., 2016, Ward et al., 2021). Additionally, error was found to have a cumulative effect, growing from the beginning of the profile towards the end as systematic errors consistently skewed results.

Understanding that there is an error range involved with these measurements, even skewed data is still useful as it reliably captures the morphological shape of beaches. Beach profile graphs are visual tools that can convey information about coastal change. Much like building a database of coastal images is useful (Harley & Kinsela, 2022) to understand change in an area, having detailed graphs that show if a beach is more flat or more uneven at different times of year or after storm events is illuminating.

Organizations considering starting a beach profiling program should consider that in just an afternoon, with access to two sets of volunteers, they could make estimations on precision (repeatability) of the Emery method to help validate their data (Ward et al., 2021). If they have access to an instrument like an RTK-GPS (or can borrow one), in the same afternoon they can gather enough information to understand an error range for their data. RTK-GPS models like the Emlid Reach RS2 GNSS Receiver are making this type of technology much more affordable and accessible to groups with smaller budgets.

To reduce possible sources of error, the Emery rod sets themselves should be kept as simple as possible. Telescoping rods or rods with multiple points of visual interest can
overcomplicate the profiling process and introduce confusion in gathering and interpreting data. A footing pad to allow the rods to “float” on the beach sediment surface rather than sink in could also help mitigate systematic error (Krause, 2004).

II.D.2 – Inner Harbor vs. Outer Harbor Sites

Research Question: Did the inner harbor and outer harbor beach sites behave as expected?

The abbreviated timeframe of this beach profiling project limited the length of beach profile elevation records that could be compiled for each site. However, while the dataset may be lacking from a technical standpoint in a temporal sense, the spatial variety of the dataset is a real strength. Twelve beach sites were selected for this project. Some of the sites were research priorities of the Stone Living lab, certain sites were of interest to both researchers and volunteers, and other sites were chosen by participants of the project because of a personal connection they felt towards their beach. The resulting collection of beaches serving as research sites for this project were very diverse in physical location. Some beach sites were located along the outer harbor, facing the North Atlantic Ocean with little protection from storm waves. Other sites were partially protected from wind and wave action by the islands within the harbor (Figure 12).
Observing how different beaches in different physical environments behave throughout the year and as a response to episodic storms can inform researchers, policy makers, and community members about what an expected range of change at a specific site may look like (Ashton et al., 2008; Chaumillon et al., 2017). It was expected that in general, the beaches in the inner harbor that are protected by the harbor islands would undergo less change over the course of the project than beaches facing the Atlantic Ocean directly. The collection of island drumlins serves as a natural barrier for the inner shores of Boston Harbor and absorb a lot of wind and wave action that can impact beach profiles and lead to coastal flooding in the outer harbor while the inner harbor remains protected by the islands (Kirshen et al., 2018) The beach sites outside of the radius of protection from the island endure more
intense energy regimes and are therefore theoretically more prone to larger changes in elevation.

Below is a figure taken from the 2018 Feasibility of Harbor-wide Barrier Systems published by the UMass Boston Sustainable Solutions Lab (2018) in partnership with the Woods Hole Group (Figure 13). The figure is based on outputs from a model called the Boston Harbor Flood Risk Model (BH-FRM). This robust model was developed by the Woods Hole Group at the request of the Massachusetts Department of Transportation (MassDOT) and the Federal Highway Administration (FHWA) in response to growing concerns of coastal flooding in Boston following Hurricane Sandy in 2012 (Department of the Interior & U.S. Geological Survey, 2012, Bosma et al., 2015)

The model is based on a numerical mesh that holds a digital representation of the bathymetric and topographical elevation of both coastal land and coastal waters near Boston at a very high resolution (10 meters between nodal points). This mesh is paired with other models (the Advanced CIRCulation (ADCIRC) model for water levels and velocities and the UNSWAN model (unstructured simulated waves nearshore) to calculate wave generation and transformation) that consider significant processes related to storm-induced coastal flooding such as wind, fetch, wave formation, storm surges, river discharge, and sea level height to estimate the impacts of coastal flooding in the Boston area. BH-FRM uses historical high-water data from past storm events to calibrate and improve its outputs (Bosma et al., 2015). It is considered the scientific standard for flood risk projections in Boston and served as the
basis for the Massachusetts Coastal Flood Risk Model (MA-FRM), which is being developed to be used in studies statewide (Woods Hole Group, 2021).

Figure 13: Wave Model Results for Project Sites (Source: Kirshen et al., 2018)

One of the output products of the BH-FRM model is simulated storm wave heights. In the Figure 13 taken from the 2018 Feasibility of Harbor-wide Barrier Systems report, modeled wave heights that are expected around Boston Harbor in the event of a Moderate Coastal Nor’easter storm are depicted. The model pulled real weather data from a Nor’easter that hit Boston’s shorelines in early 2018. The graphic illustrates how during episodic storm events, wave height can be rapidly reduced as their energy becomes dissipated within the
harbor as a result of the harbor islands. Wave heights decrease from the mouth of the harbor towards the inner shores. Fetch within the inner harbor can be significant and causes wave heights of 1-2 feet along most shorelines, while the outer harbor sites have even higher waves (Kirshen et al., 2018).

Model projections like this are of great value and interest as sea level rise increases and coastal storms become more frequent and intense (Kirshen et al., 2008; Douglas & Fairbank, 2010; Douglas & Kirshen, 2022). On the beach sites chosen for this project, it was expected that the range of observed elevations would correspond with these model projected storm wave heights. This beach profiling project ran from April to December of 2021. During this period, a total of 35 participants visited their beach sites a total of 74 times, resulting in 172 individual beach profiles from sites around Boston. A collection of profiles called a beach profile envelope was assembled with all profile measurements included to illustrate the range of elevation change between visits for each beach site (Figure 14). For all sites with 4 or more visits in the April – December period, the maximum spread of beach elevation differences was recorded. The amount of transects measured at each site varied from 1-3, so the transect with the greatest number of profiles was used for each site.
All beach site locations from this project are included in the wave model figure except for Duxbury Beach. Due to Duxbury being similarly situated in terms of orientation on the North Atlantic Ocean and protection level to Nantasket Beach, as well as current wave height projections available from the National Weather Service placing wave heights at Nantasket and Duxbury in the same wave height range (Figure 15), these two beaches are assumed to have similar wave heights during a storm for this analysis. For Tenean Beach, only the first and last profiles were compared because of method errors at this site. The volunteers noticed no significant changes over time, which makes us confident in saying that there was very little change. Winthrop Beach and Constitution Beach were excluded because they were only visited 2 and 3 times, respectively.
Since beach elevation profiles change in response to seasonal changes in wind and wave energy as well as in response to episodic events (Kennedy et al., 2019), sites in more protected environments were expected to have a smaller range of elevation change than sites with less protection from the North Atlantic Ocean. Generally, as the max wave height model increased, the observed maximum spread between beach profiles also increased (Table 4). The four sites with maximum wave height under 2 feet in the model also had variations of beach elevations under 2 feet observed during the duration of this project. All four of these sites were sheltered behind the Boston Harbor islands and peninsulas, so this observed smaller range of variation was expected. The other six sites with modeled storm wave heights above 2 feet showed a greater range in profile elevations between visits. These sites are all more directly exposed to the North Atlantic Ocean, so this larger range of variation also reflects what was expected to occur (Figure 16).
<table>
<thead>
<tr>
<th>Site</th>
<th>Modeled Wave Height During Moderate Nor’easter</th>
<th>Max Observed Range in Profile Variation (Nearest 1/2ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coughlin Park</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Tenean Beach</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Malibu Beach</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>M Street Beach</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>King’s Beach</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Revere Beach</td>
<td>3</td>
<td>4.5</td>
</tr>
<tr>
<td>Wollaston Beach</td>
<td>3</td>
<td>6.5</td>
</tr>
<tr>
<td>Nahant</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Nantasket Beach</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Duxbury Beach*</td>
<td>7</td>
<td>8.5</td>
</tr>
</tbody>
</table>

Table 4: Max Modeled Nor’easter Wave Height vs. Max Observed Range in Profile Elevation

Figure 16: Observed lower (<2 ft elevation range) and higher (>2 ft range) beach sites

32
However, when compared with the modeled maximum wave heights, the observed profile ranges of Wollaston beach, Nahant Beach, and Nantasket Beach were somewhat unexpected (Figure 17). Wollaston Beach had a maximum modeled wave height of 3 feet, the same as for King’s Beach and Revere Beach, but had a profile range of 6.5 feet, 2 feet higher than at Revere. The elevation range was closer to what was seen on Duxbury Beach, a site with much higher expected wave heights during a storm. Possible factors that could be influencing the larger than expected range of elevation values on Wollaston beach include:

1) The model uses wave heights from a Nor’easter, when the harbor islands provide Wollaston with much more cover than if a storm is coming in from a different direction such as the southeast.
2) This is a relatively short, urban sandy beach that has a concrete barrier on the landward edge, so the sand does not have much space to be distributed landward and may “pile up”, where if it were in a more natural setting the sand may have spread over a longer beach profile.

3) Wollaston and Duxbury beach envelopes both included pre and post storm profiles – events where greater variation than normal was expected to be recorded. None of the other sites had these measurements. Wollaston Beach also was the most frequently visited site, so it has the most measurements in the profile envelope.

This pattern was also not followed at Nahant Beach and Nantasket Beach. While they still had variations of over 2 feet between profiles, this was much smaller than at both Wollaston and Duxbury Beach. Based on the moderate nor’easter high wave height potential at both sites due to being right on the Atlantic Ocean with no protection from barriers, more variation was expected at these two sites. This could be explained by the topography of these sites. Both sites were very long at low tide – Nantasket reached 400 feet while Nahant reached 650 feet. Both beaches are very flat for most of the profiles. Perhaps the amount of possible variation here is limited because of the flat, low-amplitude topography of these sites.

It is important to understand and acknowledge that there is error involved the Emery method that adds to uncertainty of the actual range of beach elevations at each site. For all profiles, it should be noted that error with the Emery method is cumulative and grows as you get closer to the end of the profiles – this is also where the largest range in variation was for most of the profiles. Finally, some beach sites were visited more frequently than others, so
may be displaying an artificially higher range in beach elevations than less-visited beaches for that reason. A final limitation of this analysis is the estimation of wave height for Duxbury Beach under these same moderate nor’easter conditions. Without having the exact model output for this area, it is not possible to be sure that ranking Duxbury with Nantasket is a fair assessment, though the settings of the two beaches are very similar.

Understanding the above limitations, it is still an interesting exercise into how to best utilize a beach profile dataset that is too young to confidently establish seasonal trends. This is an example of how a short-term project can play more to spatial strengths when long term temporal analysis is not possible. Analyses that raise questions are useful for improving models, generating new research questions, and helping to quality check data.

**II.D.3 - Case Study: Wollaston Beach**

Research Question 3: What ways can a short-term beach profile record be used?

The short timeframe of this participatory science project limits the amount of in-depth analysis that can be done at a given site. This research question seeks to explore the best ways to make the most out of a short-term record of beach elevation profiles. Though 1 year is not enough to establish seasonal trends, emerging patterns can be analyzed so that if more profiles are taken in the future, there are benchmarks to compare the new profiles to. Another impactful way to utilize short-term records is to utilize pre- and post-storm beach elevation profiles to analyze a beach site’s response to episodic events.
Wollaston Beach was chosen as a case study for this research question for three reasons; 1) it was the most-profiled site and therefore the most robust record generated from this project, 2) there are two different pre- and post-storm beach profile sets, and 3) it is one of two sites that will be continuing to profile on a seasonal basis in 2022 (May, August, November, February).

II.D.3.a – Emerging Seasonal Trends

Wollaston Beach was our most profiled site. Volunteers managed to visit this site 12 different times from April – December of 2021, and also in May of 2022. More years of profile information will be needed to establish seasonal patterns with certainty, but some expected seasonal variation did emerge. Typically, beaches will build up in elevation over the summer months when there are fewer intense storms. During the winter, storms with stronger wind and wave action will eat away at the beach elevations. This cycle continues until the spring arrives and a break in the intense weather allows the beach to build back up again (Kennedy et al., 2019; Eichentopf et al., 2020).

At Wollaston Beach, the spring and summer profile elevations stayed in the middle of the profile envelope (Figure 18), with average area under profiles for elevations above NAVD88 remaining below the average along Transect 2 from April to September (Figure 19). The highest beach elevation readings were in mid-October, but a Nor'easter that hit the coast on 10/27/21 had redistributed the built up sand and lowered the overall elevation when a profile was taken the following day. Volunteers noted that sand was covering up the usual
benchmark and had spilled out on to the sidewalk above. The beach built back up after this storm to be quite high in November, but the lowest elevation was recorded in December. When volunteers were able to get back out in May of 2022, the beach elevation had built back up towards the higher end of the profile envelope again (Figure 18; 19).

From the profiles available, it seems that generally the warmer months had less change in elevation and overall area between visits, while the months of October – December had very variable beach profile elevations. More years of data are needed to determine whether the observed profile changes do indeed follow a seasonal cyclic pattern. The volunteers at this site are planning to continue profiling on a seasonal basis, so moving forward there will be more profiles to either strengthen the support for this seasonal pattern or disprove it.
**Figure 18:** Wollaston Beach Complete Beach Profile Envelope

**Figure 19:** Wollaston Average Area Under Profiles (Elevations over NAVD88, Along Transect 2)
II.D.3.b – Pre- and Post- Storm Analysis

Besides changes happening on Wollaston Beach on a seasonal basis, beach profiles are also sensitive to episodic storms. The most rapid and dramatic changes in beach profile elevations happen after episodic events, which are more common during certain times of year but unpredictable in timing and intensity (Burvingt et al., 2017; Kennedy et al., 2019). In an effort to capture the impacts of these episodic events, volunteers at Wollaston Beach were able to take pre- and post- storm profiles for two different storms. In the context of a short-term record, these measurements are perhaps the most impactful profiles participants can measure (Eichentopf et al., 2020). The first storm was a larger precipitation event on July 9\textsuperscript{th}, 2021. The second storm was a headline-making Nor’easter on October 27\textsuperscript{th}, 2021 (Table 5).

<table>
<thead>
<tr>
<th>Storm Date</th>
<th>Date Range</th>
<th>Storm Precip</th>
<th>Storm Prevailing Wind Direction</th>
<th>Storm Max Wind Speed</th>
<th>Storm Max Wave Height</th>
<th>Period Precip</th>
<th>Period Max Wave Height</th>
<th>Period Max Wind Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 9\textsuperscript{th} 2021</td>
<td>7/6 – 7/16</td>
<td>1.96 in</td>
<td>SE</td>
<td>11.4 mph</td>
<td>1.68 ft</td>
<td>5.86 in</td>
<td>1.68 ft</td>
<td>15.6 mph</td>
</tr>
<tr>
<td>October 27\textsuperscript{th} 2021</td>
<td>10/14 – 10/28</td>
<td>1.61 in</td>
<td>NE</td>
<td>20.9 mph</td>
<td>8.61 ft</td>
<td>4.42 in</td>
<td>8.61 ft</td>
<td>20.9 mph</td>
</tr>
</tbody>
</table>

*Table 5: Precipitation Data from Hingham COOP Station (NOAA), wind and wave data from Massachusetts Bay Buoy (NOAA, Station 44013 (LLNR 420))*

July of 2021 was historically rainy, eventually becoming the second-wettest July ever on record in the Boston area (Cappucini, 2021). Volunteers took profiles on July 6\textsuperscript{th} and July 16\textsuperscript{th}, on either side of the July 9\textsuperscript{th} storm. This was not the only rainy day between the volunteer visits, but the largest amount of precipitation (1.96”) did fall on that day. It also had the highest maximum wave height for the 7/6-7/16 period at 1.68 ft. Wind speeds
reached 11.4 mph during the July 9th storm but were exceeded by 15.6 mph another time during the period. The prevailing wind direction came from the southeast. Precipitation data for this analysis were pulled from the NOAA Hingham COOP Station (Climate NOWData), while wind and wave data were pulled from the NOAA Massachusetts Bay Buoy Station 44014, LLNR 420 (NDBC - Station 44013 Recent Data).

Though it was a very rainy period, the impact on Wollaston Beach profiles from the July 9th storm was minimal. The pre- and post- storm profiles for Transect 2 are nearly identical (Figure 20b). However, the two profiles for Transect 1 and 3, on either side of Transect 2 were a bit different (Figure 20a; 20c). The changes are slight, but the 3-dimensional line graphs help illustrate this (Figure 21a; 21b).

An area under the curve analysis was performed for each transect before and after the storm, using the last shared distance from benchmark as an end point. The area under the curve of 7/16 was just 13.42 square feet less than under the curve of the 7/6 reading. For Transect 1, this difference was slightly more exaggerated, with the difference amounting to 35.42 square feet of sand lost. Most interestingly, the profile along Transect 3 did not lose sand at all, but instead gained it. There was 32.32 square feet more sediment along Transect three on 7/16 than on 7/7. Two groin-like structures sticking out into the water on either side of Transect 3 likely helped it hold on to this sediment (Figure 22). The average change across the three profiles was a loss of 5.5 square feet of sediment. As Transects 1 and 3 are about 800 feet apart, this amounts to an estimated sediment loss for this period of 4405 cubic feet of sediment (Table 6).
Figure 20: pre-and post-July storm transects on Wollaston Beach for A) Transect 1, B) Transect 2, and C) Transect 3
Figure 21: All Transects Along Wollaston Beach A) Pre-Storm (7/6/21) and B) Post-Storm (7/16/21)
It should be noted that volunteers observed beach reservation employees “raking” the beach on 7/15 in an effort to smooth out the surface for beachgoers. Upon being asked, the employees reported that in the summer months, beach raking at this site is commonly done up to twice a week. This has a flattening effect on the morphology of the beach but should not change the overall volume of sediment on the beach.

<table>
<thead>
<tr>
<th>Event</th>
<th>July</th>
<th>October</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transect 1 (ft^2 change)</td>
<td>-35.42</td>
<td>35.1</td>
</tr>
<tr>
<td>Transect 2 (ft^2 change)</td>
<td>-13.42</td>
<td>-293.3</td>
</tr>
<tr>
<td>Transect 3 (ft^2 change)</td>
<td>32.32</td>
<td>115.4</td>
</tr>
<tr>
<td>Average (ft^2 change)</td>
<td>-5.51</td>
<td>-47.63</td>
</tr>
<tr>
<td>Approx Sediment moved</td>
<td>-4405.33</td>
<td>-38106.7</td>
</tr>
<tr>
<td>(Across 800 ft Distance)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Volumetric Analysis for July and October storms

Figure 22: Wollaston Transects 1-3 and Groins
Though the October 27th Nor’easter had less precipitation than the July event at 1.61 inches, everything else about the storm was more intense (Sobey, 2021). As the name suggests, strong winds of up to 20.9 mph blew in from the northeast direction. This created waves of up to 8.6 feet out in Massachusetts Bay (Table 5). The difference between the profiles taken on 10/14 and 10/28 were much more dramatic than with the July storm (Figure 23: pre-and post- October storm transects on Wollaston Beach for A) Transect 1, B) Transect 2, and C) Transect 3 The same area under the curve analysis was performed for these profiles. The profile along Transect 2 showed the biggest difference in elevation change, losing 293.3 square feet of sand (Figure 23b; Table 6). Transect 1 and 3 both gained sediment (Figure 23a; 23c). Transect 1 added 35.1 square feet of sediment to its profile, while Transect 3 added 115.3 square feet. The average change across all three transects was a loss 47.63 square feet. Spread across 800 feet, this amounts to a net loss of about 38100 cubic feet of sediment, almost 9 times more than the July storm (Table 6).

The profiles from both storms demonstrate that for this stretch of Wollaston Beach, sediment in along different transects does not respond uniformly to storms. Within a relatively short distance, all three transects behaved somewhat differently. This points to Wollaston Beach responding to these two storms by redistributing the sand along its coast, rather than consistently eroding or accreting sediment. This is supported by volunteers telling us that they noticed sand up covering up one of the usual benchmarks. Pictures from before and after the storm were taken from Transect 2 facing Transect 3 and illustrate this redistribution of sand (Figure 25).
Figure 23: pre-and post-October storm transects on Wollaston Beach for A) Transect 1, B) Transect 2, and C) Transect 3
Figure 24: All transects along Wollaston Beach A) Pre-storm (10/14/21) and B) Post-storm (10/28/21)
II.E - Conclusions and Further Exploration

An initial analysis of the beach profiling data collected throughout the April–December extent of the project shows that there are a variety of uses for the information gathered. An error analysis estimated that on average, measurements made by volunteers using our Emery rod kits would likely have fallen somewhere between 0.4 feet below and 0.8 feet (0.13 and 0.23 m, respectively) above the actual beach elevation for each point. It also revealed that this error appeared to be cumulative, increasing in size as the Emery rod user moves from the beginning of the profile towards the water line. These errors could be a product of the Emery method itself (the cumulative nature especially) but also could be due to our specific profiling kits. Even with the error, the profiling method was shown to be capable of capturing the general geomorphology of the beach. Knowing how the shape of the beach changes is useful information even if there is an error offset to the actual elevation.
numbers, especially when paired with photographs taken from the same vantage point (Figure 25). Similar photographs of beaches are being used in the global participatory science program CoastSnap, and detailed profiling data could be used to strengthen estimations of beach elevation change observed in photographs over time (Hart, 2021; Harley & Kinsela, 2022). Understanding that the method has associated error, the data were also used to explore energy levels of sites, seasonal trends, and sediment volume change analysis due to storms.

With the limitations of a short-term record, focusing on spatial and episodic differences in elevation change across beaches is an impactful way to use the dataset to generate further research questions and interest in the participatory science program. Further explorations of the data collected during this project could include 1) comparing the profiles to other historic records as they are available 2) looking at other nearby profiles taken by researchers involved with the Stone Living Lab, and 3) exploring the differences in volume change on narrow vs. wide beaches.

Of particular interest on Wollaston beach is the function of the groin structures on either side of Transect 3 (Figure 22). During both storms, this sediment was accumulated along this transect (Table 6). The buildup of sediment on the eastern side of both groins (Figure 22) indicates that longshore transport occurs at Wollaston beach moving from the east to the west (Bush et al., 2001; McLachlan & Brown, 2006). Further analysis of current and future beach profiling data could explore the relationship between the different transects over a longer time scale or along a larger area of Wollaston beach to evaluate the consistency of groin performance at this site.
CHAPTER III

PARTICIPATORY SCIENCE – THE PROGRAM

III.A – Perspective Importance

The goals of participatory science programs that engage the public are twofold – a high quality data set that can be used by researchers to learn something new, and increased engagement of a broader range of participants. Along with data quality, participant motivation is another common challenge facing participatory science programs. Though these issues are present in studies using public participation, many established successes especially in the field of marine science have demonstrated how networks of participants can greatly enhance the reach of scientific research efforts (Thiel et al., 2014).

While data accuracy and quality are important, this is not the only available metric to assess success of a program. In fact, some perspectives hold that the level of data accuracy is a poor standard for evaluating the success of a participatory science program. Instead, it is thought that participatory science programs should also be evaluated for success based on how well the program performs at meeting social goals (Kovaka, 2021). For the Stone Living
Lab, these goals include increasing public understanding of coastal processes that will be impacting greater Boston’s shorelines and building a network of community members invested in coastal resiliency research and efforts.

III.B—Research Questions

Research questions that explore what worked during year one of the program, how feedback from volunteers was used to improve the program, and what continued engagement with the Stone Living Lab looks like for participants help illuminate the successes and shortcomings of the program. To help evaluate the success of this model of the first year of the program and identify improvements that need to be made going forward, three more research questions were addressed to help examine the success of the program based on participatory-science focused goals. This section addresses both step 3 (build a community) and step 5 (sustain and improve your project) of the Citizen Science Toolkit guide (CitizenScience.Gov).

4. Research Question 4: How can volunteer scientist contributions be valued?

5. Research Question 5: Why and in what ways did volunteers continue to be involved with the lab after their initial engagement?

6. Research Question 6: How did volunteers improve the project and program?
III.B.1 – Program Participants

Research Question 4: How can volunteer scientist contributions be valued?

Participatory science programs are a fantastic way to amplify the reach of research efforts. A team of participants can reach many more places many more times than a small research team would be able to. The program succeeded in training a group of about 35 community members to conduct beach elevation measurements at various sites around Boston Harbor. The collection of elevation profiles during the duration of this project is a source of pride for both the researchers and volunteers involved in this project. These profiles represent the beginning of a robust record of coastal elevation data for this region. Our volunteer network visited their twelve beach sites a total of 74 times, resulting in 172 individual beach profiles from sites around greater Boston Harbor (Figure 26).

![SLL Beach Profiling Site Visits 2021](image)

*Figure 26: Timeline of beach site visits April-December of 2021*

The volunteer teams were made of mother and daughter duos, families, neighbors, teachers, recent graduates, professionals, and even kite surfers. Many of the volunteers lived
close to their beaches and had a personal interest in gaining a deeper understanding of their beaches, while others were thrilled to have a reason to make regular beach trips. As Eberhardt et al. (2022) points out, volunteer time though not paid is not “free.” An estimated 945 hours were donated by these participants over the course of this project through conversations with researchers, attending trainings and meetings, taking time to travel to their beach sites, and dutifully profiling their transects (Table 7).

Paired with efforts of the lead scientist, project coordinator, and Stone Living Lab support team, the total estimated time spent on this project from March – December of 2021 is approximately 1,935 hours. Of those nearly 2,000 hours, the volunteers involved in this project contributed an estimated 945 hours – nearly doubling the total time spent on the project.

<table>
<thead>
<tr>
<th>Role</th>
<th>People</th>
<th>Description of Duties</th>
<th>Estimated Monthly Hours</th>
<th>Total Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific Lead</td>
<td>1</td>
<td>Training involvement, consultation meetings, data QC help</td>
<td>3</td>
<td>27</td>
</tr>
<tr>
<td>Project Coordinator</td>
<td>1</td>
<td>Emery rod kit assembly, volunteer training, volunteer communication, data QA/QC, website maintenance and upkeep, event planning, media content</td>
<td>72</td>
<td>648</td>
</tr>
<tr>
<td>Support Team</td>
<td>3</td>
<td>Data entry, event planning assistance, project tracking, media content</td>
<td>10/person</td>
<td>315</td>
</tr>
<tr>
<td>Participatory Scientists</td>
<td>35</td>
<td>Attending training and meetings, transportation to and from sites, profiling transects, submitting data</td>
<td>3/person</td>
<td>945</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td></td>
<td>108</td>
<td>1,935</td>
</tr>
</tbody>
</table>

*Table 7: Estimated time spent by project participants March - December of 2022*
This amounts to about 80 days of beach profiling, almost half of which is made up of volunteer efforts. Another angle to consider is that if these volunteers were being paid for their time, the current Massachusetts living wage rate of $21.88/hour (MIT, 2022) would make the total estimated volunteer contribution to this project worth a little over $20,600. Another way to consider the value of this project is to evaluate estimated educational value. Each credit at the University of Massachusetts Boston costs about $600 for a matriculated in-state student (UMass Boston, 2021). A credit is assumed to reasonably approximate 15 hours of educational learning (NECHE, 2021). At 945 hours, this works out to an educational value of $37,800.

While the Stone Living Lab team of 5 spend the majority of the time on this project preparing volunteer materials and working with volunteer data, without those 945 hours from volunteers there would be no profiles to analyze. These hours on both the research and participant side of the program have all been spent expanding the reach of the core research at the Stone Living Lab, both by physically collecting data and also exposing more members of the public (both volunteers and onlookers) to active coastal research efforts.

In a survey sent to the twelve site leaders, all twelve responded that they would recommend working with the Stone Living Lab on a participatory science project to others. Volunteer groups at two sites, Wollaston Beach and Duxbury Beach Reservation, elected to continue measuring profiles on a seasonal basis to work towards building a long-term record of seasonal change. The estimated almost 2,000 hours spent by participants in various roles of this project has all been time spent towards increasing public education of coastal
resilience principles and building a network of community members concerned about coastal change.

**III.B.2 – Continued Engagement**

Research Question 5: Why and in what ways did volunteers continue to be involved with the lab after their initial engagement?

Another way to qualify the success of a participatory science program is through volunteer turnover rates (West & Pateman, 2016). If volunteers are enjoying participating in a program, then it follows that they would be more likely to continue participating. A low volunteer turnover rate is a good indication of positive volunteer experiences. We expected about half of the site leaders to want to continue profiling their beach sites. This did not happen – as of now, only two sites will continue to be profiled (Wollaston and Duxbury beach). However, 6 out of 12 site leaders did end up continuing to engage with the Stone Living Lab in ways beyond continuing in the beach profiling project. Factors that seem to have influenced this pattern as well as other types of engagement are explored below.

In considering reasons volunteers may not choose to continue to engage with the lab, the personal importance of their beach site was explored. Did personal investment in a beach site increase the likelihood of volunteers returning? The twelve sites were chosen in one of three ways – 1) the site was a research priority and volunteers were recruited specifically for the site, 2) the site was of interest to researchers and was chosen from a list by interested volunteers, or 3) the site was specifically requested by a volunteer and chosen because of its importance to them. Two sites were research priorities, five were of interest to both
researchers and volunteers, and five were chosen at the request of the volunteer. Of these three site types, two volunteer groups of each have had continued engagement with the lab (Figure 27). It seems that when compared to this classification of sites, the site selection type did not have a large bearing on whether a volunteer would elect to continue to engage with the Stone Living Lab under some capacity.

![Site selection category and continued SLL engagement](image)

**Figure 27: Site selection category and continued SLL engagement**

Time spent profiling may have had an impact on volunteer willingness for continued engagement with the Stone Living Lab. For sites where the average time to complete one transect was under 30 minutes, 4 out of 6 volunteer teams have continued to engage with the lab. For sites where the average transect took longer than 30 minutes to profile, only 2 out of 6 volunteer teams have elected to currently engage with the lab (Figure 28). Based on feedback from our volunteers, designing participatory science projects to not take longer than an hour is a good target for a site visit duration.
A final reason for low volunteer turnover is likely the timeline of the project itself. The Stone Living Lab participatory science program outlines that there will be a series of 4 different participatory science projects, each running from April – December of the calendar year. When recruiting volunteers, this is the timeline that they agree to. Being a participatory science project based in the Northeast, we did not expect or ask volunteers to take profiles during the cold and potentially dangerous winter period of January – March. Come April, interest in the project may have waned, or other priorities in volunteers’ daily lives had come around.
III.B.2.a – Other Avenues of Continued Community Engagement

Moving forward, volunteers at the Wollaston Beach and Duxbury Beach sites will continue monitoring their beaches on a seasonal basis. If the volunteers can continue this long-term, a multiyear dataset of seasonal beach profile changes will be available at both of these two high-energy sites. This is exciting to both researchers and the volunteer groups at these sites, but is not the only continued engagement outcome to result from involvement in this project. Volunteers at other sites that did not elect to continue profiling have expressed interest in the new SLL participatory science project based on intertidal biodiversity monitoring. One group of volunteers has already begun monitoring the intertidal area in Savin Hill Cove, and two others are considering joining if a site can be established in their area. Beyond this, volunteers from this project have attended and presented at the SLL’s Boston Harbor Educator’s workshop (Stone Living Lab, 2022), connected with SLL educators for one-off beach profiling education events, and one volunteer is even producing a podcast episode focused on their experience with beach profiling (Table 8).

An interesting theme with volunteers who elected for continued engagement was that though only two wanted to continue beach profiling, 3 out of 6 have officially joined the new intertidal monitoring project, and the other 3 are interested in joining. This shows some support for the project turnover approach. Different types of projects may be more appealing or interesting to participants, or getting experience with a variety of research topics and methods may be a draw for volunteers.
Perhaps one of the most exciting outcomes of this project is the potential interest for a large-scale regional beach profiling network. The details of the SLL beach project were presented at a January 2022 South Shore Climate Network meeting. This group is a coalition of South Shore communities, multiple non-profits, and Massachusetts state agencies. During the meeting, it became clear that there are other small scale beach profiling efforts using the Emery method happening in areas of coastal Massachusetts like Hull and Cohasset. A partnership between SLL and other organizations paired with a platform like MyCoast could expand this program to an even larger scale given the appropriate time, personnel, and funding.

Table 8: Volunteer Continued Engagement

<table>
<thead>
<tr>
<th>Site</th>
<th>Continued Profiling</th>
<th>Intertidal Project</th>
<th>Other Avenues of Engagement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duxbury</td>
<td>Y</td>
<td>Y</td>
<td>attended SLL Education workshop, creating podcast episode about BP project, attended Volunteer Dinner</td>
</tr>
<tr>
<td>Wollaston</td>
<td>Y</td>
<td>Y</td>
<td>helped with RTK-GPS error analysis, attended Volunteer Dinner</td>
</tr>
<tr>
<td>Malibu</td>
<td>N</td>
<td>Y</td>
<td>attended Volunteer Dinner</td>
</tr>
<tr>
<td>Coughlin</td>
<td>N</td>
<td>M</td>
<td>interested in BP workshop for HS students, attended Volunteer Dinner</td>
</tr>
<tr>
<td>Nahant</td>
<td>M</td>
<td>M</td>
<td>interested in continuing volunteering, attended Volunteer Dinner</td>
</tr>
<tr>
<td>Tenean</td>
<td>N</td>
<td>M</td>
<td>interested in intertidal project, attended Volunteer Dinner, attended and presented own work at SLL Education Workshop</td>
</tr>
</tbody>
</table>

Perhaps one of the most exciting outcomes of this project is the potential interest for a large-scale regional beach profiling network. The details of the SLL beach project were presented at a January 2022 South Shore Climate Network meeting. This group is a coalition of South Shore communities, multiple non-profits, and Massachusetts state agencies. During the meeting, it became clear that there are other small scale beach profiling efforts using the Emery method happening in areas of coastal Massachusetts like Hull and Cohasset. A partnership between SLL and other organizations paired with a platform like MyCoast could expand this program to an even larger scale given the appropriate time, personnel, and funding.
III.B.3 – Volunteer-inspired Improvements

Research Question 6: How did volunteers improve the project and program?

Surveys are one of the most popular ways to gather information from volunteers involved in a program (Peter et al., 2021). Two surveys were sent out to site leaders to be filled out anonymously throughout the course of the project. Feedback was also received from volunteers in less formal ways through email conversations and discussions during group meetings. This information from participants was used to help develop aspects of the beach profiling project and implement improvements to the overall participatory science program.

III.B.3.a – Project-level Improvements

Beyond collecting valuable beach elevation data, volunteers also provided researchers with information to both improve the elevation measurement protocols and the interpretation of results. Volunteers at both Wollaston and Revere beaches noted that on occasion they observed employees “raking” the beaches with large combs towed behind vehicles to create a more appealing flat surface for beachgoers. This is very helpful information, especially when considering morphological changes between profiles that may have been muted by the rakes.

Volunteers also had suggestions for amendments to the elevation measuring protocol based on challenges at their specific beach sites. At Tenean Beach in Dorchester, there was no visible horizon. This is typical of some smaller urban beaches, and we wanted to try the
Emery Method there despite not having that horizon visibility. The group at this site did their best to agree on a point of reference, but ultimately it turned out that without the horizon the elevation data they were collecting was off. On their last trip to their site during December, it was dark enough to use a small handheld laser to point at a surface and use as a point of reference. This December profile was a success, and overall showed that volunteers need to be able to have a steady point of reference for this method of profiling to be reliable. This is very useful information to have when considering sites where the Emery method would be appropriate to use.

At some of the longer beaches, measuring the transects with the supplied 6-foot rope to separate the two Emery rods was incredibly time consuming. At Nahant Beach, where the longest profile reached 540 feet long, volunteers created their own 24-foot rope to use instead and were able to complete the profiles much more quickly. Because of the consistently long and flat morphology at this site, the profiles still picked up the shape of the beach without needing 6-foot measurement increments. Another accommodation we made at the request of volunteers at these longer beaches was instructing them to complete the profile along their middle transect first, and then do the transects on either side as time allowed.

III.B.3.b – Program-Level Improvements

In a mid-project survey, volunteers were asked for three things they would improve about this program. The first theme in the responses was that volunteers pointed out the data submission was complicated and inefficient. Volunteers had to fill out paper data sheets, take
pictures of them, and finally email the pictures to researchers. An in-app submission would have streamlined the process and made both sending the data and receiving the data easier. Early on in the project we explored a partnership with MyCoast, an app run by Massachusetts CZM. The CZM development team were incredibly helpful in creating a beta version of a beach profile submission form on their platform, which they did as an unpaid favor to the Stone Living Lab. However, difficulties with the data submission form held up rolling out the app and ultimately it was not used for the project. If we were to bring back the project on a large scale again, it would absolutely be worth dedicating time and budget resources to making in-app submission of data a reality.

The second theme was volunteers expressing there would be use for a larger network of beach profilers than we were able to recruit in year one of the project. Some months, volunteers were unable to make it to their sites due to personal scheduling conflicts. With a larger reserve of volunteers, these sites could have been covered and the monthly visits could have been more consistently checked off. Volunteers were also sent weather alerts when a storm was coming that pre- and post- storm measurements could be taken around. The bandwidth of volunteers at many of the sites was already stretched too thin to be able to dedicate more time to storm sampling, but a dedicated storm response team of volunteers could be used to step in a fill this need.

Finally, the third and most common theme for suggested project improvements was a desire for more consistent communication and interaction with the researchers. This would have made the experience more meaningful to them. Part of this was of course due to the
COVID-19 pandemic. Volunteers were required to attend a virtual training and invited to a couple of virtual meetings, but virtual fatigue set in for volunteers and interest in connecting in this manner waned. Because of the lack of face-to-face interaction and infrequent virtual meetings, some volunteers fell out of touch with researchers. This is to be expected when having people volunteer their time for a project, but more consistent communication would go a long way to holding volunteer’s interest. We were able to host an in-person volunteer appreciation dinner in February of 2022, and volunteers who were comfortable with the current COVID-19 climate attended. This is more of what we would like to do for our volunteers going forward as the pandemic wanes.

III.B.3.c – Implementing Volunteer Suggestions

One way we were virtually able to communicate data updates with volunteers was to set up a StoryMap website for the project (https://arcg.is/0r5j9b). This has been a fantastic way to educate people about the project and also connect with the volunteers in a more interactive way. This StoryMap includes information about the project, beach profiling in general, and also dashboard to interact with profile data from all 12 of the beach sites. We will continue to update this website as new data comes in, conclusions and interesting observations are made about the profiles, and other project developments occur. The StoryMap has almost 2,000 views and is used by our volunteers, educators, and other members of the public alike.
The second year of the Stone Living Lab participatory science program kicked off in Spring of 2022. The project is focused on intertidal biodiversity monitoring and temperature tracking at sites around greater Boston Harbor. Learning from feedback from volunteers last year, we have taken time to design this project with a few key things in mind. First, the site visits are designed to not take longer than an hour, though volunteers who would like to spend more time at their sites are welcome to do so. Secondly, we are utilizing two apps (HOBOmobile and Survey123) so volunteers can more quickly and easily record and submit data to researchers. This eliminates frustration on both ends of the data collection and interpretation side of the project. Finally, we are listening to the interest in more frequent interaction with researchers. Part of this will be asking for feedback on more surveys to track the progress of the participant experience in the Stone Living Lab’s participatory science program. In addition to setting up another StoryMap for this project with even more interactive features, we are also taking advantage of the higher COVID-19 vaccination rates and summer weather to plan an in-person event for our volunteers at one of our intertidal sites.

**III.D – Program Success Summary**

Eberhardt et, al (2022) lists recommendations of best practice suggestions for designing and maintaining participatory science based coastal research programs. One of the standouts was to identify and encourage the motivations of volunteer participants. Surveys were sent out to site leaders to complete in September of 2021 and in January of 2022.
When asked to describe what they have learned about coastal change as a result in participating in this project, 7/12 respondents highlighted learning about beach elevation rates of change. Some pointed out being amazed to see their beach change slowly over the seasons or quickly after a storm, while others remarked at how little change happened on their sheltered beaches. The remaining 5/12 highlighted how they learned a lot about the power of data visualization in terms of plotting beach profiles. These realizations spurred new questions for them – does my beach look like this at the same time each year? How can this information inform coastal resilience decision makers? How might these patterns change given sea-level rise?

When asked to rank how important they felt their beach profiles were and how comfortable they felt explaining the coastal resilience principles of the project to other people on a scale of 1-6, a pattern seemed to emerge. Generally, as confidence in the perceived value of their profiles increased, so did their level of comfort in explaining the project (Figure 29). By increasing engagement and nurturing the questions and motivations the volunteers have, we can help them feel more confident to be ambassadors of coastal resiliency research.
Finally, when asked to list their three favorite things about the beach profiling project, volunteers pointed out being thankful for the opportunity to learn a new skill, spend time getting to know their beaches on a deeper level, and feeling like they are doing something to actively contribute to the conversation around climate change. However, an unforeseen result revealed in the survey responses was that the best part for many volunteers was meeting the people involved in the project – new neighbors, new friends, and new contacts. The social support of a collaborative project should not be underestimated as it contributes to continued engagement and greater investment in the research (Peter et al., 2021).

Participatory science projects provide a framework to empower members of the public by allowing them to get actively involved in the conversation around coastal resiliency. It also allows researchers to build a social connection with community members.
that is lacking in traditional academic research. One volunteer wrote: “My relationship with my beach has changed for the better now that I get to see it change. I pride myself on being an ambassador for my beach, and spending time there with a purpose has elevated that.”

With the threats of climate change looming large over our shorelines, the need for strong partnerships between communities, researchers, and decision makers is at an all-time high. While the data gathered by volunteers is incredibly useful, the network built through projects like this are invaluable (Thiel et al., 2014). The results of this analysis into the social benefits of this program are encouraging that as the Stone Living Lab participatory science program continues, the network community members associated with the lab will continue to grow and spread the coastal resilience educational benefits to their circles.

In just a short 18 months, the SLL was able to form the basis of a network of community members who are interested in and motivated to participate in coastal research. For some of the volunteer site leaders, the annual model worked very well and allowed them to change research projects. The new intertidal monitoring project may suit their interests better, be more convenient for them time-wise, or offer an opportunity to learn new skills, something many of them identified as important to them.
CHAPTER IV

SUMMARY

The first year of participatory science at the Stone Living Lab generated 172 measurements of beach profile elevation at 12 different beaches around Boston Harbor. This is a unique dataset to the area, and while it is still a relatively short record, it can be expanded upon in the future to create a picture of long-term trends and changes at these beaches. Initial evaluations of the data collected using the Emery method of beach profiling have shown that even though there is some error with the method, the elevation profiles can be useful to depict geomorphology, emerging seasonal trends, and storm analysis.

It is important to keep in mind that the success of both participatory science projects is not exclusively tied to the quality or quantity of data collected. Participatory science provides a framework for members of the public to explore their nearby natural world in a different, more analytical way. Just inviting people to experience these places in a new lens broadens the perspectives of people involved in conversations about coastal resilience and climate change. Researchers can benefit from the expansion of these viewpoints in many ways.
Volunteers from the first year of the program have already strengthened our growing network. They have brought interesting research questions to us and invited peers to get involved. They have attended and even presented at the Stone Living Lab’s first Educator Workshop in February of 2022. Some volunteers chose to continue beach profiling, while others decided to continue doing participatory science and are now involved in the Intertidal Monitoring Project. As the network of Stone Living Lab participatory scientists grows, we hope to move closer to a true partnership with community members concerned about our coastal spaces and act as a resource for them to explore their own research initiatives that directly impact their lives. The goals of expanding access and understanding of coastal resilience research efforts as well as building a network of community members concerned about coastal change have been met through the efforts of the first year of the program, and we have seen support for the annual model of rotating project topics lending itself to continued engagement from volunteers.

Different types of participatory science projects can be piloted and explored at the Stone Living Lab in the coming years to address research questions focused on sea level rise, ecological health, and environmental quality. Projects involving in-person site visits to collect data from water level loggers, assess biodiversity, and evaluate metrics of water quality could be employed. Project designs that lean more heavily on technology could also work very well at the Stone Living Lab. Examples like the herring run count at the Mystic River Watershed Association and Floating Forest kelp classification at NASA show that photos and videos can be used by volunteers at home to dedicate short amounts of time to improving and adding to datasets. This could be applied to a live camera of a habitat for rare
birds, an eroding cliff, or even to evaluate water color after stormwater input. A project could also be modeled after a program like CoastSnap (Harley & Kinsela, 2022), which installs smartphone camera mounts in places where images of the coastline would be of particular interest to coastal change research. These photos all go to a centralized location and can be analyzed by researchers there. Plugging in to an existing global participatory science effort could help the efforts of Stone Living Lab participants go even further.

The Stone Living Lab participatory science program is open to all members of the public who are interested in getting involved. Our participants have included high school students, recent college graduates, neighbors, professionals, retirees, families, and even a group of recreational kite surfers. However, as a new program, we recognize that our base of volunteer scientists has a lot of room to grow. A more robust participatory science program would have the time and resources to actively identify and invite different groups to participate that are not typically reached by advertising through the usual channels. Targeted invitations as well as offering small stipends, workshops, and guest talks can help grow the base of participatory scientists. As the program develops, we are hopeful to grow closer to true community science and act as a resource for members of the public to satisfy their own research questions, rather than just enlisting volunteers to help research our own.

As the network of Stone Living Lab volunteer scientists grows, attention will be paid to concerns and questions coming from community members and should be allowed and encouraged to drive the future projects. Growing the network may require more careful invitation to groups not already involved in environmental causes, and resources could be allocated to things like providing small stipends for participants who would not otherwise be
able to volunteer their time to do an unpaid activity. Intentionally cultivating a network of participants as diverse as possible is key to the overall goal of broadening the perspectives and voices of people currently involved in the conversation of coastal resilience in the greater Boston area. Participatory science is a powerful tool to help educate the public and foster new relationships between researchers, policy makers, and residents of Boston and nearby coastal towns.
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73


74


