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Report on Collection and Analysis of Tidal Data from Boston Harbor, Meetinghouse Pond, Chatham Fish Pier, Outermost Harbor and Stage Harbor: August 2019 – October 2020 Including a Brief Review and Discussion of the Recent Tidal and Geomorphological Changes

by

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for

The Pleasant Bay Resource Management Alliance
and
The Town of Chatham

Report prepared by the Coastal Processes and Ecosystems Laboratory
at the Center for Coastal Studies
Publication: 21-CL04

March 12, 2021

Suggested citation: Giese, G.S. and Legare, B.J. 2021. Report on Collection and Analysis of Tidal Data from Boston Harbor, Meetinghouse Pond, Chatham Fish Pier, Outermost Harbor and Stage Harbor: August 2019 – October 2020. Center for Coastal Studies, Provincetown MA, Tech Rep: 21-CL04. p. 29.

INTRODUCTION

In this series of reports on the collection and analysis of tidal data from the Nauset Beach - Pleasant Bay – Chatham Harbor barrier beach system, the authors have presented and discussed the results of their study within the context of a conceptual model of the cyclic evolution of the system developed by Giese, Mague and Rogers (2009) as a guide for management decision-making. The current report is no different in that respect, however here - in addition to presenting and discussing the most recent data - we review the conceptual model and compare it with our data, both our previous as well as recent sets. Results of that comparison indicate that the cyclic pattern of changes in the barrier beach system, at least in its familiar historical form, will likely end sooner than anticipated, and that a more nuanced approach to management is required.

We begin with a brief review of the series of events that led to the study, the subsequent events and conditions that led to the situation existing today, and a brief statement of our objectives. This "background" section is followed by a description of our data acquisition and analysis methodologies, and a graphical presentation of the results of those efforts. The numerical data plotted in the graphs will be found in an appendix to the report.

BACKGROUND

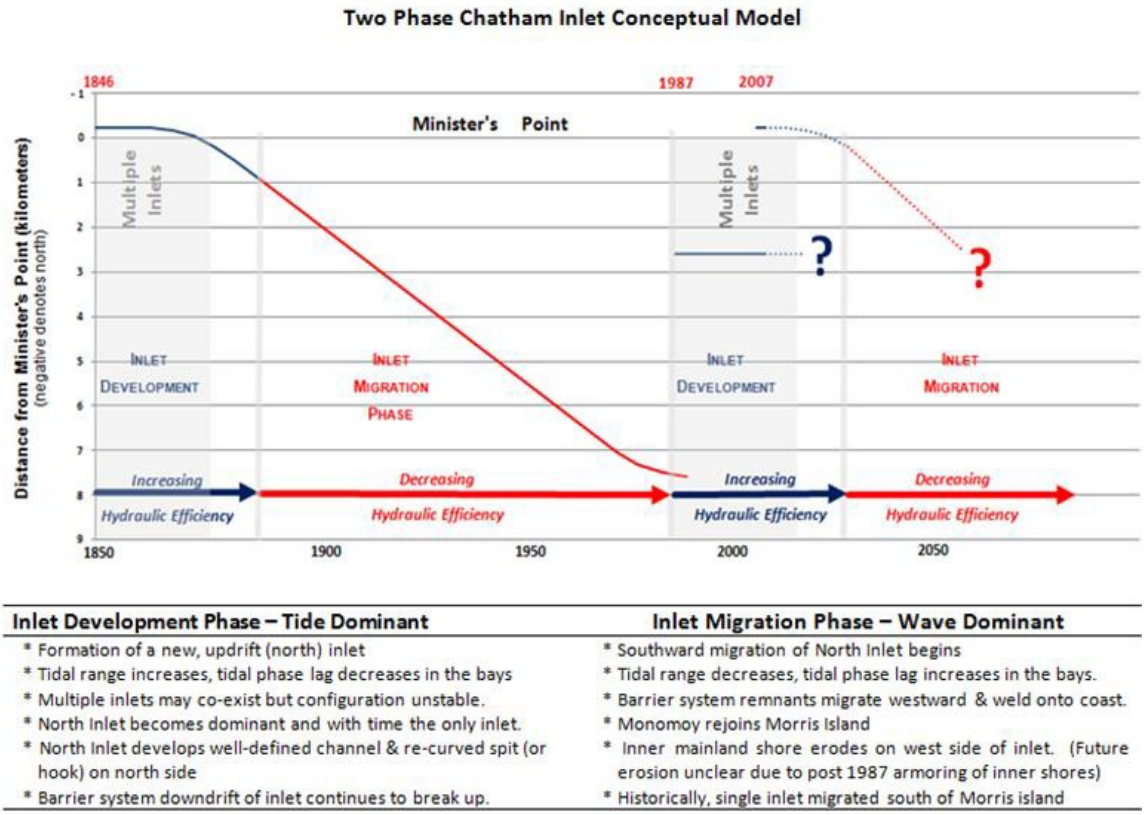
The breaching of Nauset Beach, known locally as "North Beach", during a severe northeasterly storm on January 2, 1987, ended a long period of southward growth of the barrier beach. Following its formation, the new inlet – initially called "New Inlet" and later "South Inlet - deepened rapidly, and in less than a decade the detached south end of Nauset Beach, "South Beach", joined the mainland at its

north end. As a result, a single tidal inlet provided tidal flow to and from Pleasant Bay and Chatham Harbor (Figure 1, 2006 panel).

Figure 1. North Beach from "New Inlet" (later "South Inlet') northward to lower Pleasant Bay showing annual stages of development of North Inlet from 2007 to 2009 (courtesy: Ted Keon).

In April, 2007, a new inlet - "North Inlet" - was unexpectedly initiated as a breach of the barrier beach opposite Minister's Point. Being unanticipated and raising significant management questions, the opening of North Inlet motivated the 2009 study referred to above ("Introduction'). With the goal of anticipating future changes, the authors presented a two-phase conceptual model of the "cyclic" evolution of the Nauset Beach – Pleasant Bay – Chatham Harbor system (Figure 2). In the model, the pre-1987 barrier beach growth period is referred to as the

"inlet migration" phase of the cycle in reference to the incremental southward migration of the system's tidal inlet from its mid-19th C. initial location seaward of Minister's Point. In contrast, the model refers to the period *beginning* with the 1987 breaching - the second phase of the cycle - as the "inlet development" (or equivalently, "inlet transition") phase – a period in which old channels closed and new channels and shoals formed (Figure 2).



Inlet Development Phase – Tide Dominant	Inlet Migration Phase – Wave Dominant
* Formation of a new, updrift (north) inlet	* Southward migration of North Inlet begins
* Tidal range increases, tidal phase lag decreases in the bays	* Tidal range decreases, tidal phase lag increases in the bays.
* Multiple inlets may co-exist but configuration unstable.	* Barrier system remnants migrate westward & weld onto coast.
* North Inlet becomes dominant and with time the only inlet.	* Monomoy rejoins Morris Island
* North Inlet develops well-defined channel & re-curved spit (or hook) on north side	* Inner mainland shore erodes on west side of inlet. (Future erosion unclear due to post 1987 armoring of inner shores)
* Barrier system downdrift of inlet continues to break up.	* Historically, single inlet migrated south of Morris island

Figure 2. Diagram depicting a conceptual model of the cyclic evolution of the Nauset Beach-Pleasant Bay-Chatham Harbor barrier beach system presented by Giese, Mague and Rogers (2009). See discussion in text.

Unlike the behavior of the initial inlet, for several years North Inlet remained shallow and, as a result, strongly flood-dominant. While it augmented the system's tidal prism, it failed to capture the main ebb channel. Instead, by contributing to southward ebb flow through Chatham Harbor, it initially maintained the dominance of South Inlet. North Beach Island (formed by the initiation of North

Inlet) increasingly narrowed due to erosion on its eastward side, and grew southward and westward, reducing the breadth of South Inlet and the width of southern Chatham Harbor.

Between 2013 and 2017, three factors - continued southward and westward extension of North Beach Island, shoaling within Chatham Harbor, and anthropogenic channel restriction associated with mainland armoring - combined to reduce flow from the north through South Inlet. Flow between the two inletswas further reduced by the breaching of South Beach's connection to the mainland in April 2017 ("Fool's Inlet", see Figure 3). A few months later the northern tip of North Beach Island was lost to erosion and the ebb channel from Pleasant Bay became better established at North Inlet making it the bay's dominant tidal inlet.

Objectives

The continuous change of the channels and inlets of the Nauset Beach - Pleasant Bay - Chatham Harbor system alter its tidal and wave patterns which in turn, affect the system's ecology and socio-economic health. The purpose of this study is to monitor, analyze and report sea level, tide level and tidal range patterns to provide the information required to improve understanding and management of this dynamic system.

The initial objective of the long-term study, which includes the present report, was to compile and analyze tidal data acquired at Meetinghouse Pond, at the extreme head of the Pleasant Bay – Chatham Harbor system, and at Chatham Fish Pier which lies within Chatham Harbor. Additional gauges were added; the first at Outermost Harbor Marina in March 2017 (in anticipation of the breaching of South Beach that occurred on April 1, 2017), and the second at Stage Harbor in April

2018. During the course of the study it was determined that some pronounced changes within Pleasant Bay - Chatham Harbor are direct responses to regional tidal characteristics. To help delineate these regional influences, limited tidal data from Boston Harbor have been included in this report.

Summarizing, here we report results of our study of tidal data recorded between the beginning of August 2019, and the end of October 2020, at five stations: two within the Pleasant Bay – Chatham Harbor system, one in Outermost Harbor (adjacent to "Fools Inlet"), one in Stage Harbor, and one in Boston Harbor. To aid interpretation, we include data either extending back to June 2016, or the beginning of the data stream. The original tide readings at all five stations were recorded at 6-minute intervals, except for occasional periods of instrument malfunction. In a later section ("Discussion"), we review these and earlier results in light of their relevance to the conceptual model of the system.

METHODS

The objective of the analysis was to focus attention on patterns of sea level, tide level and tidal range change within the Pleasant Bay - Chatham Harbor system at annual and inter-annual time scales. All available verified tide data from the recorders within the system were accessed at six-minute observations from tide recorders at Chatham Fish Pier, Meetinghouse Pond, Outermost Harbor and Stage Harbor. In addition, as mentioned above, tide data from the NOAA/NOS tide recorder at Boston Harbor was accessed to define regional trends.

Meetinghouse Pond, Chatham Fish Pier, Outermost Harbor, and Stage Harbor

Tide data collected during this reporting period (July 2019 – October 2020) were recorded by Onset HOBO pressure recorders installed at Nauset-East Marina on

Meetinghouse Pond and at Chatham Fish Pier (Figure 1) and at Outermost Harbor Marine and Stage Harbor (Figure 2).

Boston Harbor

The Boston Harbor data (NOAA Station #8443970) were recorded on a NOAA tide recorder and made available on the NOAA tides and water levels website (www.tidesandcurrents.noaa.gov).

Analysis

Initial tide data from the stations within the estuary were corrected for the effects of atmospheric pressure using data from an Onset® HOBO atmospheric pressure recorders established at the Chatham Fish Pier and at Meetinghouse Pond to remove error due to the distance between the tidal and atmospheric pressure-recording instruments.

The sea level data were then adjusted to the vertical geodetic datum, NAVD88, by means of precision GPS (Global Positioning System) surveys. The instrument-provided tide levels are also periodically checked against visual readings of a nearby tide staff and compared to the now repaired NOAA tide gauge at Chatham Fish Pier. Times are reported as local standard time.

Statistics for each data set were calculated using MATLAB software. Using the six-minute data as input, mean sea level (MSL), mean high and low water (MHW and MLW), and mean tidal range (MTR) were derived for the individual time series.

Figure 3. Location of tide recorders at Meetinghouse Pond, Chatham Fish Pier, Outermost Harbor and Stage Harbor. Points of interest are identified and imagery from 2019 and 2013 is presented.

Figure 4. Location of tide recorders at Chatham Fish Pier and Outermost Harbor from March 2017 to present (Left). Location of Stage Harbor tide recorder from

RESULTS

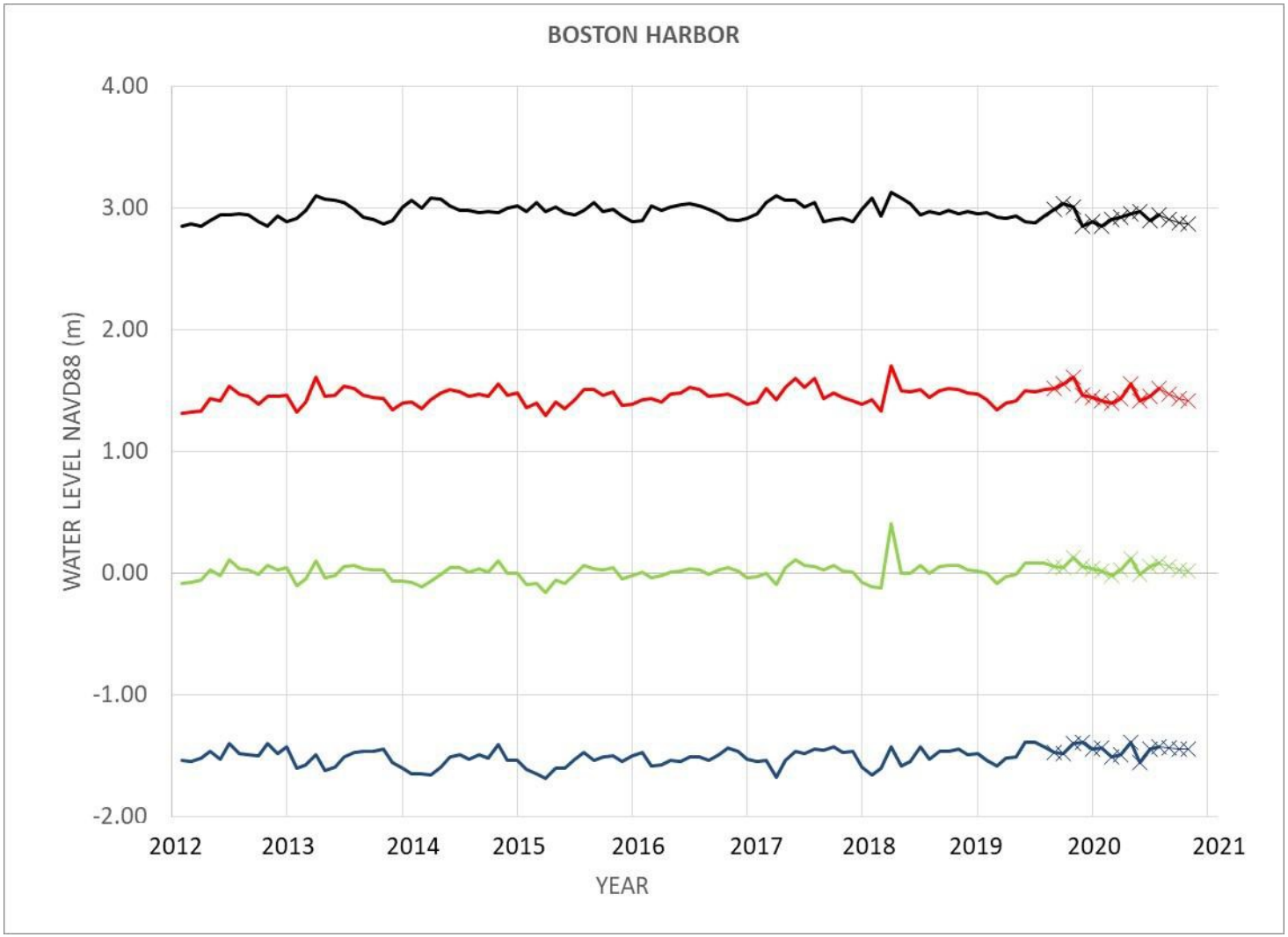


Figure 5. Summary data from Boston Harbor NOAA (Station #8443970) tide recorder from January 2012 to October 2020. Mean Sea Level (Green), Mean High Water (Red), and Mean Low Water (Blue) are given in NAVD88 (meters). Tide Range (Black) is also given in meters. Data collected during this reporting period indicated by marks (X).

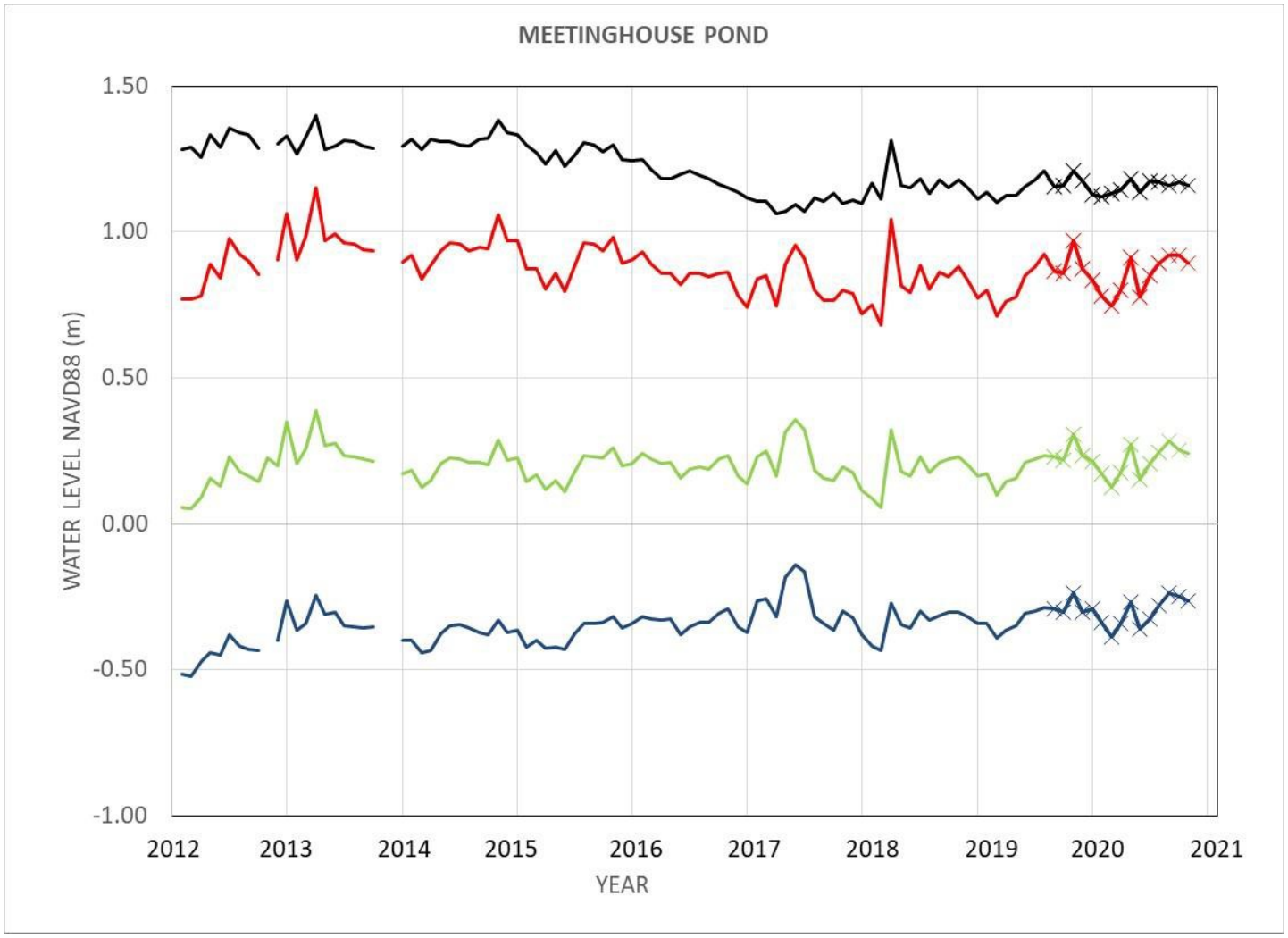


Figure 6. Summary data from Meetinghouse Pond tide recorder from January 2012 to October 2020. Mean Sea Level (Green), Mean High Water (Red), and Mean Low Water (Blue) are given in NAVD88 (meters). Tide Range (Black) is also given in meters. Data collected during this reporting period indicated by marks (X).

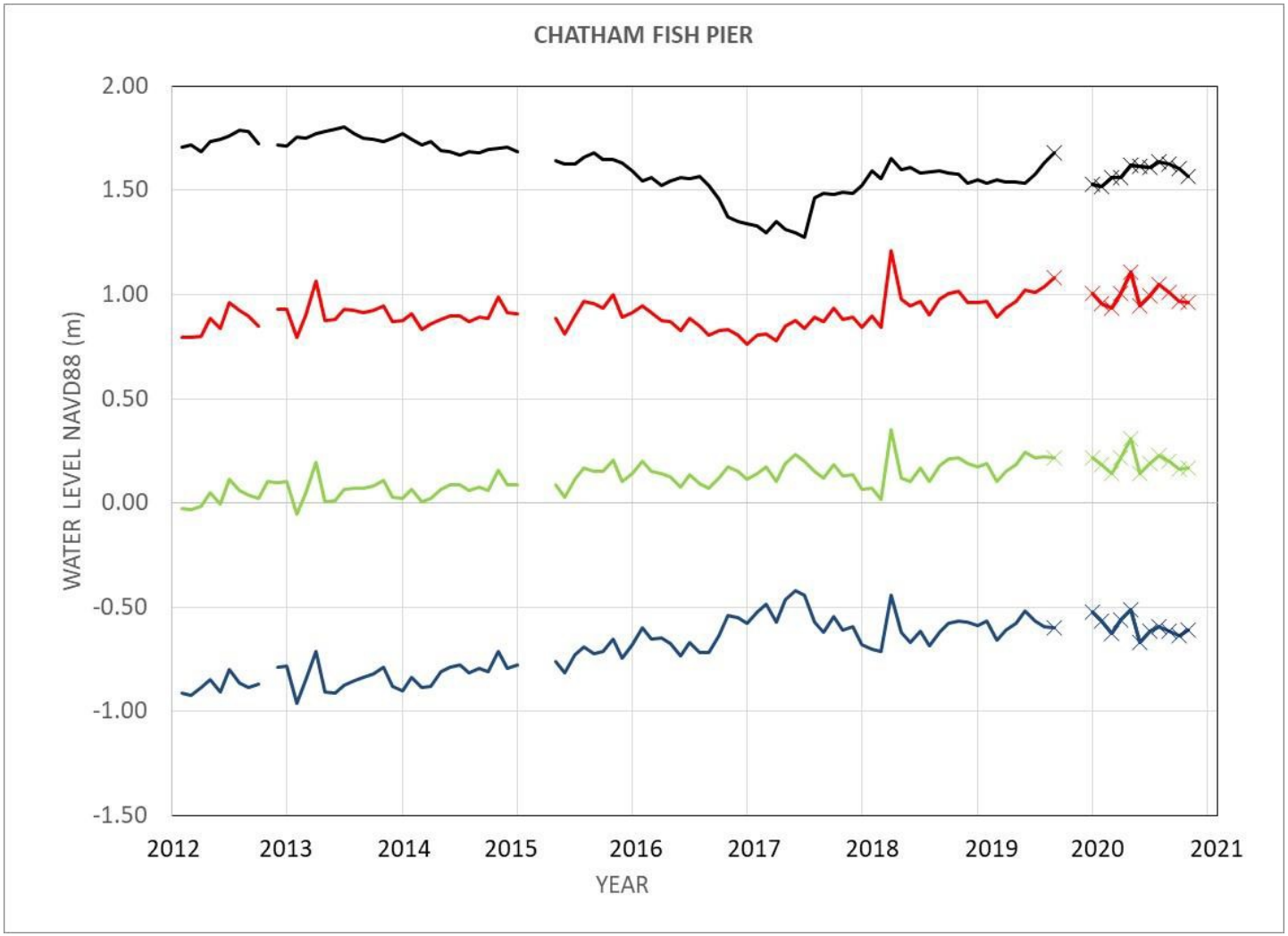


Figure 7. Summary data from Chatham Fish Pier tide recorder from January 2012 to October 2020. Mean Sea Level (Green), Mean High Water (Red), and Mean and Low Water (Blue) are given in NAVD88 (meters). Tide Range (Black) is also given in meters. Data collected during this reporting period indicated by marks (X).

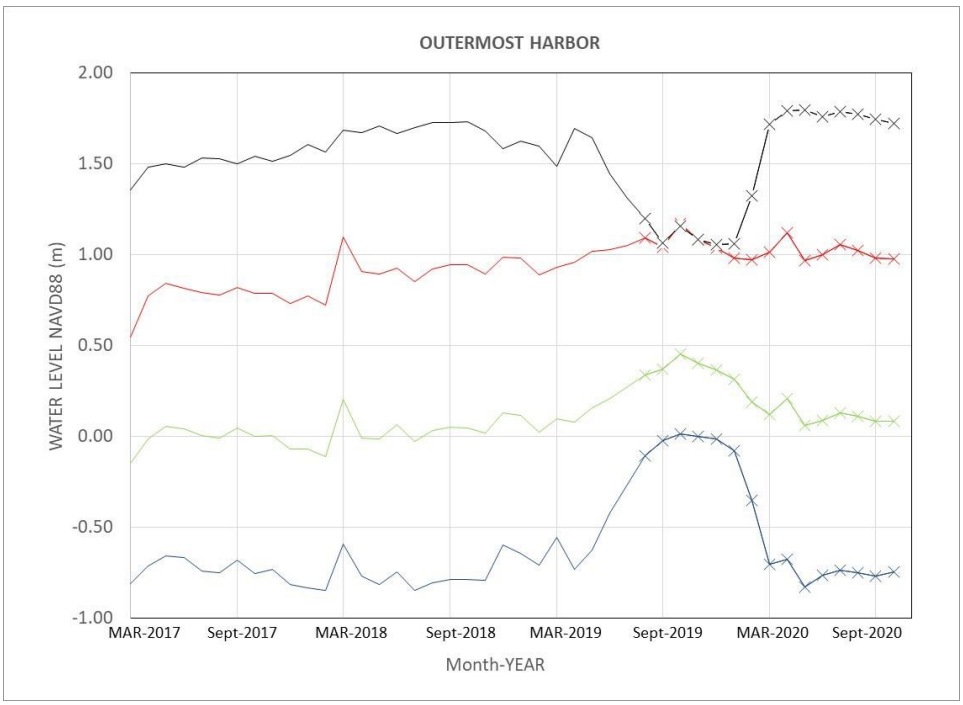


Figure 8. Summary data from Outermost Harbor tide recorder from March 2017 to October 2020. Mean Sea L
(Green), Mean High Water (Red), and Mean Low Water (Blue) are given in NAVD88 (meters). Tide Range(B
is also given in meters. Data collected during this reporting period indicated by marks (X).

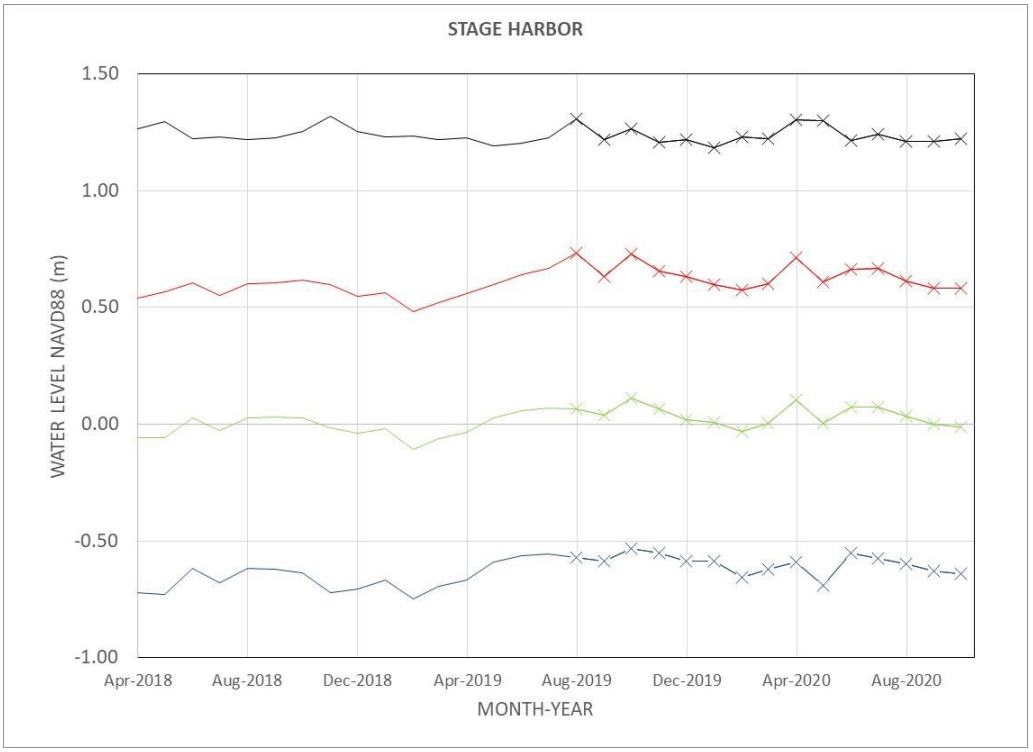


Figure 9. Summary data from Stage Harbor tide recorder from April 2018 to October 2020. Mean Sea Level
(Green), Mean High Water (Red), and Mean Low Water (Blue) are given in NAVD88 (meters). Tide Range(B
is also given in meters. Data collected during this reporting period indicated by marks (X).

DISCUSSION

Meetinghouse Pond / tidal restriction

The monthly data from Meetinghouse Pond for the present reporting period (Figure 6) show little change from that of the preceding year; in fact, they seem to generally reflect regional patterns as reflected in the data from Boston (Figure 5). To better evaluate the present trends of Meetinghouse Pond tides, we view them in relation to the full history of our monthly data from that station beginning in 2005 (Figure 10).

These data indicate that within ten years following the 2007 breaching of Nauset Beach - the event that initiated North Inlet - Pleasant Bay tidal range was smaller than it had been prior to the breach. Except for the expected adjustment (low water decrease/high water increase) for a few years following initiation of North Inlet, Meetinghouse Pond tidal range gradually decreased to a minimum in 2017 – lower than the pre-inlet range – and has increased only slightly since then. (Figure 8).

The major contributor to the tidal restriction was discussed in a previous report (Giese and Legare 2019): the role played by *increasing low water* levels to decreased tidal range at both Meetinghouse Pond and Chatham Fish Pier prior to mid-2017. That discussion concluded that the increasing low water levels – and accompanying decreasing tidal ranges – were associated with the tidal hydraulic processes leading to the end of the "inlet development phase" of the system's long-term "cycle".

But since that time, while tidal range at Chatham Fish Pier has rebounded by almost a foot (30 cm) since mid-2017 (Figure 7), tides at Meetinghouse Pond remain as restricted as they were prior to the initiation of North Inlet. The question arises: Why? If the "critical period" of 2017 - mid-2018 marked the end of the inlet transition (development) phase – the phase during which the model (Figure 2) predicts increasing hydraulic efficiency due to increasing access to the forcing "outside" tides – why do we now see a near-minimum tidal range at Meetinghouse Pond? The answer, as shown in Figure 11 and Figure 12, lies in the role played by *relatively decreasing high water* levels in Pleasant Bay following the "critical period" of 2017 – mid-2018.

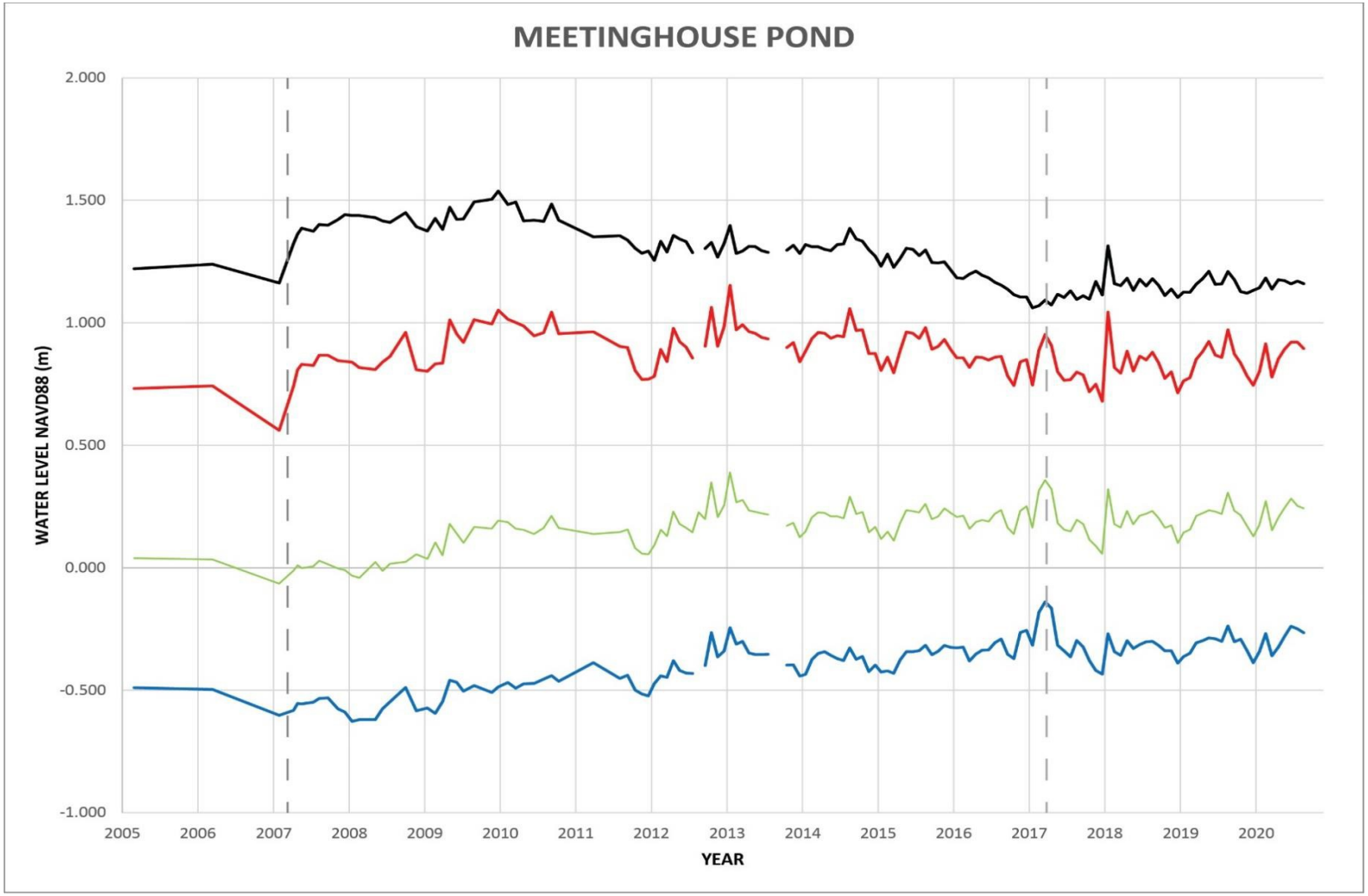


Figure 10. Meetinghouse Pond tide levels and range between April 2005 and October 2020. Mean Sea Level (Green), Mean High Water (Red), and Mean Low Water (Blue) are given in NAVD88 (meters). Tide Range (Black) is also given in meters. Dashed vertical line on left indicates initiation of North Inlet; the line on right indicates initiation of "Eagle" inlet.

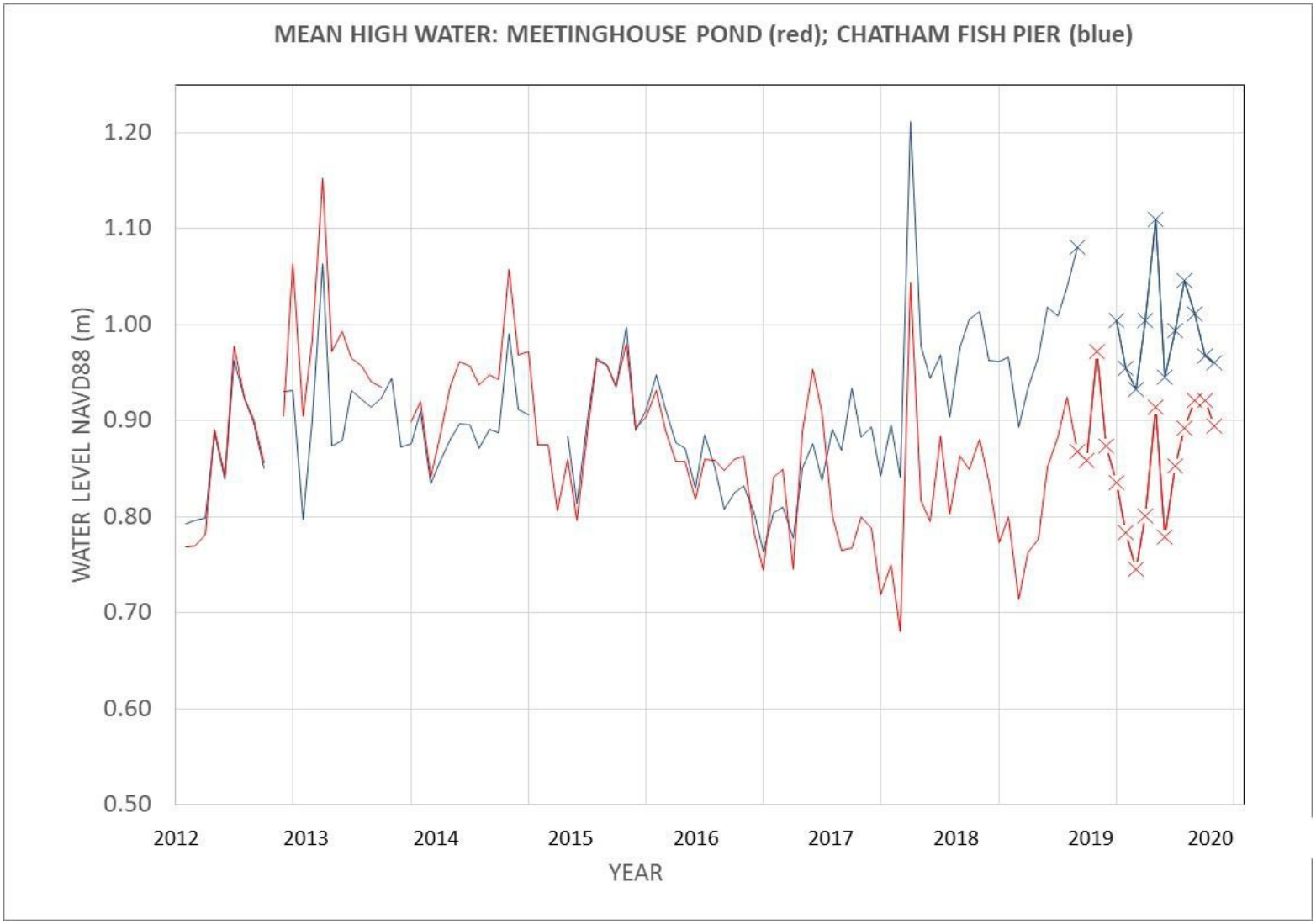


Figure 11. Monthly mean high water at Meetinghouse Pond and Chatham Fish Pier between 2012 and October 2020. Meetinghouse Pond (Red), and Chatham Fish Pier (Blue) tides are given in NAVD88 (meters). Data collected during this reporting period indicated by marks (X). The figure indicates that during the critical 2017 to mid-2018 time period ending the "inlet transition" phase, a major shift took place in the relative heights of MHW at Chatham Fish Pier and Meetinghouse Pond

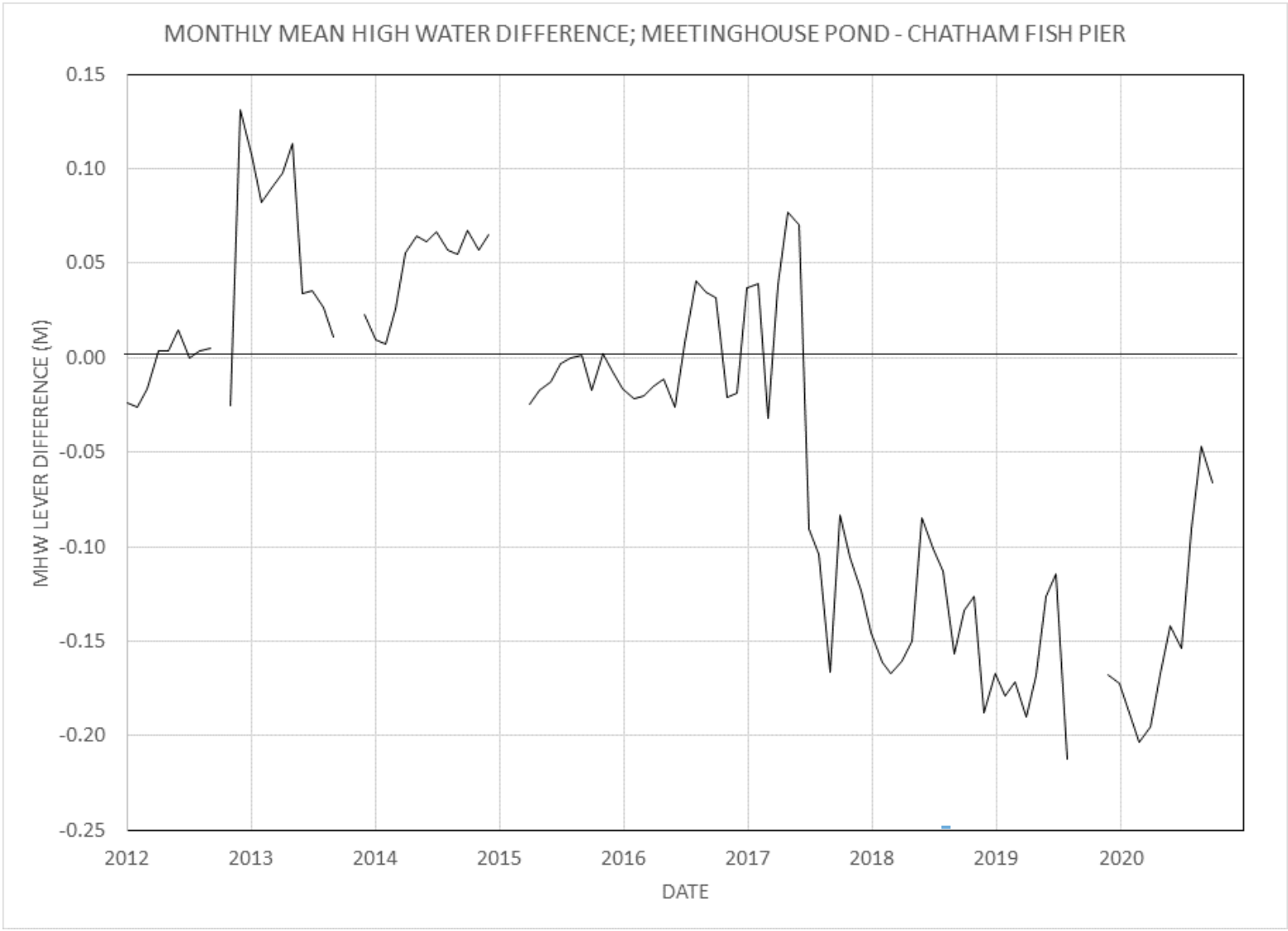


Figure 12. Differences between monthly mean high water levels at Meetinghouse Pond and Chatham Fish Pier between 2012 and October, 2020. The shift from similar levels to *relatively reduced high water* levels at Meetinghouse Pond occurred during the 2017 to mid-2018 "critical period" (marked by blue lines; see text). The two vertical lines show the period referred to as the "critical period" (see text).

The cause of the relative reduction of high water at Meetinghouse Pond when compared with that at Chatham Fish Pier becomes evident when the six-minute tide data for September, 2016, and April, 2018, from the two stations are compared (Figure 13). The figure reveals a tidal phase shift and amplitude reduction at Meetinghouse Pond relative to Chatham Fish Pier during the critical 2017 to mid-2018 time period ending the "inlet transition" phase of the system. Those changes are the result of increasing constriction of the tidal channel between the southern terminus of North Beach and Minister's Point (Figure 14). With increasing deposition associated with the growing terminal spit, the channel has shifted westward, but coastal stabilization structures on Minister's Point have prevented the shoreline from retreating to accommodate the increasing flow. As a result, the channel has narrowed and flood currents entering Pleasant Bay meet increasing resistance, resulting in both a delay in time and reduction in amplitude of high tide as recorded at Meetinghouse Pond.

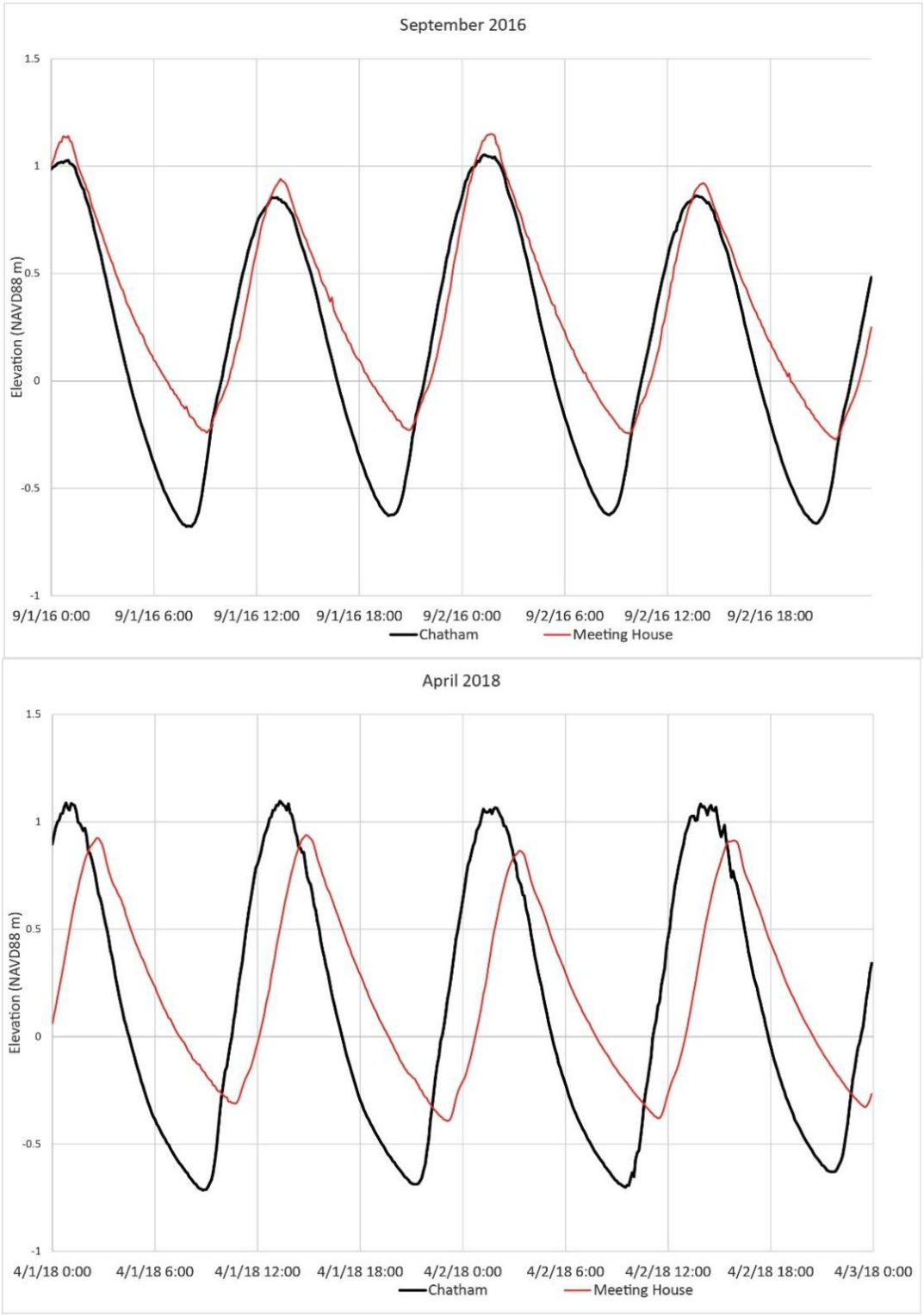


Figure 13. (Top): Six-minute tide data from Meetinghouse Pond (red) and Chatham Fish Pier (black) recorded in September, 2016. (Bottom): Similar data recorded in April, 2018. A comparison of the two plots reveals a tidal phase shift and amplitude reduction at Meetinghouse Pond relative to Chatham Fish Pier during the critical 2017 to mid-2018 time period ending the "inlet transition" phase of the system. Those changes resulted from constriction of the tidal channel between the southern terminus of North Beach and Minister's Point (see Figure 14).

Figure 14. Aerial photograph looking northeastward from North Chatham showing, at top center, Minister's Point, the narrowing tidal channel leading to Pleasant Bay, and the southern terminus of North Beach.

Summarizing, the data that have now been acquired from Meetinghouse Pond indicate that increasing hydraulic efficiency - predicted from the model to result from the dominant inlet transition to North Inlet - has not taken place. Rather, due to coastal armoring - an element not included in the model - tidal flow has become more restricted.

Historical records suggest that early in the previous (1846 -1987) "cycle" the channel off Minister's Point had similarly been forced to shift westward, but that at that time the headland shore had retreated to accommodate the increased flow. An 1868 U.S. Coast Survey Topographic Sheet (T-Sheet) of North Chatham shows an elongated spit extending southward from Minister's Point (Figure 15), presumably formed of sediment eroded from the then not-stabilized north-facing shore of the headland.

Figure 15. Minister's Point, formerly Allen's Point, as depicted on a 1868 T-Sheet of North Chatham. The long spit trending southward off the Point was likely formed of sediment eroded along the north coast by strong tidal currents in conjunction with wind waves and high tides. (Source: U.S. Coast Survey)

In addition to shoreline stabilization by coastal armoring, we note another significant change in the relationship between the Chatham mainland coast and the barrier beach system - the shoreward migration of North Beach between 1938 and 2018 (Figure 16). Notable for the present discussion are (1) the long-term stability of a short section of the barrier beach in South Orleans - referred to herein as the "Apex" - and (2) the clockwise rotation of the barrier beach south of the Apex – referred to as "North Beach Spit".

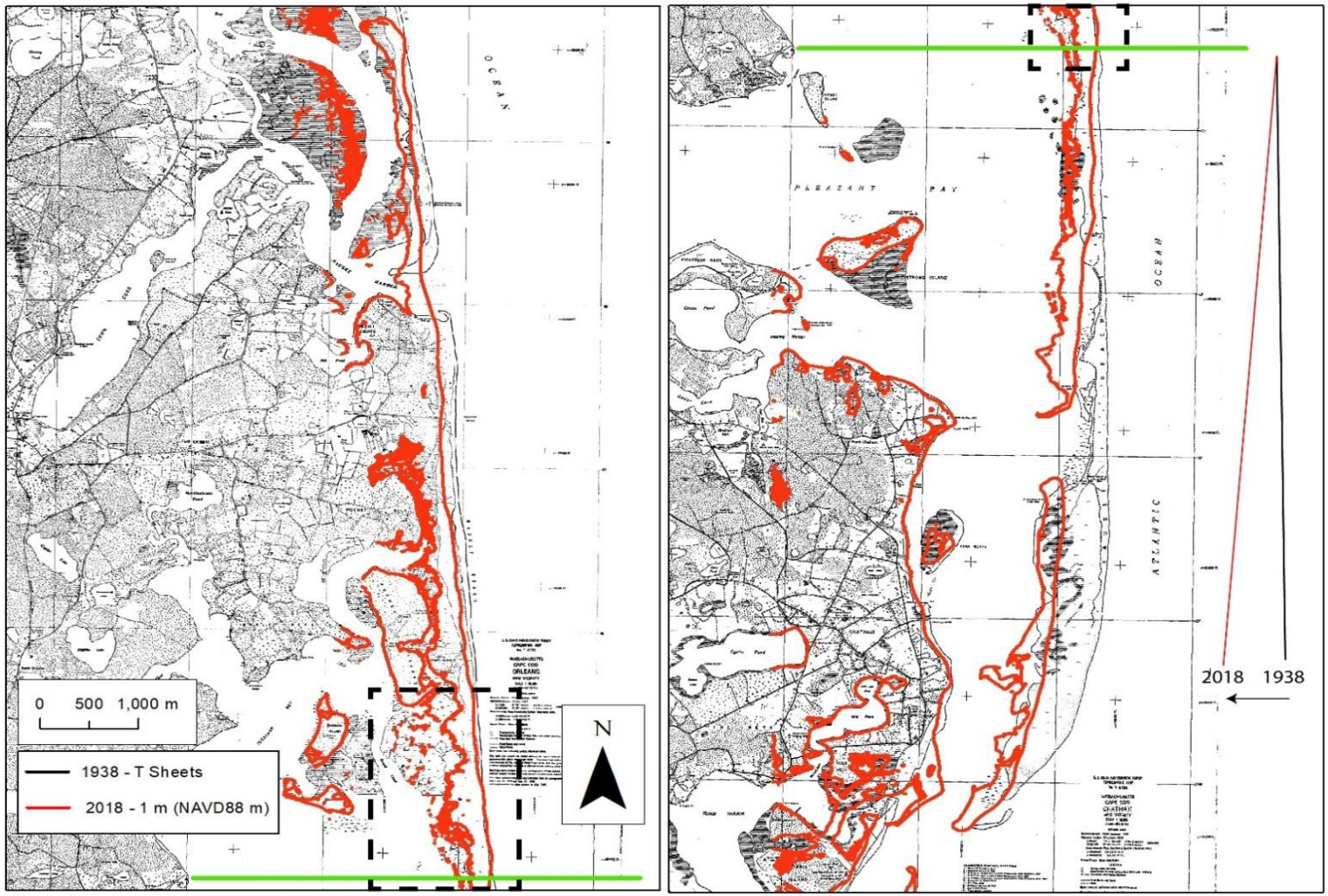


Figure 16. Comparison of Nauset Beach coastal form obtained from a 2018 USGS Lidar survey (1 m NAVD 88 contour; red) with the 1938 T-Sheet (black background). The northern section is shown in left panel; the southern section in right panel. The green match line is drawn directly east of the prominent point at

The clockwise rotation of North Beach Spit since 1938 has resulted in a westward translation of the barrier by approximately 300 m (1,000 ft) in the vicinity of Minister's Point. A large part of that rotation has taken place over the past 2-3 decades and may not continue, at least at the same rate. However, we note that the rotation of North Beach Spit together with the existing stabilization of the Chatham shoreline may cut short the expected century-long period of "inlet migration" and that a new pattern of change may be initiated.

In summary, two factors - shoreward migration of North Beach Spit and coastal stabilization structures at Minister's Point - contribute to the Pleasant Bay tidal restriction indicated by our recent Meetinghouse Pond and Chatham Fish Pier data. Those two factors, in combination, may interfere with the full completion of the expected "inlet migration" phase of the cyclic evolution of the Nauset Beach – Pleasant Bay – Chatham Harbor system. As a result of the introduction of these new elements, a less regular, more chaotic pattern may evolve.

Chatham Fish Pier / Outermost Harbor / Stage Harbor

The recent tide data from Chatham Fish Pier (Figure 7) have been discussed to some extent above with respect to Pleasant Bay tidal restriction. However, when considered either independently or in comparison to Outermost Harbor (Figure 8) or Stage Harbor (Figure 9) tides, they appear to continue the relatively unrestricted pattern noted previously (Giese and Legare 2019). High water levels at Chatham Fish Pier and Outermost Harbor continue to be at near-maximum levels and to resemble each other and Boston high water in overall pattern, suggesting little difference between them and the "outside" (open Atlantic) forcing tides. Low water levels at Chatham Fish Pier also continue their previous patterns and height - about a half meter above the outside tide (Giese and Legare, 2020).

The dramatic changes in low water at Outermost Harbor reflect the channel shoaling mentioned in our previous report followed by a very successful channel dredging operation. As a result, the data indicate that low water levels in the harbor were restored to their previous levels. Interestingly, post-dredging low water levels at Outermost Harbor are a little below those at Chatham Fish Pier, suggesting a more efficient connection with ocean tides.

Stage Harbor monthly tide levels were remarkably stable over the study period considering the major sedimentation occurring in the passage between Morris

Island and North Monomoy. Stage Harbor, being within Nantucket Sound, has significantly lower high-water levels than those at Chatham Fish Pier (Figure 17). Low water levels were similar to those at Chatham Fish Pier, but briefly – at the time of low water at Chatham – slightly higher. That small, brief gradient in tidal elevation is responsible for a short-period, low velocity ebb tidal current flow in a reverse direction to the major westerly current through the passage forced by the usually higher ocean tides to the east.

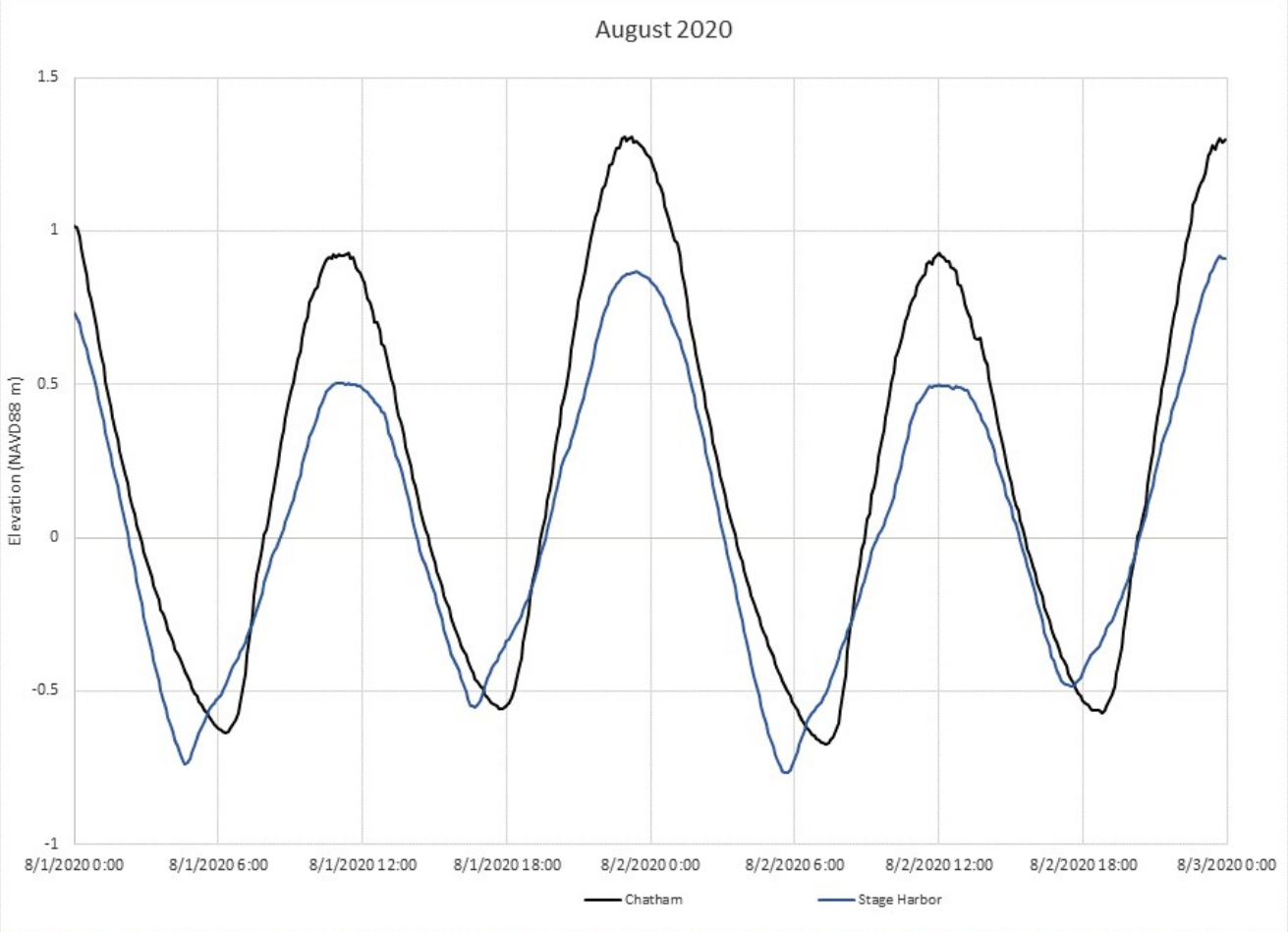


Figure 17. Six-minute tide data from Stage Harbor (Blue) and Chatham Fish Pier (black) recorded in August, 2020.

ACKNOWLEDGEMENTS

This study was supported by the Pleasant Bay Resource Management Alliance, and benefitted greatly from the guidance of its director, Carole Ridley, the members of its Coastal Resource Work Group, and the Director of Coastal Resources for the Town of Chatham, Ted Keon, whose comments on an earlier version of this report contributed significantly to its clarity.

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Appendix

Table 1. Summary data from Meetinghouse Pond tide recorder from May 2016 to October 2020. Mean Sea Level (MSL), Mean High Water (MHW), and Mean Low Water (MLW) are given in NAVD88 (meters). Tide Range (Range) is also given in meters. Data collected during this reporting period indicated by **bold** lettering.

	Meetinghouse Pond					Meetinghouse Pond			
Month	MSL	MHW	MLW	Range	Month	MSL	MHW	MLW	Range
May-2016	0.16	0.82	-0.38	1.20	Aug-2018	0.21	0.86	-0.31	1.18
Jun-2016	0.19	0.86	-0.35	1.21	Sep-2018	0.22	0.85	-0.30	1.15
Jul-2016	0.20	0.86	-0.34	1.19	Oct-2018	0.23	0.88	-0.30	1.18
Aug-2016	0.19	0.85	-0.34	1.18	Nov-2018	0.20	0.84	-0.32	1.15
Sep-2016	0.22	0.86	-0.31	1.17	Dec-2018	0.16	0.77	-0.34	1.11
Oct-2016	0.24	0.86	-0.29	1.15	Jan-2019	0.17	0.80	-0.34	1.14
Nov-2016	0.16	0.78	-0.35	1.14	Feb-2019	0.10	0.71	-0.39	1.10
Dec-2016	0.14	0.74	-0.37	1.12	Mar-2019	0.14	0.76	-0.36	1.13
Jan-2017	0.23	0.84	-0.26	1.11	Apr-2019	0.16	0.78	-0.35	1.13
Feb-2017	0.25	0.85	-0.26	1.11	May-2019	0.21	0.85	-0.31	1.16
Mar-2017	0.16	0.75	-0.32	1.06	Jun-2019	0.22	0.88	-0.30	1.18
Apr-2017	0.31	0.89	-0.18	1.07	Jul-2019	0.23	0.92	-0.29	1.21
May-2017	0.36	0.95	-0.14	1.09	**Aug-2019**	**0.22**	**0.86**	**-0.30**	**1.16**
Jun-2017	0.32	0.91	-0.16	1.07	**Sep-2019**	**0.31**	**0.97**	**-0.24**	**1.21**
Jul-2017	0.18	0.80	-0.32	1.12	**Oct-2019**	**0.23**	**0.87**	**-0.30**	**1.18**
Aug-2017	0.16	0.77	-0.34	1.10	**Nov-2019**	**0.22**	**0.84**	**-0.29**	**1.13**
Sep-2017	0.15	0.77	-0.36	1.13	**Dec-2019**	**0.15**	**0.78**	**-0.36**	**1.14**
Oct-2017	0.20	0.80	-0.30	1.10	**Jan-2020**	**0.17**	**0.78**	**-0.34**	**1.12**
Nov-2017	0.18	0.79	-0.32	1.11	**Feb-2020**	**0.13**	**0.75**	**-0.39**	**1.13**
Dec-2017	0.11	0.72	-0.38	1.10	**Mar-2020**	**0.17**	**0.80**	**-0.34**	**1.14**
Jan-2018	0.09	0.75	-0.42	1.17	**Apr-2020**	**0.27**	**0.91**	**-0.27**	**1.18**
Feb-2018	0.06	0.68	-0.43	1.11	**May-2020**	**0.15**	**0.78**	**-0.36**	**1.14**
Mar-2018	0.32	1.04	-0.27	1.31	**Jun-2020**	**0.21**	**0.85**	**-0.32**	**1.18**
Apr-2018	0.18	0.82	-0.34	1.16	**Jul-2020**	**0.25**	**0.89**	**-0.28**	**1.17**
May-2018	0.16	0.79	-0.36	1.15	**Aug-2020**	**0.28**	**0.92**	**-0.24**	**1.16**
Jun-2018	0.23	0.88	-0.30	1.18	**Sep-2020**	**0.25**	**0.92**	**-0.25**	**1.17**
Jul-2018	0.18	0.80	-0.33	1.13	**Oct-2020**	**0.24**	**0.89**	**-0.26**	**1.16**

Table 2. Summary data from Chatham Fish Pier tide recorder from May 2016 to October 2020. Mean Sea Level (MSL), Mean High Water (MHW), and Mean Low Water (MLW) are given in NAVD88 (meters). Tide Range (Range) is also given in meters. Data collected during this reporting period indicated by **bold** lettering.

Month	MSL	Chatham MHW	MLW	Range	Month	MSL	Chatham MHW	MLW	Range
May-2016	0.08	0.83	-0.73	1.56	Aug-2018	0.18	0.98	-0.62	1.60
Jun-2016	0.13	0.89	-0.67	1.55	Sep-2018	0.21	1.01	-0.58	1.58
Jul-2016	0.10	0.85	-0.72	1.57	Oct-2018	0.22	1.01	-0.56	1.58
Aug-2016	0.07	0.81	-0.72	1.52	Nov-2018	0.19	0.96	-0.57	1.54
Sep-2016	0.12	0.83	-0.63	1.46	Dec-2018	0.17	0.96	-0.59	1.55
Oct-2016	0.17	0.83	-0.54	1.37	Jan-2019	0.19	0.97	-0.57	1.54
Nov-2016	0.15	0.80	-0.55	1.35	Feb-2019	0.11	0.89	-0.66	1.55
Dec-2016	0.11	0.76	-0.58	1.34	Mar-2019	0.15	0.93	-0.61	1.54
Jan-2017	0.14	0.80	-0.53	1.33	Apr-2019	0.19	0.97	-0.58	1.54
Feb-2017	0.17	0.81	-0.49	1.30	May-2019	0.24	1.02	-0.52	1.54
Mar-2017	0.10	0.78	-0.57	1.35	Jun-2019	0.22	1.01	-0.57	1.58
Apr-2017	0.19	0.85	-0.46	1.31	Jul-2019	0.22	1.04	-0.59	1.63
May-2017	0.23	0.88	-0.42	1.30	**Aug-2019**	**0.22**	**1.08**	**-0.60**	**1.68**
Jun-2017	0.20	0.84	-0.44	1.28	**Sep-2019**				
Jul-2017	0.15	0.89	-0.57	1.46	**Oct-2019**				
Aug-2017	0.12	0.87	-0.62	1.49	**Nov-2019**				
Sep-2017	0.19	0.93	-0.55	1.48	**Dec-2019**	**0.22**	**1.00**	**-0.52**	**1.53**
Oct-2017	0.13	0.88	-0.61	1.49	**Jan-2020**	**0.18**	**0.96**	**-0.57**	**1.52**
Nov-2017	0.14	0.89	-0.59	1.48	**Feb-2020**	**0.14**	**0.93**	**-0.63**	**1.56**
Dec-2017	0.06	0.84	-0.68	1.52	**Mar-2020**	**0.22**	**1.00**	**-0.56**	**1.56**
Jan-2018	0.07	0.90	-0.70	1.59	**Apr-2020**	**0.31**	**1.11**	**-0.51**	**1.62**
Feb-2018	0.02	0.84	-0.71	1.55	**May-2020**	**0.14**	**0.95**	**-0.67**	**1.62**
Mar-2018	0.35	1.21	-0.44	1.66	**Jun-2020**	**0.19**	**0.99**	**-0.61**	**1.61**
Apr-2018	0.12	0.98	-0.62	1.60	**Jul-2020**	**0.23**	**1.05**	**-0.59**	**1.64**
May-2018	0.10	0.94	-0.67	1.61	**Aug-2020**	**0.20**	**1.01**	**-0.62**	**1.63**
Jun-2018	0.17	0.97	-0.61	1.58	**Sep-2020**	**0.16**	**0.97**	**-0.64**	**1.60**
Jul-2018	0.10	0.90	-0.69	1.59	**Oct-2020**	**0.17**	**0.96**	**-0.61**	**1.57**

Table 3. Summary data from Outermost Harbor tide recorder from March 2017 to October 2020. Mean Sea Level (MSL), Mean High Water (MHW), and Mean Low Water (MLW) are given in NAVD88 (meters). Tide Range (Range) is also given in meters. Data collected during this reporting period indicated by **bold** lettering.

Outer Most Harbor				
Month	**MSL**	**MHW**	**MLW**	**Range**
Mar-2017	-0.15	0.55	-0.81	1.36
Apr-2017	-0.01	0.77	-0.71	1.48
May-2017	0.06	0.84	-0.65	1.50
Jun-2017	0.04	0.81	-0.67	1.48
Jul-2017	0.01	0.79	-0.74	1.53
Aug-2017	-0.01	0.78	-0.75	1.53
Sep-2017	0.05	0.82	-0.68	1.50
Oct-2017	0.00	0.79	-0.75	1.54
Nov-2017	0.01	0.79	-0.73	1.51
Dec-2017	-0.07	0.73	-0.82	1.55
Jan-2018	-0.07	0.78	-0.83	1.61
Feb-2018	-0.11	0.72	-0.85	1.57
Mar-2018	0.20	1.10	-0.59	1.69
Apr-2018	-0.01	0.91	-0.77	1.67
May-2018	-0.01	0.90	-0.81	1.71
Jun-2018	0.06	0.92	-0.74	1.67
Jul-2018	-0.02	0.85	-0.85	1.70
Aug-2018	0.04	0.92	-0.80	1.73
Sep-2018	0.05	0.94	-0.78	1.73
Oct-2018	0.05	0.94	-0.79	1.73
Nov-2018	0.02	0.89	-0.79	1.68
Dec-2018	0.13	0.99	-0.59	1.58
Jan-2019	0.12	0.98	-0.64	1.62
Feb-2019	0.03	0.89	-0.71	1.60
Mar-2019	0.10	0.93	-0.56	1.49
Apr-2019	0.08	0.96	-0.73	1.69
May-2019	0.16	1.02	-0.62	1.65
Jun-2019	0.21	1.03	-0.42	1.45
Jul-2019	0.27	1.05	-0.26	1.31
Aug-2019	**0.34**	**1.10**	**-0.11**	**1.20**
Sep-2019	**0.37**	**1.04**	**-0.02**	**1.07**
Oct-2019	**0.45**	**1.17**	**0.02**	**1.16**
Nov-2019	**0.41**	**1.09**	**0.00**	**1.08**
Dec-2019	**0.37**	**1.04**	**-0.01**	**1.05**
Jan-2020	**0.31**	**0.98**	**-0.08**	**1.06**
Feb-2020	**0.19**	**0.97**	**-0.35**	**1.32**
Mar-2020	**0.12**	**1.01**	**-0.70**	**1.72**
Apr-2020	**0.21**	**1.12**	**-0.67**	**1.79**
May-2020	**0.06**	**0.97**	**-0.83**	**1.79**
Jun-2020	**0.09**	**1.00**	**-0.76**	**1.76**
Jul-2020	**0.13**	**1.05**	**-0.74**	**1.79**
Aug-2020	**0.11**	**1.03**	**-0.75**	**1.78**
Sep-2020	**0.08**	**0.98**	**-0.77**	**1.75**
Oct-2020	**0.08**	**0.98**	**-0.75**	**1.72**

Table 4. Summary data from Stage Harbor tide recorder from April 2018 to October 2020. Mean Sea Level (MSL), Mean High Water (MHW), and Mean Low Water (MLW) are given in NAVD88 (meters). Tide Range (Range) is also given in meters. Data collected during this reporting period indicated by **bold** lettering.

	Stage Harbor			
Month	**MSL**	**MHW**	**MLW**	**Range**
Apr-2018	-0.06	0.54	-0.72	1.26
May-2018	-0.06	0.57	-0.73	1.29
Jun-2018	0.03	0.61	-0.62	1.22
Jul-2018	-0.03	0.55	-0.68	1.23
Aug-2018	0.03	0.60	-0.62	1.22
Sep-2018	0.03	0.60	-0.62	1.23
Oct-2018	0.03	0.62	-0.64	1.25
Nov-2018	-0.02	0.60	-0.72	1.32
Dec-2018	-0.04	0.55	-0.71	1.25
Jan-2019	-0.02	0.56	-0.67	1.23
Feb-2019	-0.11	0.48	-0.75	1.23
Mar-2019	-0.06	0.52	-0.70	1.22
Apr-2019	-0.03	0.56	-0.67	1.23
May-2019	0.03	0.60	-0.59	1.19
Jun-2019	0.06	0.64	-0.56	1.20
Jul-2019	0.07	0.67	-0.56	1.22
Aug-2019	**0.07**	**0.73**	**-0.57**	**1.31**
Sep-2019	**0.04**	**0.63**	**-0.59**	**1.22**
Oct-2019	**0.11**	**0.73**	**-0.53**	**1.26**
Nov-2019	**0.07**	**0.66**	**-0.55**	**1.21**
Dec-2019	**0.02**	**0.63**	**-0.59**	**1.22**
Jan-2020	**0.01**	**0.60**	**-0.59**	**1.18**
Feb-2020	**-0.03**	**0.57**	**-0.65**	**1.23**
Mar-2020	**0.00**	**0.60**	**-0.62**	**1.22**
Apr-2020	**0.10**	**0.71**	**-0.59**	**1.30**
May-2020	**0.00**	**0.61**	**-0.69**	**1.30**
Jun-2020	**0.07**	**0.66**	**-0.55**	**1.21**
Jul-2020	**0.07**	**0.67**	**-0.57**	**1.24**
Aug-2020	**0.04**	**0.61**	**-0.60**	**1.21**
Sep-2020	**0.00**	**0.58**	**-0.63**	**1.21**
Oct-2020	**-0.01**	**0.58**	**-0.64**	**1.22**