

Section G

Construction Methodologies



G. CONSTRUCTION METHODOLOGIES

Given the size, scale, and complexity of the Nauset Estuary dredging project, different methods of constructing the project are proposed for (3) distinct reaches of the Estuary:

- Town Cove and the Central Main Channel(s),
- The Eastern Main Channel and Behind the Barrier Beach, and
- The Pricilla Landing and Mill Pond spur channels.

Different construction methods have been proposed to account for variability in dredged sediment quantity and quality, proximity to suitable dewatering areas, limitations on pumping distance and/or capacity of dredging equipment, and the need to minimize impacts to coastal resource areas in and adjacent to the Estuary. Prior to mobilization, it is assumed that a pre-construction bathymetric survey will be conducted and provided to the selected contractor(s). Specific methodologies for dredging and disposing of and/or beneficially reusing dredged material in the (3) reaches of the Estuary are described below.

1.0 Town Cove and the Central Main Channel

It is estimated that 9,660 cy of material will need to be dredged from Town Cove and the Central Main Channel. The material in this reach of the Estuary is primarily sand, with some fine, muddy material located closer to the mouth of Town Cove (0.2% gravel, 96.0% sand, and 3.8% fines). Due to the distal location of Town Cove and the Central Main Channel from the primary dewatering basin north of Nauset Public Beach and the lack of suitable, nearby dewatering sites, it is expected that this reach of the Estuary will be dredged mechanically. Dredge spoils will be barged to Goose Hummock Landing, dewatered, trucked, and stockpiled at upland sites in the Towns of Orleans and/or Eastham for beneficial reuse. Stockpiles will be managed and turned regularly to facilitate desiccation of red tide cysts. Testing will be performed on the stockpile prior to reuse to reduce the risk of transporting viable red tide cysts.

1.1 Mobilization and Construction - It is anticipated that mechanical dredging equipment will be brought over-the-road, assembled on-site, and launched at Goose Hummock and/or Cove Road landing(s). It is anticipated that the equipment needed to complete this section of the project will include:

- (1) dredge superstructure with anchoring spuds to support (1) large track excavator and/or crane with clamshell bucket
- A minimum of (2) modular barges or self-contained scows to transport dredged material to Goose Hummock Landing
- (1) primary push boat to position the dredge superstructure, move barges/scows, and transfer fuel to the dredging equipment
- (1) support skiff to transport the dredge crew
- Up to (12) roll-off containers to dewater and transport dredge spoils to the upland stockpile
- (1) large, wheeled loader to facilitate shoreside materials management



- Turbidity curtains adjacent the dredge and Goose Hummock Landing
- Geotextile liners and concrete perimeter containment at Goose Hummock Landing
- Trucking fleet to transport dredge spoils to the upland stockpile and return empty roll-off containers

Once on-site and assembled, the dredge superstructure will be transported to the dredge site by the primary push boat and anchored in place. A barge loaded with (2-3) roll-off containers or a 50-100 cy scow will be positioned adjacent the dredge superstructure. Turbidity curtains will then be deployed around the dredge superstructure and barge or scow. Dredged material will then be loaded directly into the roll-off containers located on the barge or into the scow. Given the overall sandy nature of the material, it is expected that spoils will dewater rapidly, with slurry waters flowing back into the estuary within the confines of the turbidity curtains. If the crew encounters a particularly silty patch of material, landside dewatering times will be extended (see offloading/dewatering protocol below).

1.2 Dewatering and Transport of Dredged Material - Once they reach capacity, the barge or scow will be transported back to Goose Hummock Landing. It is assumed that the barge or scow will have an articulating landing ramp allowing the spoils to be unloaded on the existing Goose Hummock Landing boat ramp, which has a maximum width of approximately 25 ft. Roll-off containers will be hauled up the boat ramp and staged in the Town Landing parking area, well back from the existing bulkhead, to finish dewatering, if necessary. If a scow is used to transport the spoils, they will be transferred to empty roll-off containers staged in the parking area using the wheeled loader. A concrete perimeter and geotextile liner will direct slurry waters back down the boat ramp to the Estuary. Turbidity curtains around the landing site will mitigate turbidity in nearshore waters. Once the dredge spoils have sufficiently dewatered, the roll-off containers will be hauled off site and placed at an approved, off-site, upland stockpile located in the Town of Orleans and/or Eastham. It is expected that a second barge or scow will be running in tandem, allowing dredging operations to continue while offloading/transport occurs. The process will be repeated until all 9,660 cy have been removed from the navigation channel and transported to the stockpile.

1.3 Production Rate and Re-Fueling - Production is expected to average 160 cy/day under ideal conditions, (assuming an 8-hour workday), allowing dredging in this reach of the Estuary to be completed in 61 working days. Assuming tri-axle roll-off containers are used, this equates to approximately 10 roll-off container/truck loads per day (16 cy/container), this number could be reduced to (6-7) roll-off container loads/day if larger, trailer-sized (26 cy) containers are used. As mentioned above, this production schedule assumes ideal weather conditions. If production is delayed due to a storm event, it is assumed that the dredge superstructure, barges and/or scows and all ancillary equipment will be secured at Goose Hummock Landing.

It is anticipated that the excavator and/or crane will be refueled every-other-day using a diesel transfer tank located on the primary push boat. The primary push boat, support skiff, and



wheeled loader will be refueled at Goose Hummock Landing. It is expected that a fuel service company will be contracted to provide regular fuel deliveries for the duration of the project.

1.4 Demobilization - Once the Town Cove and Central Main Channel reaches are complete, all dredging equipment and associated ancillary equipment will return to Goose Hummock Landing and will be disassembled and hauled from the water using the Goose Hummock and/or Cove Road boat ramp(s). All equipment will be hauled from the site over-the-road. Prior to removing the wheeled loader from the site, the gravel-lined Goose Hummock Town Landing parking area will be regraded. All erosion controls and turbidity curtains will be disassembled and removed from the site.

2.0 Eastern Main Channel and Behind the Barrier Beach

It is estimated that 119,830 cy of material will need to be dredged from the Eastern Main Channel and areas located Behind the Barrier Beach. The material in this reach of the Estuary is nearly all sand, with minimal amounts of gravel and fines (2.0% gravel, 96.6% sand, 1.4% fines). Due to the long pumping distances from the Eastern Main Channel and Behind the Barrier Beach to the primary dewatering basin north of Nauset Public Beach and the highly dynamic nature of the Estuary in this location, it is expected that this reach of the Estuary will be dredged using hydraulic dredging equipment with sidecasting capabilities. Dredge spoils will be sidecast 60-80 ft away from the edge of the channel to maximize dredging efficiency and production rates while reducing safety risks to the dredging equipment and crew.

2.1 Mobilization and Construction - It is anticipated that the hydraulic dredging equipment needed to complete these reaches of the Project will be brought over-the-water and through Nauset Inlet during a spring tide event. If depths in the mouth of Nauset Estuary are deemed insufficient to support this methodology, the hydraulic dredge will be disassembled, brought over-the-road, assembled on-site, and launched at Goose Hummock and/or Cove Road landing(s). Over-the-road transport and assembly on-site is not preferred due to the added mobilization expense. It is anticipated that the equipment needed to complete this section of the project will include:

- (1) Ellicott 670, 870 (or similar) hydraulic cutter-suction pump dredge superstructure
- (1) short < ~200' length of dredge pipe with side-cast diffuser
- (1) primary push boat to position the dredge superstructure, manipulate the dredge pipe, and transfer fuel to the dredging equipment
- (1) support skiff to transport the dredge crew

Once on-site, the dredge superstructure will anchor in the dredge channel and direct the pipeline with sidecast diffuser 60-80 ft to the west of the dredged channel. The dredge will then agitate the bottom substrate into a slurry and pump the material through the pipe. When the material reaches the diffuser, the stream of water and sand will be broken up, allowing the sand to be deposited on the shoals adjacent the dredge channel. The primary push boat will be used to



manage the location of the discharge pipe, to ensure that too much dredged material does not accumulate in any one location. If the dredge superstructure requires additional support/stability in high velocity currents in locations Behind the Barrier Beach, the primary push boat will stabilize the superstructure and the support skiff will manage the pipe and diffuser. As previously stated, this is the preferred methodology in this reach of the Estuary, to maximize productivity, reduce the length of the project, and mitigate risks associated with maintaining long lengths of dredge pipeline in high velocity currents.

2.2 Placement of Dredged Material - Dredged material will be pumped directly into Land Under the Water adjacent the navigation channel. As sand accumulates under the sidecast pipe, the primary push boat and/or support skiff will reposition the pipeline. Given the sandy nature of the material, lack of fines, and high velocity currents, it is not anticipated that turbidity curtains will be required in this reach of the Estuary.

2.3 Production Rate and Re-Fueling - Sidecast production using the Ellicott 670, 870 (or similar) hydraulic dredging equipment is expected to average 400 cy/hour, or 2400 cy/day under ideal conditions, (assuming an 8-hour workday, 6 hours pumping time), which would allow dredging in this reach of the Estuary to be completed in 50 working days. This production schedule assumes ideal weather conditions and that the size and specifications of the dredging equipment will be sufficient to withstand the high velocity currents found in this reach of the Estuary and allow operations to continue through the full tidal cycle. At the end of each working day, it is assumed the dredge superstructure will be removed from high velocity zones in the channel Behind the Barrier Beach and anchored for the night in more quiescent areas of the Eastern Main Channel. If production is delayed due to a storm event, it is assumed that the dredge superstructure, pipeline, and all ancillary equipment will be removed from this vulnerable location well ahead of the arrival of inclement weather and secured at Goose Hummock Landing in Town Cove.

The Ellicott 670, 870, or similar hydraulic dredge burns an estimated 28 gallons of diesel fuel/hour or 224 gallons/day under maximum load. Given the large fuel capacity of this class of hydraulic dredge and the highly dynamic nature of this reach of the estuary, it is anticipated that the dredge superstructure will be refueled weekly at Goose Hummock Landing by a fuel service company to maximize safety and reduce the risk of an unintended spill. The primary push boat and support skiff will also be refueled at Goose Hummock Landing. If deemed necessary, small amounts of diesel fuel < 100 gallons may be delivered to the dredge superstructure using a transfer tank mounted on the primary push boat.

2.4 Demobilization - Upon completion of the Eastern Main Channel and channel Behind the Barrier Beach, the dredge superstructure and all associated, ancillary equipment will be removed from the site over-the-water on a spring tide through Nauset Inlet. If depths are insufficient to support removal of equipment through Nauset Inlet, equipment may be disassembled, hauled from the water, and transported over-the-road using the Goose Hummock and/or Cove Road boat ramps.



3.0 Pricilla Road Spur and Mill Pond Channel

It is estimated that a combined 26,080 cy of material will need to be dredged from the Pricilla Road Spur and Mill Pond Spur channels. The material in this quiescent reach of the Estuary is finer-grained (0.7% gravel, 83.3% sand, 16% fines). Due to the proximity of the Pricilla Road Spur and Mill Pond Spur channels to the preferred dewatering area located at the north end of Nauset Public Beach and the quiescent conditions located in this reach of the Estuary, it is anticipated that these areas will be dredged using hydraulic dredging equipment with two (2) in-line booster pumps. Dredged material will be transported along the pipeline to the dewatering area where it will be beneficially reused in the dune core, improving the resilience of the adjacent upland.

3.1 Mobilization and Construction - It is anticipated that the hydraulic dredging equipment needed to complete this reach of the Estuary will be brought over-the-water and through Nauset Inlet during a spring tide event. If depths in the mouth of Nauset Estuary are deemed insufficient to support the draft of the dredge, the dredge superstructure will be disassembled, brought over-the-road, assembled on-site, and launched at Goose Hummock and/or Cove Road landing(s). Over-the-road transport of the dredge and assembly on-site is not preferred due to the added mobilization expense.

Dredge pipe needed inside the estuary will be transported through the inlet in long (up to 500') lengths. Dredge pipe needed outside the Estuary will be transported over the road, fused into longer sections, and installed along the coastal beach.

The two (2) in-line booster pumps will be transported over-the-road. One of the pumps will be staged on a small barge in the Pricilla Landing basin. The second in-line booster will be staged on skids at the eastern end of Callanan's Pass ORV access route.

Sufficient lead time will be needed to prep the dewatering area, install erosion controls, containment berms, drainage pipe(s), and perimeter fencing.

It is anticipated that the equipment needed to complete this section of the project will include:

- (1) Ellicott 670, 870 (or similar) hydraulic cutter-suction pump dredge superstructure
- (1) primary push boat to position the dredge superstructure, manipulate the dredge pipe, and transfer fuel to the dredging equipment
- (1) secondary work boat to manage the dredge pipe
- (1) support skiff to transport the dredge crew
- (2) in-line booster pumps
- (1) small barge and mooring to support first in-line booster
- Fuel containment barrier for second, beach-based in-line booster
- (2) miles of HPDE dredge pipe
- Dredge pipe attachments, fittings, floats
- (1) Dredge pipe fusion machine



- (2) land-based, wheeled loaders to manage dredge pipeline, and manage dredge spoils
- (1) bulldozer to establish dewatering pit and manage dredge spoils
- Erosion controls, drainage pipe(s), and perimeter fencing for dewatering area
- Turbidity curtains

Once mobilization is complete, the dredge superstructure will anchor in the dredge channel. Once dredging begins, the first in-line booster pump will add head pressure to the pipeline from its position on a barge in the Pricilla Landing basin. The dredge pipeline will then cross through an overwash feature in the barrier beach at the east of the Pricilla Rd. Landing before running south along the coastal beach at the toe of the coastal dune. The second in-line booster pump will add head pressure at the eastern end of the Callanan's Pass ORV access route. The pipeline will then cross to the back side of the coastal dune, running along an existing footpath before terminating at the dewatering area.

3.2 Pipeline Construction - Inside the estuary long (~500 ft) sections of dredge pipe will be positioned, fused, and fastened together using the primary push boat, secondary work boat, and pipe fusion machine. Sections of dredge pipe required outside the Estuary will be transported to the site over-the-road and will be fused into longer (~100 ft) sections using a pipe fusion machine at the eastern end of the Callanan's Pass ORV access path. These longer sections of pipe will then be transported along the coastal beach north of Callanan's Pass using bulldozer(s) and/or wheeled loader(s) and installed, fused, and fastened together along the toe of the coastal dune. A similar methodology will be used along the existing footpath extending south of Callanan's Pass to the dewatering area. To facilitate the transition of the dredge pipe from the coastal beach to the footpath, a ~100 ft trench will be dug through the coastal dune and the pipeline will be buried. This methodology is necessary to minimize the slope of the pipeline, thereby reducing the chance of a clog.

3.3 Dewatering and Beneficial Reuse of Dredged Material - The 6.8 acre dewatering basin will be constructed in advance of dredging using large bulldozer(s) and/or wheeled loader(s). A construction staging area will be established at the north end of the Nauset Public Beach parking area. Construction access to the dewatering area will be via a low-lying swale extending north from the northern-most beach access pathway. Prior to construction of the dewatering area, perimeter fencing, erosion control silt fencing, and a mulch-filled silt-sock will be installed around the perimeter of the dewatering basin and staging area. A second row of silt fencing and silt-sock will be installed around the perimeter of the bordering vegetated wetland (BVW), located along the western edge of the dewatering site.

A total of 50,000 cy of sand will be excavated from the dewatering basin by the dozer(s) and/or loader(s) to establish the basin and surrounding containment berms. Approximately 28,000 cy of the excavated material will be used to create the containment berms and the remaining 22,000 cy will be stored temporarily at the northern end of the Nauset Beach parking lot and adjacent dune. During construction of the seaward containment berm, a narrow trench will be dug and a temporary drainage pipe will be installed – extending from the dewatering basin through the



containment berm and/or existing dune, allowing excess slurry water to discharge on the coastal beach and drain back to the Atlantic Ocean. While dredging is occurring, the dozer(s) and/or loader(s) will be used to manage and stockpile the dredge spoils, clear and manage erosion and scour around both ends of the drainage pipe, and redirect the discharge pipe(s).

Once the dewatering area has been filled with the estimated 26,080 cy of dredged material from the Pricilla Road Spur and Mill Pond Spur channels, the containment berms will be deconstructed by the dozer(s) and/or wheeled loader(s). Approximately 14,000 cy of sand from the containment berms, and 10,000 cy from the temporary stockpile in the Nauset Beach parking lot, will be used to top-dress the dredged material and reestablish existing grades with a natural, scalloped aesthetic. A portion of the berm along the west side of the dewatering basin will be left in place to serve as a secondary dune. The entirety of the disturbance area will be revegetated with bare-root American beach grass (*A. breviligulata*) plugs prior to the start of the growing season. Once the coastal dune has been regraded and revegetated, a monitoring program to test for red tide cyst viability will be initiated.

It is estimated that 12,000 cy of sand from construction of the dewatering basin will be available for beneficial reuse at other sites in the Town of Orleans and/or Eastham after the final regrading is complete. Excess sand will be trucked to an approved, upland stockpile or directly to the approved project location for beneficial reuse.

3.4 Production Rate and Re-Fueling - Pipeline production using the Ellicott 670, 870 (or similar) hydraulic dredging equipment is expected to average 200-400 cy/hour, or 1200-2400 cy/day under ideal conditions, (assuming an 8-hour workday, 6 hours pumping time), which would allow dredging in this reach of the Estuary to be completed in 11-22 working days. This production schedule assumes ideal weather conditions and that the size and specifications of the dredging equipment will be sufficient to pump dredged material along a 2+ mile pipeline and allow operations to continue through the full tidal cycle. At the end of each working day, it is assumed that the dredge superstructure will be anchored in the dredge channel and support boats will be secured to the booster pump barge in the Pricilla Landing basin. If production is delayed due to a storm event, it is assumed that the dredge superstructure and all ancillary equipment will be removed from this vulnerable location well ahead of the arrival of inclement weather and secured at Goose Hummock Landing in Town Cove. All ancillary, shore-based equipment supporting dewatering operations will be stored in the construction staging area at the north end of the Nauset Public Beach parking area at the conclusion of each workday.

The Ellicott 670, 870, (or similar) hydraulic dredges and booster pumps burn an estimated 28 gallons of diesel fuel/hour or 224 gallons/day under maximum load. Given the large fuel capacity of this class of hydraulic dredge, it is anticipated that the dredge superstructure will be refueled weekly at Pricilla Landing by a fuel service company to maximize safety and reduce the risk of an unintended spill.

Booster pumps, support boats, and land-based equipment have significantly smaller fuel reserves. Daily fuel deliveries will be made to Pricilla Landing to fill a fuel transfer tank mounted



on the primary push boat to shuttle fuel to the first in-line booster pump in the Pricilla Landing basin. Daily fuel deliveries will be made to the second in-line booster pump at the end of Callanan's Pass and to equipment manning the dewatering area by a fuel service company. The primary push boat and support skiff will be refueled at Pricilla Landing on an as-needed basis.

3.5 Demobilization - Once the Pricilla Road and Mill Pond Spur channels are complete, the dredge superstructure, support boats, and dredge pipe located inside the Estuary will be removed from the site over-the-water on a spring tide through Nauset Inlet. If depths are insufficient to support removal of equipment through Nauset Inlet, equipment may be disassembled, hauled from the water, and transported over-the-road using the Goose Hummock and/or Cove Road boat ramps. Dredge pipe outside the Estuary will be broken down into manageable lengths, removed from the coastal beach and/or coastal dune via Callanan's Pass, and hauled off-site over-the-road. The dewatering area drainage pipe will be removed from the seaward containment berm/coastal dune during final regrading. The construction access pathway from the staging area to the dewatering area will be regraded and revegetated to reflect pre-existing conditions. Once complete, all erosion controls and silt-socks will be removed from the dewatering area.

Section H

Regulatory Reviews & Compliance



H. LIST OF REQUIRED PERMITS & REVIEWS

Issuing Agency	Application	Application or File No.	Permit Name
Executive Office of Energy and Environmental Affairs (EEA)	Expanded Environmental Notification Form	TBD	Certificate of the Secretary of EEA
Executive Office of Energy and Environmental Affairs (EEA)	Draft and Final Environmental Impact Reports	TBD	Certificate of the Secretary of EEA
Orleans Conservation Commission	Notice of Intent Application	TBD	Order of Conditions
Eastham Conservation Commission	Notice of Intent Application	TBD	Order of Conditions
MA Fish & Wildlife/NHESP	MESA Review/Orleans	TBD	MESA Determination
MA Fish & Wildlife/NHESP	MESA Review/Eastham	TBD	MESA Determination
DEP Waterways Regulation Program	Chapter 91 Waterways Permit Application	TBD	Chapter 91 Permit
DEP Division of Wetlands & Waterways	401 Water Quality Certification Application	TBD	401 Water Quality Certification
MA Coastal Zone Management (CZM)	Request for CZM Federal Consistency	TBD	Consistency Determination
U.S. Army Corps of Engineers	Individual Permit Application	TBD	Individual Permit
National Park Service	NEPA – National Environmental Policy Act Review	TBD	Categorical Exclusion, Environmental Assessment, or Environmental Impact
Cape Cod Commission	District of Regional Impact (DRI) Application	TBD	DRI Decision



H. COMPLIANCE STATEMENT

The proposed project is located within the jurisdiction of the Massachusetts Wetlands Protection Act, M.G.L. c. 131, s. 40, Chapter 91 - Massachusetts Public Waterfront Act, Section 401 of the federal Clean Water Act, Orleans Wetlands Bylaw Chapter 160, and the Eastham Wetlands Bylaw. As such, all work for the proposed project was designed to comply with the requirements of the State (310 CMR 10.00 Wetlands Protection, 310 CMR 9.00 Waterways, and 314 CMR 9.00 Water Quality Certification) and local wetland regulations. All attempts have been made to design a construction plan that will have the least impact, both temporary and permanent, on the site's resources.

1.0 Wetlands Protection (310 CMR 10.00)

The project will have impacts on the following Wetland Resources:

- Land Under the Ocean
- Coastal Beach
- Coastal Dune
- Barrier Beach
- Land Containing Shellfish
- Estimated Habitats of Rare Wildlife (for coastal wetlands)

The following paragraphs address performance standards for the wetland resource areas listed above and compliance of the Project with those performance standards.

Excerpts from 310 CMR 10.25 - Land Under the Ocean

WHEN LAND UNDER THE OCEAN OR NEARSHORE AREAS OF LAND UNDER THE OCEAN ARE FOUND TO BE SIGNIFICANT TO THE PROTECTION OF MARINE FISHERIES, PROTECTION OF WILDLIFE HABITAT, STORM DAMAGE PREVENTION OR FLOOD CONTROL, 310 CMR 10.25 (3) through (7) SHALL APPLY:

(3) Improvement dredging for navigational purposes affecting land under the ocean shall be designed and carried out using the best available measures so as to minimize adverse effects on such interests caused by change in:

(a) bottom topography which will result in increased flooding or erosion caused by an increase in the height or velocity of waves impacting the shore;

(b) sediment transport processes which will increase flood or erosion hazards by affecting the natural replenishment of beaches;

(c) water circulation which will result in an adverse change in flushing rate, temperature, or turbidity levels; or

(d) marine productivity which will result from the suspension or transport of pollutants, the smothering of bottom organisms, the accumulation of pollutants by organisms, or the destruction of marine fisheries habitat or wildlife habitat.



The Project proposes improvement dredge of an existing navigation channel that has shoaled extensively. The proposed dredge channels will be widened and deepened to reduce shoaling and improve navigation within Nauset Estuary. The dredging work will not cause an increase in wave heights or current velocities, and therefore the Project will not result in increased flooding or erosion to the estuary shorelines. Improvement dredging within Nauset Estuary will not impact the natural sediment transport processes along the seaward side of the barrier beach. Numerical modeling conducted during the Feasibility Study indicated that the Project will result in a small increase in tidal range in the estuary. Similar small improvements in tidal flushing and water quality were indicated. Given the degraded water quality in the estuary, these changes in tidal range and flushing are viewed as beneficial. The proposed Project is not expected to result in changes to marine productivity caused by the introduction of pollutants, smothering of bottom organisms, or destruction of marine fisheries habitat or wildlife habitat. The project will have temporary impacts on benthic communities in channel reaches behind Nauset Barrier Beach and in the Eastern Main Channel as result of the sidecasting of dredged sediment. However, these disturbed areas are highly dynamic and support benthic communities that are well suited to areas with dynamic sediment transport processes, and therefore the Project is not expected to adversely impact benthic communities. Time of year restrictions will be observed for dredging and disposal work in order to protect active habitat use.

(4) Maintenance dredging for navigational purposes affecting land under the ocean shall be designed and carried out using the best available measures so as to minimize adverse effects on such interests caused by changes in marine productivity which will result from the suspension or transport of pollutants, increases in turbidity, the smothering of bottom organisms, the accumulation of pollutants by organisms, or the destruction of marine fisheries or wildlife habitat.

The proposed project will help to maintain public safety and navigability of channels within Nauset Estuary. Initial dredging within the estuary will be considered improvement dredging, while any subsequent dredging to maintain navigability of the channels will be considered maintenance dredging. As described above, dredging within the estuary is not expected to result in changes to marine productivity caused by the introduction of pollutants, smothering of bottom organisms, or destruction of marine fisheries habitat or wildlife habitat.

(5) Projects not included in 310 CMR 10.25(3) or 10.25(4) which affect nearshore areas of land under the ocean shall not cause adverse effects by altering the bottom topography so as to increase storm damage or erosion of coastal beaches, coastal banks, coastal dunes, or salt marshes.

All Project work is included in 310 CMR 10.25(3) and 10.25(4).



(6) Projects not included in 310 CMR 10.25 (3) which affect land under the ocean shall if water-dependent be designed and constructed, using best available measures, so as to minimize adverse affects, and if non-water dependent, have no adverse effects, on marine fisheries habitat or wildlife habitat caused by:

- (a) alterations in water circulation;
- (b) destruction of eelgrass (*Zostera marina*) or widgeon grass (*Rupia maritima*) beds;
- (c) alterations in the distribution of sediment grain size;
- (d) changes in water quality, including, but not limited to, other natural fluctuations in the level of dissolved oxygen, temperature or turbidity, or the addition of pollutants; or
- (e) alterations of shallow submerged lands with high densities of polychaetes, mollusks or macrophytic algae.

All Project work is included in 310 CMR 10.25(3).

(7) Notwithstanding the provisions of 310 CMR 10.25(3) through (6), no project may be permitted which will have any adverse effect on specified habitat sites of rare vertebrate or invertebrate species, as identified by procedures established under 310 CMR 10.37.

The proposed Project will not have adverse impacts on specified habitat for rare vertebrate or invertebrate species as recommended time of year restrictions for protection of these species will be followed.

Excerpts from 310 CMR 10.27 – Coastal Beach

WHEN A COASTAL BEACH IS DETERMINED TO BE SIGNIFICANT TO STORM DAMAGE PREVENTION, FLOOD CONTROL OR PROTECTION OF WILDLIFE HABITAT, 310 CMR 10.27 (3) through (7) SHALL APPLY:

(3) Any project on a coastal beach, except any project permitted under 310 CMR 10.30(3)(a), shall not have an adverse effect by increasing erosion, decreasing the volume or changing the form of any such coastal beach or an adjacent or downdrift coastal beach.

The proposed project will not increase erosion on the coastal beaches, nor will it result in a decrease in sediment volume to beaches. The project will have temporary impacts to the beach as a result of the pipeline between the dredge and the dewatering basin extending across 2,164 linear feet of beach. Impacts associated with placement of the dredge pipeline have been minimized through the use of rubber-tired vehicles during placement and retrieval of the dredge pipe. Upon completion of the Project all disturbed areas of the coastal beach will be restored to their original condition.

(4) Any groin, jetty, solid pier, or other such solid fill structure which will interfere with littoral drift, in addition to complying with 310 CMR 10.27(3), shall be constructed as follows:



- (a) It shall be the minimum length and height demonstrated to be necessary to maintain beach form and volume. In evaluating necessity, coastal engineering, physical oceanographic and/or coastal geologic information shall be considered.*
- (b) Immediately after construction any groin shall be filled to entrapment capacity in height and length with sediment of grain size compatible with that of the adjacent beach.*
- (c) Jetties trapping littoral drift material shall contain a sand by-pass system to transfer sediments to the downdrift side of the inlet or shall be periodically redredged to provide beach nourishment to ensure that downdrift or adjacent beaches are not starved of sediments.*

N/A – This project does not include a solid fill structure.

- (5) Notwithstanding 310 CMR 10.27(3), beach nourishment with clean sediment of a grain size compatible with that on the existing beach may be permitted.*

N/A - The proposed project does not involve beach nourishment.

WHEN A TIDAL FLAT IS DETERMINED TO BE SIGNIFICANT TO MARINE FISHERIES OR THE PROTECTION OF WILDLIFE HABITAT, THE FOLLOWING REGULATION SHALL APPLY:

- (6) In addition to complying with the requirements of 310 CMR 10.27(3) and 10.27(4), a project on a tidal flat shall if water-dependent be designed and constructed, using best available measures, so as to minimize adverse effects, and if non-water-dependent, have no adverse effects, on marine fisheries and wildlife habitat caused by:
 - (a) alterations in water circulation,*
 - (b) alterations in the distribution of sediment grain size and*
 - (c) changes in water quality, including, but not limited to, other than natural fluctuations in the levels of dissolved oxygen, temperature or turbidity, or the addition of pollutants.**

The proposed project will result in temporary impacts to tidal flats in channel reaches behind Nauset Barrier Beach and in the Eastern Main Channel from the proposed dredging and the sidecast placement of dredged material. The Project will not alter water circulation in these tidal flat areas, nor will it alter the existing sediment characteristics. Tidal currents in these channel reaches of the estuary are strong and the changes in water depth are not expected to have any impact on water circulation. Minor impacts on water quality due to increased turbidity will be localized to the immediate area of dredging/disposal and there will be no lasting effects on water quality or grain size distributions.

- (7) Notwithstanding the provisions of Sections 10.27(3) through (6), no project may be permitted which will have any adverse effect on specified habitat sites or rare vertebrate or invertebrate species, as identified by procedures established under 310 CMR 10.37.*



The project is located in mapped habitat for Piping Plovers and Terns. In order to protect these species, all dredging and disposal work will follow the recommended time of year restrictions.

Excerpts from 310 CMR 10.28 – Coastal Dune

WHEN A COASTAL DUNE IS DETERMINED TO BE SIGNIFICANT TO STORM DAMAGE PREVENTION, FLOOD CONTROL OR THE PROTECTION OF WILDLIFE HABITAT, 310 CMR 10.28(3) through (6) SHALL APPLY:

- (3) Any alteration of, or structure on, a coastal dune or within 100 feet of a coastal dune shall not have an adverse effect on the coastal dune by:*
- (a) affecting the ability of waves to remove sand from the dune;*
 - (b) disturbing the vegetative cover so as to destabilize the dune;*
 - (c) causing any modification of the dune form that would increase the potential for storm or flood damage;*
 - (d) interfering with the landward or lateral movement of the dune;*
 - (e) causing removal of sand from the dune artificially; or*
 - (f) interfering with mapped or otherwise identified bird nesting habitat.*

The proposed Project will have temporary impacts to the vegetative cover and form of the coastal dune. These impacts will be limited to the period of construction and during dewatering of the dredged material. Once the dredging is complete the dune landform will be restored to its original condition and a secondary dune will be added to the system for added coastal resiliency. Since the Project will be located on the landward side of the existing coastal dune, there will be no impacts on the ability of waves to remove sand from the primary dune. The addition of the secondary dune will modify the dune form in a beneficial way that will minimize the potential for storm or flood damage to impact properties west of the project area. The coastal dune will maintain the ability to migrate laterally or in a landward direction, as it will still be subject to sediment transport processes via winds, waves and tides. Upon completion of the project all disturbed areas will be replanted with Cape American beach grass installed 18 in on center. The vegetation is expected to recolonize within one growing season. The Project will result in the removal of sand from the dune; however, upon completion the total volume of sediment comprising the dune will be increased. Thus, there will be a net gain in sediment on the dune. The dewatering and dune enhancement area is not located in an area where bird nesting has previously occurred; however, impacts to NHESP habitat area will be avoided by adhering to applicable time of year restrictions.

- (4) Notwithstanding the provisions of 310 CMR 10.28(3), when a building already exists upon a coastal dune, a project accessory to the existing building may be permitted, provided that such work, using the best commercially available measures, minimizes the adverse effect on the coastal dune caused by the impacts listed in 310 CMR 10.28(3)(b) through 10.28(3)(e). Such an accessory project may include, but is not limited to, a small shed or a small parking area for residences. It shall not include coastal engineering structures.*



N/A – The proposed project does not include the construction or alteration of a dwelling, parking area, or coastal structure.

(5) The following projects may be permitted, provided that they adhere to the provisions of 310 CMR 10.28(3):

(a) pedestrian walkways, designed to minimize the disturbance to the vegetative cover and traditional bird nesting habitat;

(b) fencing and other devices designed to increase dune development; and

(c) plantings compatible with the natural vegetative cover.

In areas where sand is placed along the coastal dune, culms of cape American beach grass, *A. brevilgulata*, will be planted to mimic adjacent vegetative cover and to enhance the stability of the coastal resource areas.

(6) Notwithstanding the provisions of Sections 10.28(3) through (5), no project may be permitted which will have any adverse effect on specified habitat sites of rare vertebrate or invertebrate species, as identified by procedures established under 310 CMR 10.37.

See discussion above in 10.27(7) and 10.28(3)(f).

Excerpts from 310 CMR 10.29 - Barrier Beach

(3) When a Barrier Beach is Determined to be Significant to Storm Damage Prevention, Flood Control, Marine Fisheries or Protection of Wildlife Habitat. 310 CMR 10.27(3) through 10.27(6)(coastal beaches) and 10.28(3) through 10.28(5) (coastal dunes) shall apply to the coastal beaches and to all coastal dunes which make up a barrier beach.

See discussions above in Coastal Beach and Coastal Dune.

(4) Notwithstanding the provisions of 310 CMR 10.29(3), no project may be permitted which will have any adverse effect on specified habitat sites of rare vertebrate or invertebrate species, as identified by procedures established under 310 CMR 10.37.

See discussions above in Coastal Beach and Coastal Dune.

Executive Order 181 – Barrier Beaches

Executive Order No. 181 identifies barrier beaches as an important resource. The executive order specifies the following policies:

1. Barrier beaches shall be given priority status for self-help and other state and federal acquisition programs and this priority status shall be incorporated into the Statewide



Outdoor Comprehensive Recreation Plan. The highest priority for disaster assistance funds shall go towards relocating willing sellers from storm damaged barrier beach areas.

2. State funds and federal grants for construction projects shall not be used to encourage growth and development in hazard prone barrier beach areas.

3. For state-owned barrier beach property, management plans shall be prepared which are consistent with state wetland policy and shall be submitted to the Secretary of Environmental Affairs for public review under the provisions of the Massachusetts Environmental Policy Act.

4. At a minimum, no development shall be permitted in the velocity zones or primary dune areas of barrier beaches identified by the Department of Environmental Quality Engineering.

5. Coastal engineering structures shall only be used on barrier beaches to maintain navigation channels at inlets and then only if mechanisms are employed to ensure that downdrift beaches are adequately supplied with sediment.

6. Dredge material of a compatible grain size shall be used for barrier beach nourishment, if economically feasible.

7. The Coastal Zone Management Office shall coordinate state agency management policy for barrier beach areas.

The proposed Project is consistent with the Executive Order as part of the management of barrier beaches with beneficial reuse of compatible material for dune nourishment.

Excerpts from 310 CMR 10.34 – Land Containing Shellfish

WHEN A RESOURCE AREA, INCLUDING LAND UNDER THE OCEAN, TIDAL FLATS, ROCKY INTERTIDAL SHORES, SALT MARSHES, OR LAND UNDER SALT PONDS IS DETERMINED TO BE SIGNIFICANT TO THE PROTECTION OF LAND CONTAINING SHELLFISH AND THEREFORE TO THE PROTECTION OF MARINE FISHERIES, 310 CMR 10.34(4) through (8) SHALL APPLY:

(4) Except as provided in 310 CMR 10.34(5), any project on land containing shellfish shall not adversely affect such land or marine fisheries by a change in the productivity of such land caused by:

- (a) alterations of water circulation,*
- (b) alterations in relief elevation,*
- (c) the compacting of sediment by vehicular traffic,*



*(d) alterations in the distribution of sediment grain size,
(e) alterations in natural drainage from adjacent land, or
(f) changes in water quality, including, but not limited to, other than natural fluctuations in the levels of salinity, dissolved oxygen, nutrients, temperature or turbidity, or the addition of pollutants.*

Changes in water circulation patterns and sediment distributions as a result of the proposed Project are not expected. Since the work will be confined to areas within Land Under the Ocean there will be no impacts to natural drainage from the adjacent land. The only vehicular traffic will be on the barrier beach, coastal beach, and dune, which will be used to lay the pipeline. Dredging will be conducted in the late Fall and early Winter and will therefore minimize impacts to shellfish habitat. The majority of dredging will occur in areas with medium to fine-grained sandy sediment, which is expected to settle out quickly and have no lasting effects on water quality.

(5) Notwithstanding the provisions of 310 CMR 10.34(4), projects which temporarily have an adverse effect on shellfish productivity but which do not permanently destroy the habitat may be permitted if the land containing shellfish can and will be returned substantially to its former productivity in less than one year from the commencement of work, unless an extension of the Order of Conditions is granted, in which case such restoration shall be completed within one year of such extension.

The proposed project does not intend to destroy or degrade any shellfish habitat. Shellfish relays will be conducted prior to construction. During construction there will be temporary and localized impacts on water quality caused by increased turbidity, but this not expected to have an adverse impact on shellfish habitat. Given that the Project is proposed in dynamic areas with active sediment transport, the temporary disruptions to shellfish habitat from the dredging area are expected to mimic natural conditions and should allow the shellfish habitat to return to its former productivity in less than one year.

(6) In the case of land containing shellfish defined as significant in 310 CMR 10.34(3)(b) (i.e. those areas identified on the basis of maps and designations of the Shellfish Constable), except in Areas of Critical Environmental Concern, the issuing authority may, after consultation with the Shellfish Constable, permit the shellfish to be moved from such area under the guidelines of, and to as suitable location approved by, DMF, in order to permit a proposed project on such land. Any such project shall not be commenced until after the moving and replanting of the shellfish have been commenced.

Prior to the start of dredging, shellfish relays shall be conducted under the supervision and direction of the Orleans and Eastham Natural Resource Managers.



(7) Notwithstanding 310 CMR10.34(4) through 10.34(6), projects approved by DMF that are specifically intended to increase the productivity of land containing shellfish may be permitted. Aquaculture projects approved by the appropriate local and state authority may also be permitted.

N/A – The proposed project is not specifically intended to increase the productivity of Land Containing Shellfish and does not involve an aquaculture project.

(8) Notwithstanding 310 CMR10.34(4) through 10.34(7), no projects may be permitted which will have any adverse effect on specified habitat of rare vertebrate or invertebrate species, as identified by procedures established under 310 CMR 10.37.

All dredge areas within Land Containing Shellfish are also located in mapped habitat for Piping Plovers and Terns. At these sites all dredging work will follow the recommend time of year restrictions to protect nesting shorebirds.

310 CMR 10.37 - Estimated Habitats of Rare Wildlife (Endangered Species)

See discussions above.

2.0 Waterways (310 CMR 9.00)

Excerpts from 310 CMR 9.40: Standards for Dredging and Dredged Material Disposal

(1) Limitations on Dredging and Disposal Activity

(a) The project shall not include any dredging of channels, mooring basins, or turnaround basins to a mean low water depth greater than 20 feet.

The proposed Project includes dredging to -5 ft MLW with 1 ft of overdepth dredging. As such, the Project complies with this regulation.

(2) Resource Protection Requirements.

(a) The design and timing of dredging and dredged material disposal activity shall be such as to avoid interference with anadromous/catadromous fish runs. At a minimum, no such activity shall occur in such areas between March 15th and June 15th of any year, except upon a determination by the Division of Marine Fisheries, pursuant to M.G.L. c. 130, § 19, that such an activity will not obstruct or hinder the passage of fish.



N/A – The proposed Project is not located in an anadromous/catadromous fish run.

- (b) The design and timing of dredging and dredged material disposal activity shall be such as to minimize adverse impacts on shellfish beds, fishery resource areas, and submerged aquatic vegetation. The Department may consult with the Department of Fish and Game or the natural resource officer of the municipality regarding the assessment of such impacts.*

It is expected that the dredging will take place during the late Fall and early Winter and as such will minimize adverse impacts on shellfish beds, fishery resource areas and submerged aquatic vegetation. The project proponents will work with the regulatory agencies to identify a work window that will be protective of these resources.

(3) Operational Requirements for Dredging.

- (a) The extent of dredging shall not exceed that reasonably necessary to accommodate the navigational requirements of the project and provide adequate water circulation.*
- (b) The shoreward extent of dredging shall be a sufficient distance from the edge of adjacent marshes to avoid slumping. In general, for improvement dredging projects the edge of the dredging footprint, including any side cuts, should be at least 25 feet from any marsh boundary. In areas where significant wake or wash will be generated by vessel traffic, increased setbacks may be incorporated based on appropriate design calculations.*
- (c) In general, no basin, canal, or channel shall be dredged deeper than the main channel to which it is connected.*
- (d) To the maximum reasonable extent, basins shall have wide openings and short entrance channels to promote tidal exchange within the basin.*
- (e) In general, hydraulic dredging shall be favored over mechanical methods, except when open water disposal of fine grained material is proposed.*

The proposed Project complies with all Operational Requirements for Dredging. The extent of dredging has been minimized to the maximum extent possible to allow safe navigation between the public landings, mooring fields, and the inlet. Dredging will be no closer than 50 ft to salt marsh resources, and in most cases the dredging will have a much greater offset to salt marsh resources. The spur channels are proposed to be dredged to the same water depth as the main channel and will therefore not be deeper than the main channel to which they are connected. Hydraulic dredging is proposed in all areas where it is feasible; however two channel reaches that are not proximal to beach and/or dune nourishment sites, are proposed to be dredged mechanically.



(4) Operational Requirements for Dredged Material Disposal.

(a) *Where determined to be reasonable by the Department, clean dredged material shall be disposed of in a manner that serves the purpose of beach nourishment, in accordance with the following provisions:*

1. *in the case of a publicly-funded dredging project, such material shall be placed on publicly-owned eroding beaches; if no appropriate site can be located, private eroding beaches may be nourished if easements for public access below the existing high water mark can be secured by the applicant from the owner of the beach to be nourished;*
2. *in the case of a privately-funded dredging project, such material may be placed on any eroding beach.*

Where possible, the dredged material is proposed to be beneficially reused for building coastal resiliency. Project construction is expected to be publicly-funded; however all dredged material is proposed for beneficial reuse on properties owned by the Towns of Orleans and Eastham.

(5) Supervision of Dredging and Disposal Activity.

(a) *The licensee or permittee shall inform the Department in writing at least three days before commencing any authorized dredging or dredged material disposal.*

(b) *The licensee or permittee shall provide, at his or her expense, a dredging inspector approved by the Department who shall accompany the dredged material while in transit and during discharges, either upon the scows containing the dredged material or upon the boat towing them, for the following activities:*

1. *any offshore disposal;*
2. *any onshore disposal of dredged material greater than 10,000 cubic yards; or*
3. *the disposal of materials defined by the Department as potentially degrading or hazardous.*

(c) *The name, address, and qualifications of the dredging inspector shall be submitted to the Department as part of the license or permit application for approval.*

(d) *Within 30 days after the completion of the dredging, a report shall be submitted to the Department certified by the dredging inspector, including daily logs of the dredging operation indicating volume of dredged material, point of origin, point of destination, and other appropriate information.*

All requirements for supervision of the dredging and disposal activities will be followed.

3.0 Water Quality Certification (314 CMR 9.00)

Excerpts from 314 CMR 9.06: Criteria for the Evaluation of Applications for Discharge of Dredged or Fill Material



9.06(3) *Except as otherwise provided in 314 CMR 9.06(3), no discharge of dredged or fill material shall be permitted to Outstanding Resource Waters. The discharge of dredged or fill material to an Outstanding Resource Water in association with an activity listed in 314 CMR 9.06(3)(a) through (k) may be permitted without requiring the applicant to obtain a variance in accordance with 314 CMR 9.08 provided that the Department determines that the discharge of dredged or fill material may be permitted in accordance with 314 CMR 9.06(1), (2), (4), (5), and (7), and is not identified in 314 CMR 9.06(4) as a discharge of dredged or fill material that requires a variance.*

- (k) Maintenance, repair, replacement, or reconstruction of structures or facilities for water-dependent uses. In addition, the enlargement of structures or facilities for water-dependent uses is allowed only in following limited circumstances:*
- (l) in an Outstanding Resource Water that is designated for purposes other than a public water supply;*

The proposed Project involves the discharge of dredged material in an ORW. However, as noted in 9.06(3), discharge of dredged material is allowed in an ORW in certain cases listed in 9.06(3)(a) through (k). Since the Project is being proposed to restore safe and navigable waterways to areas that were previously navigable prior to shoaling, and since the work is water-dependent and will facilitate the enlargement of facilities such as public landings and mooring fields, the proposed discharge of dredged material in the ORW is allowable under 9.06(3)(k). The ORW where the work is proposed is not designated as a public water supply and there the project is allowable under 9.06(3)(l).

Excerpts from 314 CMR 9.07: Criteria for the Evaluation of Applications for Dredging and Dredged Material Management

9.07(1)(k) *Except as otherwise provided in 314 CMR 9.07(1)(k)1. through 5., no dredging shall be permitted in Outstanding Resource Waters. Dredging may be permitted in Outstanding Resource Waters, in association with the activities specified in 314 CMR 9.07(1)(k)1. through 5. provided that the Department determines that the dredging and dredged materials management may be permitted in accordance with 314 CMR 9.07(1)(a) through (j).*

- 5. Improvement dredging necessary to support or enhance the enlargement of structures or facilities for water-dependent uses, but only in the following limited circumstances:*
 - a. in an Outstanding Resource Water that is designated for purposes other than public water supply;*

The proposed improvement dredging in an ORW is necessary to restore safe and navigable waterways to areas that were previously navigable prior to shoaling. The proposed work is needed to facilitate the enlargement of facilities such as public landings and mooring fields



that have been identified as priority actions in both towns. The ORW where the work is proposed is not designated as a public water supply. As such the proposed work in an ORW can be allowed under 9.07(1)(k).

Section I

Avoidance, Minimization, & Mitigation Measures



I. AVOIDANCE, MINIMIZATION AND MITIGATION MEASURES

During planning and design for the Nauset Estuary Dredging Project (Project), steps were taken to avoid, minimize and mitigate environmental impacts. A summary of these steps for each Element of the Project includes the following:

Dredging – Mechanically dredged areas (Town Cove and Central Main) will be dewatered in barges. Turbidity impacts from the dewatering process will be *minimized* because the material that will be dredged in these areas is predominantly sand; adverse impacts from increased turbidity are therefore unlikely. This material will then be offloaded at Goose Hummock Landing, stockpiled at upland sites in Orleans or Eastham, and beneficially reused for coastal resiliency projects in the future, allowing for additional benefits elsewhere in Town. The channel reaches behind Nauset barrier beach and in the Eastern Main channel will be dredged using a hydraulic cutter suction sidecast dredge. This method *avoids* impacts of excessive transportation and greenhouse gas emissions that would have been required to transport this material to an offloading location and *avoids* removing sediment from the coastal system. Additionally, impacts from the sidecast sediment to the adjacent benthic resources will be *minimized* because 1) the grain size of the dredged material will match that of the benthic locations where material will be sidecast (i.e., predominantly sand); 2) these areas are already so dynamic, with regularly shifting sands and currents, that this action will not create a condition much different than the natural changes that occur on a daily basis; 3) these areas are highly dynamic, with benthic organisms that are well adapted to frequent disturbance and can recolonize quickly; 4) existing shellfish resources will be relayed out of the dredge impact areas; and 5) there are no eelgrass beds in these areas. The proposed dredging will also *avoid* adversely impacting the stability of the barrier beach by establishing a no dredge zone within 100 ft of the western shoreline of the barrier beach. The Priscilla Road and Mill Pond spur channels will be dredged using a hydraulic cutter suction pipeline dredge and will be pumped to a dewatering basin constructed in the dunes north of Nauset Public Beach (see Dune Nourishment description below). Impacts to the coastal beach and coastal dune from the placement of the pipeline will be *minimized* by avoiding heavily vegetated coastal dune areas, utilizing less steep overwash areas to cross the barrier beach, and using rubber-tired vehicles to place the pipeline. Closer to Nauset Beach, impacts to the coastal dune from the placement of the pipeline will be *minimized* by having equipment access and the pipeline placement utilize an existing vehicle access point, Callanan’s Pass, to access the back side of the dune and then follow an existing unvegetated path to where the dewatering basin will be.

Dewatering and Dune Enhancement North of Nauset Public Beach - Sand will be excavated from the coastal dunes to create a dewatering basin; the material will be reshaped to build containment berms around the north, south and west sides of the basin. Impacts to the coastal dune were *minimized* by minimizing the size of the dewatering basin and the volume of material to be transported here to the extent possible. Adverse impacts to the adjacent BVW were *avoided* by creating a berm to stop water and sediment from draining west into the wetland. The direct impacts to the existing dune will be *mitigated* by ultimately increasing the volume and coastal resiliency of the dune (even though material needs to be excavated initially for form the dewatering basin). Any extra sand that cannot be utilized in the dune at this



location will be removed and stored at the north end of the Nauset Beach parking lot; this material may either be utilized as nourishment for the Town's currently permitted nourishment activities as part of their retreat plan or may be utilized elsewhere in Town for other resiliency building projects. Sediment controls will be installed around limit of work for any material temporarily stockpiled at this location and around any catch basins. Although the sediment grain size composition of the dredged material to be utilized within the dune is not an exact match to existing grain size, the dredged material is more than 83% sand. The potential adverse impacts of utilizing a slightly finer material within the coastal due are *minimized* by the fact that the material will be placed well above and beyond the influence of waves, so the rate of potential sediment movement from the dune will not change, and the nourished area will be top-dressed with grain size compatible material. Since the nourishment will take place entirely within the coastal dune (i.e., above the influence of daily tides), turbidity and water quality issues will also be *avoided*. To *avoid* adverse impacts to areas outside the nourishment footprint, all boundaries of the proposed work will be clearly marked during construction showing the location and elevation of the constructed dewatering berm. To *minimize* impacts to the existing coastal dunes, equipment and machinery access will be limited to two discrete points: the first at the northern end of the Nauset Beach paved parking lot (for machinery access to construct the dewatering basin and to move sediment within or out of the basin) and the second where the pipeline will connect in from the north. Any areas disturbed during construction will be *mitigated* by planting Cape American beach grass (*Ammophila breviligulata*) 18 inches on center.

Materials Offloading at Goose Hummock Town Landing – Goose Hummock Landing will be utilized to offload mechanically dredged material. Because material dredged from Town Cove and Central Main will be dewatered in barges prior to being brought to Town Landing, impacts to adjacent coastal resources from dewatering will be *avoided*. All equipment will utilize an existing parking lot and paved boat ramp, thereby *avoiding* impacts to the surrounding resources areas. Sediment controls will be installed around any catch basins to *avoid* sedimentation and increased turbidity in the adjacent waterway.

The project will also adhere to the following measures to avoid, minimize and mitigate for environmental impacts prior to, during and following construction.

- Time of year restrictions as determined by the regulatory agencies will be followed for all work to protect and *avoid* direct impacts to endangered species and to *avoid* redistribution of red tide cysts during dredging. This will result in a work window during the late fall and winter months that will *avoid* impacts to endangered and threatened nesting shorebirds, fisheries resources, and distributions of red tide cysts. The exact time of year restriction will be refined based on agency input.
- Conduct shellfish relays prior to the start of dredging under the supervision and direction of the Orleans and Eastham Natural Resources Managers to *avoid* adverse impacts to those resources. Important areas for this action include an area of bay scallops in the Priscilla reach, areas of blue mussels, soft shell clams and surf clams behind the barrier beach and areas of quahogs in Town Cove and Priscilla; these



correspond with areas of high-density shellfish populations as determined by the September 16 and 17, 2019 shellfish surveys.

- Hold a pre-construction on-site meeting with selected contractors, project engineers and representatives from the Towns of Orleans and Eastham to ensure appropriate actions will be taken to *avoid* and *minimize* impacts to the surrounding resources.
- Submit pre- and post-dredge bathymetric surveys to the regulatory agencies. Utilize pre-dredge survey data to delineate the most efficient and effective location to dredge the channel within the permitted dredge zone, thereby *minimizing* impacts.
- Conduct pre-dredge eelgrass surveys (between July and September) to ensure that the project meets the minimum setback of 50 ft between all dredging and eelgrass resources. Make adjustments to the location of the dredge channel within the dredge zone as needed to *avoid* impacts to eelgrass.
- Install and maintain erosion and sedimentation controls in all construction and staging areas. This will include the bottom of Callanan's Pass, as well as around catch basins in upland areas (i.e., parking lots).
- *Mitigate* impacts to the coastal resource areas by restoring all beach and dune areas impacted by the dredge pipeline to pre-existing grades.
- Plant all disturbed dune areas with Cape American beach grass (*Ammophila breviligulata*) planted 18 inches on center.
- Store all fuels, hydraulic oil, etc. in a locked storage trailer or remove them off site on a daily basis.
- Refueling of all vehicles/equipment away from the wetlands and stormwater systems.
- No excessive idling of construction vehicles will occur.
- No machinery or vehicles will be stored on the coastal beach or coastal dunes overnight, and during periods of high-water levels all equipment will be moved to the construction access.
- Implementation of a post construction monitoring and maintenance plan (Section J).

Section J

Post Construction Monitoring and Maintenance



J. MONITORING AND MAINTENANCE PLAN

1.0 Introduction

The project components proposed within the Nauset Estuary and on the Nauset Barrier Beach will require periodic and direct monitoring and maintenance. The purpose of this plan is to outline the proposed monitoring and maintenance steps that will be taken to ensure that the project areas are well maintained and to update local stakeholders and town officials on progress. This plan includes monitoring methodologies to track the profile of the dune restoration, establishment of planted vegetation on the dune, and the performance and effectiveness of the channel dredging. Additionally, this monitoring plan also includes recommended maintenance actions based on monitoring outcomes.

1.1 Site Description

The Nauset Estuary Dredging Project (Project) is located within the Towns of Orleans and Eastham. A portion of the Project is also located within the Cape Cod National Seashore. At 2,200 acres in size, Nauset Estuary is one of the largest estuarine systems on Cape Cod. The estuary is protected from the Atlantic Ocean by Nauset barrier beach, which stretches north from Nauset Heights for more than 2 miles. Tidal waters between the Atlantic Ocean and the estuary are exchanged through a dynamic tidal inlet that is both narrow and shallow. Inside the estuary the system contains large areas of salt marsh with a series of natural channels that lead to open water areas and distal ponds. Ponds in the southern end of the system include Town Cove, Mill Pond, Roberts Cove, Woods Cove and Rachel Cove. Ponds and water bodies at the northern end of Nauset Estuary include Nauset Bay, Salt Pond, and Salt Pond Bay.

Nauset barrier beach and the inlet leading to the estuary are dynamic features of the system that have undergone significant changes over the past 100 years. Since the 1950s the barrier beach and inlet have experienced several periods of northerly growth, punctuated by inlet breaching to the south. The most recent period of northerly migration started in the mid- 1990s. Since this time the inlet has migrated north approximately 1.2 miles to its present location, which represents the most northerly location since early record keeping. The barrier beach and inlet are heavily influenced by longshore sand transport and the hydrodynamics of the estuary are such that sediment moving along the ocean facing beaches tends to be transported into the estuary through the inlet. This net movement of sediment into the estuary has resulted significant shoaling in the estuary channels and mooring areas.

The problem has advanced to the point where many commercial fishing vessels can no longer operate from town landings within the estuary, and instead operate from exposed moorings in the center of the navigation channel south of the inlet. Traditionally, commercial fishing vessels could only pass through Nauset inlet for 2-3 hours before and after high tide. The evolution of shoaling within the navigation channel has further restricted that window, forcing members of the commercial fleet to moor their boats and stage their equipment closer to the inlet itself, at great risk and at great personal expense.

Nauset Estuary is also a popular year-round destination for recreational kayakers, paddleboarders, and boaters. In recent years there has been a dramatic increase in recreational



boat traffic. Historically, Orleans residents accessed Nauset barrier beach via off road vehicle access pathways; however recent restrictions on access to the barrier beach have motivated many recreational users to launch or moor privately owned boats to access the beach via Nauset Estuary. This change in the way recreational users access the beach has caused recreational boat traffic within the estuary to increase, emphasizing the need for a safe and navigable channel. The Nauset Estuary Dredging Project is being proposed to address these issues by providing improvements to navigation and public safety for both commercial and recreational uses of the estuary.

1.2 Proposed Project

The Towns of Orleans and Eastham are proposing the Nauset Estuary Dredging Project to improve navigation and public safety for commercial and recreational users of the waterway. During development of the project and selection of the preferred alternative, a number of project Elements were considered. These include the following:

- Element #1: Dredge channel layout
- Element #2: Dredge channel width
- Element #3: Placement areas for dredged material
- Element #4: Dredge methodology

The preferred alternative represents a combination of these project Elements as described below.

Element #1: Dredge Channel Layout - The preferred channel layout extends approximately 4 miles from the inlet to Town Cove via the Channel Behind the Barrier Beach. The Town Cove area supports public facilities at Goose Hummock, Cove Road, Collins Landing, and Asa's Landing, as well as private facilities at the Orleans Yacht Club, Nauset Marine and the Goose Hummock Shop. A spur channel that provides access to Snow Shore and Priscilla Road Landings is also included in the preferred channel layout, as well as a channel leading to Mill Pond. In addition to the channel reaches proposed for dredging, the preferred alternative also includes a dredge zone for channel areas between the inlet and Stoney Island and for the Priscilla Rd. spur channel. The dredge zone allows for adaptive management of the channel anywhere within the zone at the time of construction, to minimize the area and volume of dredging while still maintaining the navigation channel.

Element #2: Dredge Channel Width – The preferred alternative for channel width is 100 ft wide in the channel reach Behind the Barrier Beach and 50 ft wide in all other channel areas. The channel is proposed to be dredged to -5 ft MLW (-5.5 ft NAVD) with 1 ft of possible overdepth dredging. Channel side slopes are proposed at 1V:3H.

Element #3: Placement Areas for Dredged Material – Because of the size of the proposed dredge area, a variety of placement options are included in the preferred alternative depending on where the dredging is taking place. Dredged material from the Town Cove and the Central Main Channel areas will be stockpiled in the upland within the Towns of Orleans or Eastham and beneficially reused at a later date for other permitted resiliency projects. Sand removed from the



channel Behind the Barrier Beach and the Eastern Main Channel will be sidecast approximately 60 to 80 ft from the edges of the dredged channel. Material from the Priscilla Rd. and Mill Pond spur channels will be beneficially reused to enhance the coastal dunes north of Nauset Public Beach.

Element #4: Dredge Methodology – Because of the size of the proposed dredge area and the location of the preferred placement sites, it is not possible to use one dredging methodology. As such the preferred alternatives for dredge methodology are sidecast dredging for the channel area Behind the Barrier Beach and the Eastern Main Channel, hydraulic cutter suction pipeline dredge for the Priscilla Rd. and Mill Pond spur channels, and mechanical dredging for the Town Cove and Central Main Channel areas. Using the preferred channel layout, width, and depth, it is estimated that 119,830 cy will be sidecast dredged, 26,080 cy will be dredged using a hydraulic cutter suction pipeline dredge, and 9,660 cy will be mechanically dredged.

1.3 Implementation and Reporting

The monitoring and maintenance plan will be implemented beginning with construction and until three years after project completion in order to monitor the performance and success of the improvement dredging and dune restoration. All work described below will be performed by hired consultants or by trained Town staff. The site will be monitored semi-annually during late summer for three (3) years after project completion, in addition to episodic monitoring as necessary.

In order to maintain communication and collaboration between contractors, town officials, and regulators, data collected during both annual and episodic monitoring events will be entered into an accessible database. A variety of graphs and figures illustrating changes in beach/dune profile and vegetation cover will also be included. Additionally, brief reports following each annual and episodic monitoring event will be made available to regulators and town officials after the completion of each survey period and will be sent to and kept on file with the Orleans and Eastham Conservation Departments. These reports will summarize the monitoring data to date and provide recommendations for future monitoring or maintenance actions if needed.

2.0 Construction Monitoring

Prior to construction, stakes will be used to clearly mark resource areas, construction accessways, and the dewatering area to ensure compliance with the proposed project design plans. In addition, an eelgrass survey will be conducted within Priscilla Spur Channel and Mill Pond Channel to ensure the proposed dredge zone and channel do not contain any eelgrass beds and to obtain more recent survey data. A pre-dredge bathymetry survey will also be conducted, during which coordinates will be collected to ensure that future dredging activity will stay within the designated dredge zone and that dredge operators are aware of the channel dimensions and can properly navigate and work within the dynamic channel environment.

During the initiation of the construction phase (mobilization and initial construction startup), the construction manager will conduct daily monitoring for approximately the first five days to ensure the resource areas are adequately protected and to confirm that construction and dredging activities stay within the designated work area/dredge zone. For the remainder of the



construction phase, the construction manager will conduct inspections once a week to monitor dredged material for grain size characteristics. In the event dredge material would not be compatible with the various proposed placement locations, work will cease in order to reevaluate and notify the appropriate regulatory agencies.

Immediately after project construction has been completed, a post-dredge bathymetry survey will be conducted. Dredge material offloaded at Goose Hummock will be fenced in order to protect the public and material will be monitored during construction for any spreading, in which case material would be cleaned up. The dewatering area will also be fenced off in order to protect animals and members of the public. At the close of the construction phase (final grading and demobilization) the construction manager will check for proper final grading and appropriate grain size and that construction access is restored to pre-existing conditions.

3.0 Quarterly, Episodic, and Monthly Monitoring

The site will be visually inspected quarterly for a period of three years, to assess any damage or changes that may have occurred to the dune restoration project. Additional episodic monitoring will occur immediately after a major storm event that is likely to have caused significant damage to the project area. Photographic records will be taken (from the same locations) at each inspection, which will be annotated with a brief written assessment for each inspection. Reports will be sent to the necessary regulatory agencies and kept on file with the Orleans and Eastham Conservation Departments.

Quarterly and episodic monitoring of the dune restoration will include specific visual observations of the following:

1. Dune restoration area:
 - a. Extent of established vegetation
 - b. Any areas of dead/dying/missing vegetation
 - c. Evidence of new erosional areas
 - d. Overwash areas
 - e. Extensive wrack or debris deposits
2. Upland sediment offloading area:
 - a. Sediment and erosion controls (ensure properly functioning)

The dredge channel will not be directly monitored after project completion. Rather, the need for additional dredging will be informed by recreational boaters, commercial fishermen, and Town harbormasters.

In addition to the quarterly and episodic monitoring outlined above, the dredge material placed for the dune reconstruction and the surplus of material offloaded in an upland area will need to be monitored for red tide cysts. A sample of dredge material will be collected from both locations on a monthly basis for a year after placement and sent to a lab to test for mortality of cysts. Material placed in the upland will not be used for beach nourishment until laboratory tests indicate 100% mortality of cysts.



4.0 Annual Monitoring

Annual beach and dune monitoring will include topographic profiles to document beach and dune configuration and morphological evolution of the restoration material. Monitoring will occur in mid-spring (after the threat of major winter storms has passed) beginning after project completion. Five (5) survey transects will be established approximately 150 feet apart and will extend from approximately 100 feet landward from the back toe of the dune to the seaward direction to approximately Mean Low Water. Transects will be surveyed for a total of three (3) years following project construction, at which time continued profile monitoring will be evaluated.

For the annual vegetation surveys, the dune restoration area will be surveyed to document the 1) area/extent of vegetation, 2) plant species present, and 3) percent cover of vegetation. To quantify the total area/extent of vegetation, the perimeter of the vegetated area will be mapped using a GPS. All plant species present within this area will be identified and documented. To quantify the percent cover of vegetation, a random 1 m² quadrat will be established within the restoration area along each of the topographic transects; GPS coordinates of the center of each sampling quadrat will be collected.

5.0 Maintenance

Depending on the results of the vegetation surveys, the dune restoration area may require replanting if vegetation does not survive or becomes sparse. Monitoring data on topographic beach profiles and morphological evolution of the nourishment will be used to determine if the Town would like to install fencing on the dune.

It is estimated that maintenance dredging in the Priscilla Rd. and Mill Pond channel reaches may be required every 8 to 10 years. Depending on the condition of Nauset Public Beach and the surrounding dunes at the time maintenance dredging is needed and on monitoring results, it may be advantageous to strategically locate the dewatering basin where added resiliency is needed. Although coastal beach and dune habitats require increased maintenance due to their dynamic nature, original nourishment and subsequent renourishments will provide a sediment source to downdrift, sediment-deprived beaches.

Section K

Review of Consistency w/CZM Policies



K. Review of Consistency with CZM Policies

The Proponent's proposed improvement dredging complies with the enforceable program policies of the Massachusetts approved coastal management program and will be conducted in a manner consistent with such policies.

The proposed project complies with the following Coastal Zone Management policies:

COASTAL HAZARDS

COASTAL HAZARD POLICY #1 - Preserve, protect, restore, and enhance the beneficial functions of storm damage prevention and flood control provided by natural coastal landforms, such as dunes, beaches, barrier beaches, coastal banks, land subject to coastal storm flowage, salt marshes, and land under the ocean.

The proposed project includes improvement dredging within Nauset Estuary in order to maintain essential access to harbors, recreational areas, and commercial waterfronts. Dredge material will be beneficially reused for dune enhancement on Nauset Beach. Thus, although the project will have lasting impacts to resource areas that provide storm damage and flood control, the project will not interfere with or decrease these ecosystem services. In fact, the dune enhancement component of the project will improve the services provided by the coastal beach, coastal dune, and barrier beach system by helping dissipate wave energy. The project has also been purposely designed to avoid any temporary or permanent impacts to the salt marsh.

COASTAL HAZARD POLICY #2 - Ensure construction in water bodies and contiguous land areas will minimize interference with water circulation and sediment transport. Flood or erosion control projects must demonstrate no significant adverse effects on the project site or adjacent or downcoast areas.

Dredged material used for dune enhancement will be compatible with the existing material present at the site and will supply additional sediment to the dynamic Atlantic shoreline, used for a variety of recreational activities. Material that becomes suspended during dredging activities, as well as after placement to enhance the dune, will quickly settle out, having only minor, short-term impacts on turbidity and water quality and no anticipated effect on water circulation.

COASTAL HAZARD POLICY #3 - Ensure that state and federally funded public works projects proposed for location within the coastal zone will:

- Not exacerbate existing hazards or damage natural buffers or other natural resources.
- Be reasonably safe from flood and erosion-related damage.



- Not promote growth and development in hazard-prone or buffer areas, especially in velocity zones and ACECs.
- Not be used on Coastal Barrier Resource Units for new or substantial reconstruction of structures in a manner inconsistent with the Coastal Barrier Resource/Improvement Acts.

The proposed project will be funded by a State (Office of Coastal Zone Management) funded grant.

- **The proposed improvement dredging and dune enhancement will not exacerbate existing hazards or damage natural buffers or natural resource areas. In fact, the proposed habitat restoration component will enhance storm damage protection provided by the coastal beach and dune system by dissipating wave energy.**
- **The placement of dredge material will be done so as to avoid flood and erosion-related damage. The dune profile has been designed to provide reasonable protection given certain levels of expected storms to avoid flood and erosion related damage.**
- **The project will not promote growth or development in the area; rather, the project will simply maintain essential access to already developed areas including working waterfronts and harbors.**
- **The project will not be used on Coastal Barrier Resource Units for new or substantial reconstruction of structures, which is not included in the project.**

COASTAL HAZARD POLICY #4 - Prioritize acquisition of hazardous coastal areas that have high conservation and/or recreation values and relocation of structures out of coastal high hazard areas, giving due consideration to the effects of coastal hazards at the location to the use and manageability of the area.

NA – This project does not include land acquisition or structure relocation.

ENERGY

ENERGY POLICY #1 - For coastally dependent energy facilities, assess siting in alternative coastal locations. For non-coastally dependent energy facilities, assess siting in areas outside of the coastal zone. Weigh the environmental and safety impacts of locating proposed energy facilities at alternative sites.

NA – This project does not involve energy facilities.

ENERGY POLICY #2 - Encourage energy conservation and the use of alternative sources such as solar and wind power in order to assist in meeting the energy needs of the Commonwealth.

NA – This project does not involve energy facilities.



GROWTH MANAGEMENT

GROWTH MANAGEMENT POLICY #1 - Encourage sustainable development that is consistent with state, regional, and local plans and supports the quality and character of the community.

NA – This project does not involve community development.

GROWTH MANAGEMENT POLICY #2 - Ensure that state and federally funded infrastructure projects in the coastal zone primarily serve existing developed areas, assigning highest priority to projects that meet the needs of urban and community development centers.

NA – This project does not involve infrastructure development.

GROWTH MANAGEMENT POLICY #3 - Encourage the revitalization and enhancement of existing development centers in the coastal zone through technical assistance and financial support for residential, commercial and industrial development.

NA – This project does not involve community development.

HABITAT

HABITAT POLICY #1 - Protect coastal, estuaries, and marine habitats - including salt marshes, shellfish beds, submerged aquatic vegetation, dunes, beaches, barrier beaches, banks, salt ponds, eelgrass beds, tidal flats, rocky shores, bays, sounds, and other ocean habitats – and coastal freshwater streams, ponds, and wetlands to preserve critical wildlife habitat and other important functions and services including nutrient and sediment attenuation, wave and storm damage protection, and landform movement and processes.

The proposed dune enhancement on Nauset Beach will provide additional protection to the coastal beach and dune resource areas and will therefore improve their stability and overall habitat value. The dune will also be graded to a slope that accommodates the unique habitat needs of nesting shorebirds. Additionally, placing grain-size compatible nourishment material along the project site will provide a sediment source for the eroded areas downdrift of the dune enhancement. The project will not disturb any salt marsh or eelgrass habitat areas.

HABITAT POLICY #2 – Advance the restoration of degraded or former habitats in coastal and marine areas.

Nauset Beach is located along a dynamic coastal environment and has several areas of dune overwash along the barrier beach, which threatening wildlife habitat and recreational use. The proposed coastal dune enhancement using dredge material will advance the restoration of the dune by providing added storm protection while increasing the size of the habitat and providing a sediment source for future storms.



OCEAN RESOURCES

OCEAN RESOURCES POLICY #1 - Support the development of sustainable aquaculture, both for commercial and enhancement (public shellfish stocking) purposes. Ensure that the review process regulating aquaculture facility sites (and access routes to those areas) protects significant ecological resources (salt marshes, dunes, beaches, barrier beaches, and salt ponds) and minimizes adverse effects on the coastal and marine environment and other water-dependent uses.

NA – This project does not involve aquaculture.

OCEAN RESOURCES POLICY #2 – Except where such activity is prohibited by the Ocean Sanctuaries Act, the Mass. Ocean Management Plan, or other applicable provision of law, the extraction of oil, natural gas, or marine minerals (other than sand and gravel) in or affecting the coastal zone must protect marine resources, marine water quality, fisheries and navigational, recreational and other uses.

NA – This project does not involve oil, gas or mineral extraction.

OCEAN RESOURCES POLICY #3 - Accommodate offshore sand and gravel extraction needs in areas and in ways that will not adversely affect marine resources, navigation, or shoreline areas due to alteration of wave direction and dynamics. Extraction of sand and gravel, when and where permitted, will be primarily for the purpose of beach nourishment or shoreline stabilization.

NA – This project does not involve offshore sand or gravel extraction.

PORTS AND HARBORS

PORTS AND HARBORS POLICY #1 - Ensure that dredging and disposal of dredged material minimize adverse effects on water quality, physical processes, marine productivity and public health and take full advantage of opportunities for beneficial re-use.

The proposed project will take advantage of the opportunity for beneficial reuse of dredged material by including a dune enhancement. Material will be compatible with the existing environment at the site, having only short-term impacts on turbidity and water quality, and no anticipated impact on water circulation. The same is true for material that becomes suspended during dredging activity. There are no anticipated impacts on marine productivity or public health.

PORTS AND HARBORS POLICY #2 - Obtain the widest possible public benefit from channel dredging and ensure that Designated Ports Areas and developed harbors are given highest priority in the allocation resources.



The channels within Nauset Estuary are frequently impacted by the dynamic environment, often experiencing significant shoaling. This results in safety and navigation issues for both recreational and commercial users. The proposed project will have a significant public benefit by maintaining safe access to and from, as well as within, the estuary for those who moor boats within the estuary or at designated harbor areas. The project will also ensure continued use of the estuary as a recreational environment, which attracts tourists, thus supporting the local economy. Finally, water-dependent businesses established along the estuary will benefit, which could not operate properly without sufficient channel access.

PORTS AND HARBORS POLICY #3 - Preserve and enhance the capacity of Designated Port Areas (DPAs) to accommodate water-dependent industrial uses and prevent the exclusion of such uses from tidelands and any other DPA lands over which an EEA agency exerts control by virtue of ownership or other legal authority.

NA – This project is not located within or near a Designated Port Area.

PORTS AND HARBORS POLICY #4 – For development on tidelands and other coastal waterways, preserve and enhance the immediate waterfront for vessel-related activities that require sufficient space and suitable facilities along the water’s edge for operational purposes.

NA – This project does not involve development on tidelands or coastal waterways.

PORTS AND HARBORS POLICY #5 - Encourage, through technical and financial assistance, expansion of water dependent uses in Designated Port Areas and developed harbors, re-development of urban waterfronts, and expansion of physical and visual access.

NA – This project is not located within or near a Designated Port Area or urban waterfront.

PROTECTED AREAS

PROTECTED AREAS POLICY #1 - Preserve, restore, and enhance coastal Areas of Critical Environmental Concern, which are complexes of natural and cultural resources of regional or statewide significance.

NA – This project is not located within an ACEC.

PROTECTED AREAS POLICY #2 - Protect state designated scenic rivers in the coastal zone.

NA – This project is not located in a designated scenic river.



PROTECTED AREAS POLICY #3 - Ensure that proposed developments in or near designated or registered historic places respect the preservation intent of the designation and that potential adverse effects are minimized.

NA – This project is not located in or near a registered historic place.

PUBLIC ACCESS

PUBLIC ACCESS POLICY #1 - Ensure that development (both water-dependent or nonwater-dependent) of coastal sites subject to state waterways regulation will promote general public use and enjoyment of the water's edge, to an extent commensurate with the Commonwealth's interests in flowed and filled tidelands under the Public Trust Doctrine.

The proposed project does not include additional development to the Nauset Estuary area. However, the project will maintain access to already developed areas along the estuary including working waterfront areas and other water-dependent businesses. Maintaining access to the estuary will benefit the general public by allowing for continued use of the estuary as a recreational area. Walkways used for public access disturbed during project construction will be restored to pre-existing conditions after project completion.

PUBLIC ACCESS POLICY #2 - Improve public access to existing coastal recreation facilities and alleviate auto traffic and parking problems through improvements in public transportation and trail links (land or water-based) to other nearby facilities. Increase capacity of existing recreation area by facilitating multiple use and by improving management, maintenance, and public support facilities. Ensure that the adverse impacts of developments proposed near existing public access and recreation sites are minimized.

The proposed project will not have a direct effect on land-based transportation but will help maintain a navigable channel through Nauset Estuary used to access harbors and waterfront businesses, providing an alternative transportation route to roads. As the estuary is also used for recreation, the proposed project will help to support the variety of recreational uses and activities within the estuary. No development is included in the proposed project. The coastal dune enhancement will offer increased storm protection for the north end of the Nauset Public Beach parking lot.

PUBLIC ACCESS POLICY #3 - Expand existing recreation facilities and acquire and develop new public areas for coastal recreational activities, giving highest priority to regions of high need or limited site availability. Provide technical assistance to developers of both public and private recreation facilities and sites that increase public access to the shoreline to ensure that both transportation access and the recreational facilities are compatible with social and environmental characteristics of surrounding communities.

Nauset Estuary and Nauset Beach are both very popular for recreational activities, for both year-round residents and tourists. The proposed project will maintain navigability



through the estuary, benefiting recreational boaters. Beach goes will also benefit from the proposed dune enhancement, improving the coastal beach habitat area. In addition, the coastal dune enhancement will offer improved storm protection for the north end of the Nauset Public Beach parking lot. Increased access to the estuary and enhancement of the natural environment are both compatible with the social and cultural identities of the towns of Eastham and Orleans, which both emphasize their coastal identity and characteristics.

WATER QUALITY

WATER QUALITY POLICY #1 - Ensure that point-source discharges and withdrawals in or affecting the coastal zone do not compromise water quality standards and protect designated uses and other interests.

During construction, machinery and equipment will be carefully maintained and monitored to ensure no oil or other mechanical fluid is released into the coastal zone. The completed project will consist of natural restored habitat and deeper channels, which will have no point-source discharges.

WATER QUALITY POLICY #2 – Ensure the implementation of nonpoint source pollution controls to promote the attainment of water quality standards and protect designated uses and other interests.

NA – The dune restoration will utilize only natural material and will not affect nonpoint source pollution.

WATER QUALITY POLICY #3 - Ensure that subsurface waste discharges conform to applicable standards, including the siting, construction, and maintenance requirements for on-site wastewater disposal systems, water quality standards, established Total Maximum Daily Load limits, and prohibitions on facilities in high-hazard areas.

NA – This project does not include subsurface waste discharges.

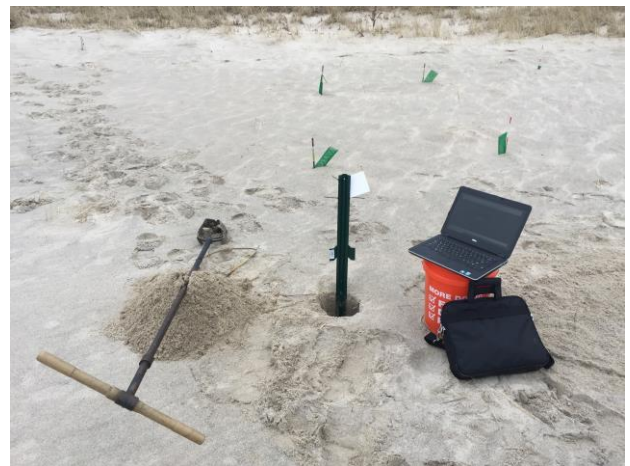
Section L

Engineering Reports & Memorandums

Sediment Dewatering Study - Nauset Estuary

Final Report

August 5, 2020



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Sediment Dewatering Study - Nauset Estuary

Final Report

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August 5, 2020

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1 BACKGROUND

Harmful algal blooms (HABs, commonly called “red tides”) are a serious economic and public health problem throughout the world. In the U.S., the most serious and widespread manifestation is paralytic shellfish poisoning (PSP), a syndrome caused by human ingestion of shellfish that accumulate toxins from dinoflagellates, predominantly in the genus *Alexandrium*. The potent neurotoxins produced by these organisms are accumulated by filter-feeding shellfish and other grazers and are passed on to humans and other animals at higher trophic levels, leading to illness, incapacitation, and even death. *Alexandrium* species cause toxicity in many different hydrographic and climatic regimes, from temperate to tropical. One reason for growth success across such a variety of habitats is that many species have a cyst stage in their life histories. This allows the organism to remain dormant in bottom sediments through temperature extremes (e.g., winter), with seasonal germination inoculating vegetative cells into the water column only during intervals where temperature and light are suitable for growth (Anderson et al., 2012). Population development is thus possible in more locations than would otherwise be the case if year-round persistence in the water column were the only means for survival.

One important area of recurrent *Alexandrium catenella* blooms is within the Nauset Estuary on Cape Cod. In this system, isolated and localized blooms are tightly linked in time and space to cyst populations in bottom sediments of the areas where toxicity occurs. These locations can be viewed as self-seeding “point sources”, in that *Alexandrium* populations originate within the embayments or estuaries, with no input of cells from coastal waters, and they deposit cysts after those blooms, to “seed” future blooms. These “localized” or “point source” blooms have been well studied by D. M. Anderson and colleagues (e.g., Anderson et al. 1983; Anderson and Stolzenbach 1985; Crespo et al. 2011; Ralston et al. 2013, 2015; Brosnahan et al. 2014).

The distribution of the *Alexandrium* blooms within Nauset Estuary is not uniform. It has been well established that the hot spots of toxicity occur at the three distal end points of the system - namely Salt Pond, Town Cove, and Mill Pond. Just south of the Nauset system is Pleasant Bay, where *Alexandrium* cysts have been detected in the past (Anderson et al. 1978), but where toxicity -related shellfish closures have not occurred for decades.

The Nauset Estuary is a highly dynamic environment, with accumulations of sediment leading to shoaling and concerns about boating access and safety. One of the issues that has been raised with respect to dredging within Nauset has been that *Alexandrium* cysts in the dredge material may remain viable after being placed on the beach for dune augmentation following dewatering. The concern is that if these cysts remain viable, a storm or heavy rainfall that moves them into adjacent coastal waters, including Pleasant Bay, could introduce this toxic organism into areas where it is not currently a major problem.

Unfortunately, there are no studies in the literature about the viability of dinoflagellate cysts following dredging operations. We can, however, hypothesize that there are multiple processes that could lead to cyst mortality during the dewatering process. These include desiccation, freezing, and salinity changes due to saltwater exchanges with freshwater during

rainfall events. Other factors may also limit germination (e.g., absence of light), leading to mortality through time in oxygenated sediments.

To address these concerns, a series of controlled field studies and laboratory analyses were conducted.

2 OBJECTIVES

The objective of this research was to determine the impact of dune burial and dewatering upon *Alexandrium* cyst survival, viability, and mortality over time. This work can be used to assess the risk that dredging operations, and specifically dredge spoil disposal in the Nauset Estuary may pose to species dispersal in the region.

This project looked at the following questions:

1. How long do *Alexandrium* cysts remain viable under shallow and deep burial conditions?
2. Which abiotic factors (e.g., temperature, salinity, desiccation) contribute to cyst mortality?

3 METHODOLOGY

3.1 Sediment Collection and Dune Burial

An important consideration in planning this experiment is that *A. catenella* cysts undergo dormancy cycling, alternating between true dormancy in which they cannot germinate, and quiescence, in which they remain in a resting state until ambient environmental conditions are supportive of germination (Fischer et al. 2018). For the dewatering experiment to be meaningful, the viability of cysts had to be assessed at each time point, which in turn requires that the cysts be in a quiescent state. The experiment was thus initiated in mid-winter, a time when past studies indicate that full quiescence was achieved.

Sediment samples were collected in Town Cove, Orleans, MA on 12/13/19 using a standard grab sampler. These were maintained in the dark at the ambient temperature in coolers. The 0-10cm sediment layers were pooled together and homogenized at the ambient sediment collection temperature. Between collection and burial, all cyst processing was conducted under red-light illumination and controlled temperature conditions. For the long-term viability studies, 10 mL aliquots of homogenized sediment were dispensed into separate 20-micron Nitex sachets (n=50) and sealed using duct tape and stainless-steel clips. These manipulations occurred on 1/2/20. The sealed sachets were placed into heavy duty plastic mesh sleeves (6-foot in length and 4 inches in diameter) with sealed ends attached to a surface expression lanyard to allow for retrieval after burial in a dune. Subsamples were processed for initial cyst density (n=5) and viability (n=3) using standard primuline staining and germination techniques (Anderson et al., 1982, 2005; methods described in more detail below).

Sixteen 10 mL amber vials filled with Nauset sediments were stored in anoxic sediment at 4°C in the laboratory to be used as controls for the germination times series. At this temperature, cysts in anoxic conditions can survive in the laboratory for an extended period of time. An additional sixteen vials, also stored in anoxic sediment, were placed in an incubator that was

adjusted on a weekly basis to mimic the temperatures within the dune. This subset is termed the Variable Control.

On 1/7/20, sachets were buried in the dune at Nauset Beach, Orleans, at two treatment depths. One was located near the surface of the dune (30 cm below the surface), and the other was closer to the water table (~1.5 meters). Sachets were initially harvested on a weekly basis and assessed for a panel of abiotic and biotic metrics including moisture content, salinity, cyst viability and cyst concentration. Based on the results of the cyst viability, sampling was adjusted thereafter to be either weekly or biweekly. Three sachets from each treatment were retrieved on each sampling day: one for germination and/or primulin preservation, one for moisture content, and one for salinity. Sediments were transported from Nauset Beach to the Woods Hole Oceanographic Institution on ice and in dark conditions for processing.

3.2 Environmental Parameters

Dune temperatures were recorded using Onset temperature loggers buried with the shallow and deep sachets, and the data were downloaded each week. The last recorded temperature on the shallow logger was used to set the corresponding Variable Control incubator temperature; the deep control treatment incubator was set at a steady 4°C.

Rainfall data were synthesized by producing a daily and weekly average from data submitted by Eastham and Orleans contributors to the Community Collaborative Rain, Hail & Snow Network (www.cocorahs.org). Three contributors from each town consistently contributed data during the time period of the field experiment, for a total of 6 data sets.

3.2.1 Moisture Content

One sachet at each depth was removed and processed weekly for soil moisture content using the standard oven-drying method (ASTM D2216-19). The contents of each sachet were pre-weighed in a tared 50 mL tube, then dried at 65 °C for 7 days. The percent water content was then calculated using the wet and dry weights of each sample.

3.2.2 Salinity

One additional sachet at each depth was removed and processed weekly for salinity. The contents of each sachet were placed into 50 mL round-bottom screw-top centrifuge tubes and centrifuged at 10,000 rpm for 15 minutes at 4°C in a fixed angle rotor. The salinity of the supernatant was determined using an Extech Portable Salinity Refractometer.

3.3 Cyst Germination

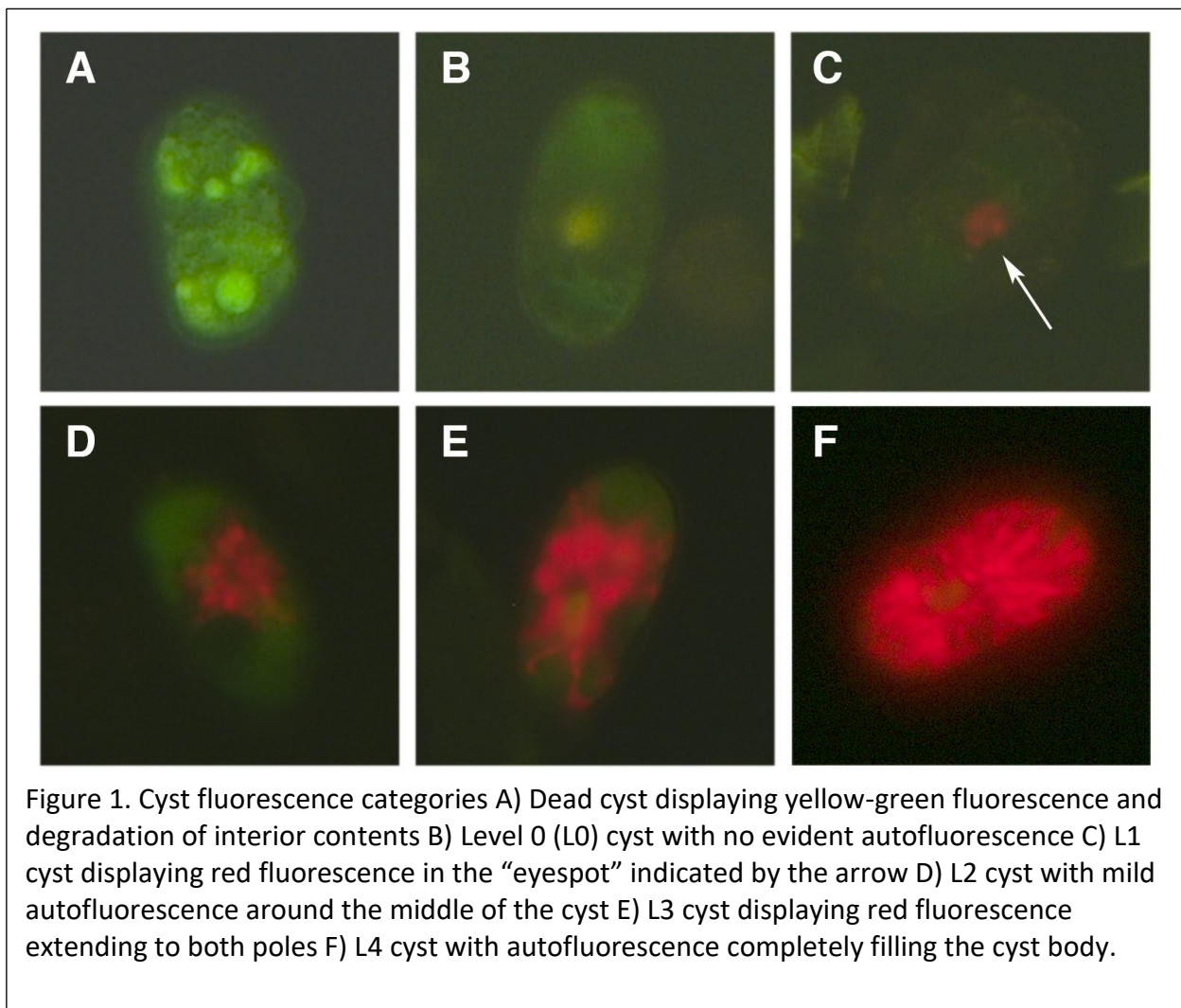
From each dune treatment, as well as the two laboratory control treatments, a well-mixed 2cc wet volume sediment subsample was resuspended to 10 ml with filtered seawater (FSW). This sediment slurry was sonicated using a Branson Sonifier 250 affixed with a 1.25 cm disruptor horn at a constant 40-W output for 1 minute, and sieved to yield a clean, 20–80µm sediment size fraction and resuspended to 15 mL (Anderson et al., 2005). During weeks when primuline processing was also being conducted, 5 mL was subsampled for germination and the remaining 10 mL was preserved for primuline processing to determine the cyst concentration in the sample.

For germination, a 5 mL well-mixed subsample was pipetted into a 50 mL round-bottom screw-top centrifuge tube and underlaid with 13 mL Nalco 1040 solution. The tube was then

centrifuged at 200 x g for 15 minutes at 4°C, and the top 13 mL was removed to a 20µm sieve, washed thoroughly with FSW, and resuspended to 5 mL. A subsample was then loaded into a Sedgewick-Rafter slide and scanned at 10x magnification under transmitted light. When a cyst was located, regardless of condition, it was mouth-pipetted into an individual well on a 96-well plate prepared with f/2-Si media (Anderson et al. 1994). A total of 40 cysts were isolated from each sample, and plates were then mapped and placed in ambient light in an incubator at 15°C. Plates were checked after two weeks, and visually scored as either “dead,” or “germinated.” Dead cysts had visible but deteriorated cell contents (see Figure 8 G-L), while germinated cysts were characterized by an empty cell wall with no internal contents. Any wells within which swimming cells could be observed were noted.

3.4 Cyst Fluorescence

In preparation for germination, *Alexandrium* cysts synthesize chlorophyll which leads to the emission of red autofluorescence (Anderson and Keafer 1985). In order to determine whether cysts were in the process of germination at the time of collection, a subsample of Nalco-concentrated sediment, was examined for autofluorescence. This was carried out using a separate aliquot than the one used for isolation and germination. The sample was loaded into a



Sedgewick-Rafter slide and scanned at 10x magnification under transmitted light on a Zeiss Compound Epifluorescence Microscope. Each cyst identified was observed under a FITC filter set, and autofluorescence was graded on a scale ranging from 0-4 (Figure 1). This process continued until ~30 cysts had been observed and graded for each sample. (Note: This component of the experiment was added during week 3 – there are no fluorescence data for T-0, Week 1 or Week 2.)

3.5 Primuline Staining

In addition to samples that were processed for primuline-based cyst enumeration at T0 (n=5), primuline counts were completed on a monthly basis. When possible, replicate sachets (n=3) were collected for multiple primuline counts. Primuline samples were sonified and sieved to isolate the 20-80µm sediment size fraction following methods outlined for cyst germination. Following modified methods from Yamaguchi et al. 1995, ACS grade formalin (100%) was added to the processed sediments at a working concentration of 5%, and samples were returned to 4°C for 180 min. Samples were then centrifuged for 10 min at 3000xg, the overlying water was aspirated, and the sediment pellet was resuspended in 10 ml ACS grade methanol and stored at 4 °C for at least 48 hours. The sample was centrifuged and aspirated as before, and resuspended in 10 ml Milli-Q water. Following centrifugation and aspiration, 2 ml of primuline stain (2 mg ml⁻¹) was added. Samples were incubated in the dark at 4 °C on a rotating mixer, centrifuged and aspirated, and washed with 10 ml Milli-Q water, centrifuged and aspirated again, and the stained sediment pellet was brought up to 10 ml with Milli-Q water. A 1 ml subsample was loaded into a Sedgewick-Rafter slide and examined using a Zeiss Imager microscope at 100X total magnification under blue light epifluorescence (Chroma filter set 19002, Chroma Corp, Bellows Falls, VT), and all *Alexandrium* cysts were enumerated (Anderson et al. 2003). In the case that sediments were too dense for accurate counting, the sample was diluted 1:10 prior to enumeration. It was not possible to tell whether those cysts were alive or dead, so the germination assays were used for that purpose.

4 RESULTS

4.1 Environmental Parameters

Because of a mild winter, the dune temperatures at both depths did not drop below 0°C for the duration of the experiment. The minimum temperatures experienced in the deep and shallow treatments were 2 and 0.8°C respectively (Fig. 2). The shallow treatment experienced greater diel variability in temperature than the deep treatment, which also experienced fewer temperature swings as well as more gradual rates of cooling and warming in the winter and spring. The maximum temperatures for each treatment were 20.6 and 23.26°C in the shallow and deep dune treatments, respectively.

The Variable Control temperature was adjusted to reflect the last data point of the deep Onset logger from the preceding week (Fig. 3). The minimum set temperature was 3.2°C and the maximum set temperature was 11.9°C, though the majority of the weekly setpoints fell between 6 and 8°C.

For the duration of the field experiment, precipitation averaged 0.95 inches per week (Fig. 4). The lowest weekly precipitation was 0.042 inches, the week ending on May 18th, and the

maximum weekly precipitation was 2.77 inches, the week of April 27th. The highest daily rainfall was 1.55 inches on April 27th. Precipitation increased over the course of the study.

4.2 Moisture Content and Salinity

At T0, when sediment was first put into the sachets, (1/7/20), the moisture content in the sachets was 46% by weight. This was the highest percent moisture observed during the experiment. Moisture content fluctuated in both treatments during the course of the study, but remained within a relatively narrow range (36%-40%) in both treatments. No significant negative trend in percent moisture over time was observed in either treatment ($p>0.05$; Figure 5).

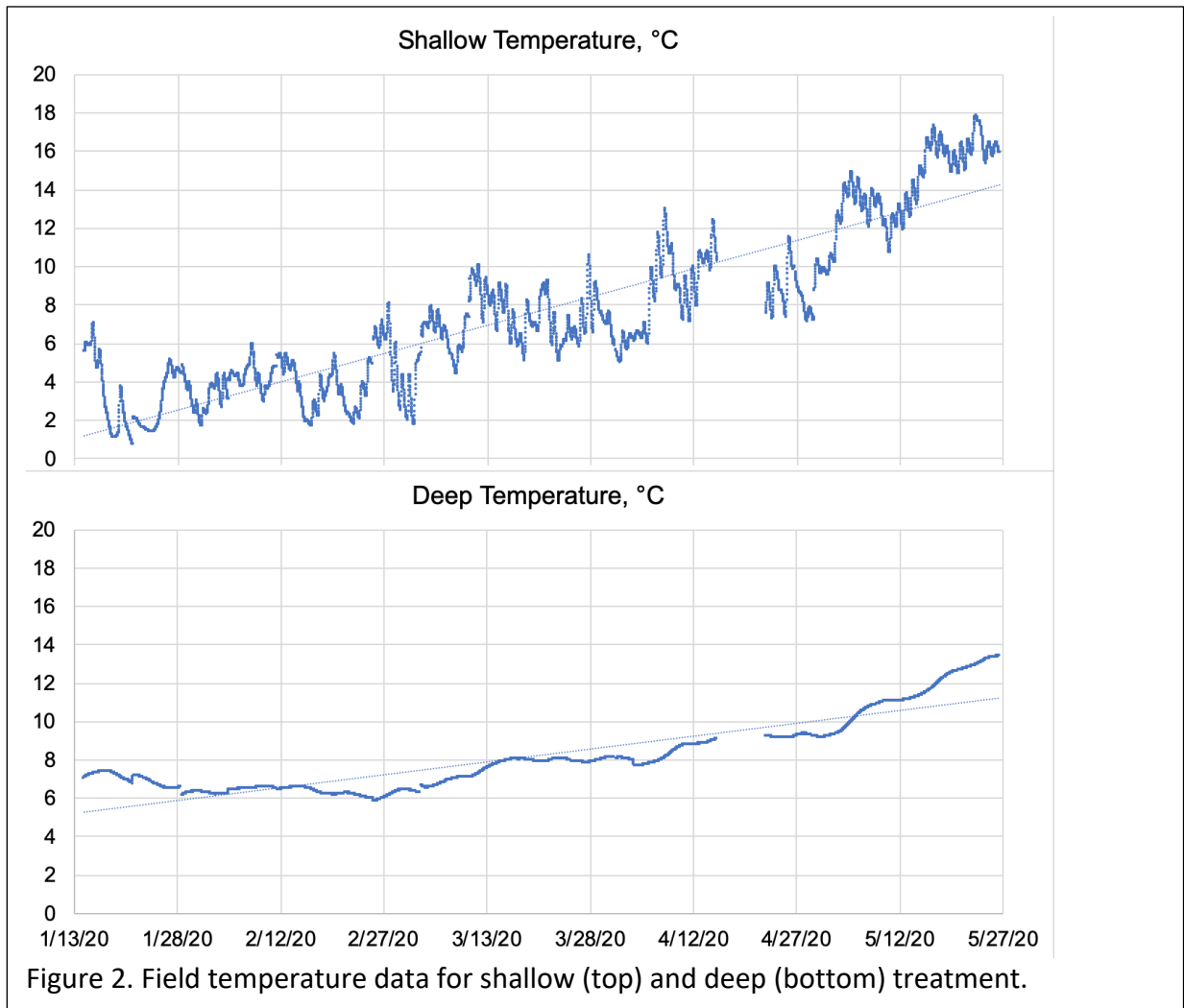
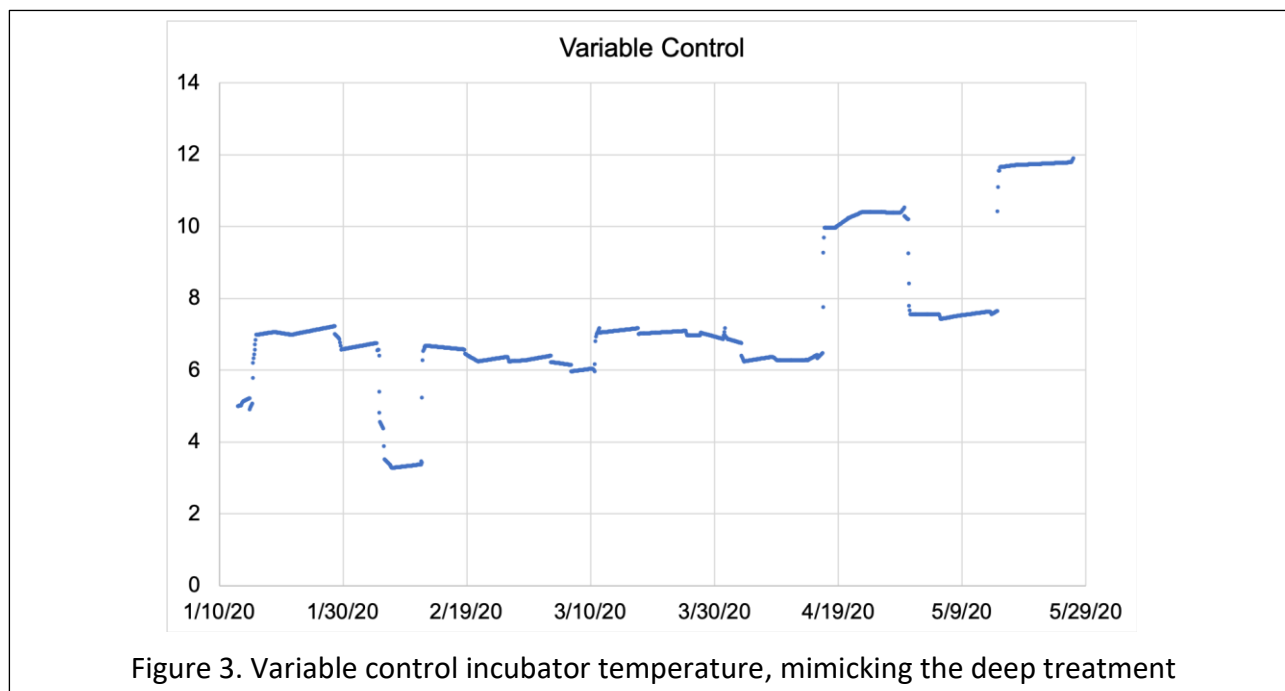


Figure 2. Field temperature data for shallow (top) and deep (bottom) treatment.

Salinity in both field treatments decreased significantly over the course of the experiment but to differing degrees (Figure 5). At T0, the salinity of the sachets was 35 ppt. By the conclusion of the experiment, salinity was 4 ppt in the shallow treatment and 17 ppt in the deep treatment. Although salinity levels fluctuated, the salinity of the deep sachets was always greater than (or in one case equal to) the salinity of the shallow sachets.



4.3 Germination Success

Some proportion of *Alexandrium* cysts within the dunes remained viable throughout the experiment, although viability decreased significantly over the course of the study, particularly in the shallow treatment (Fig. 6). During the earlier stage of the experiment, cysts from the dune sachets often displayed slightly more successful cumulative germination percentages than control cysts that were stored in anoxic laboratory conditions. In the first ten weeks of the experiment (January 8 – March 17) cumulative germination averaged 82% in the shallow treatment and 76% in the deep treatment. By comparison, cumulative germination averaged 72% in the 4°C control and 68% in the variable control. After this time, germination began to decrease and mortality to rise. Significant cyst mortality (>70%) in both field treatments was observed by Week 15 (April 22), and at the time of final sampling, mortality was complete in the shallow treatment (0% germination, 100% dead cysts), and nearly complete in the deep treatment (13% germination, 87% dead cysts; Fig. 7).

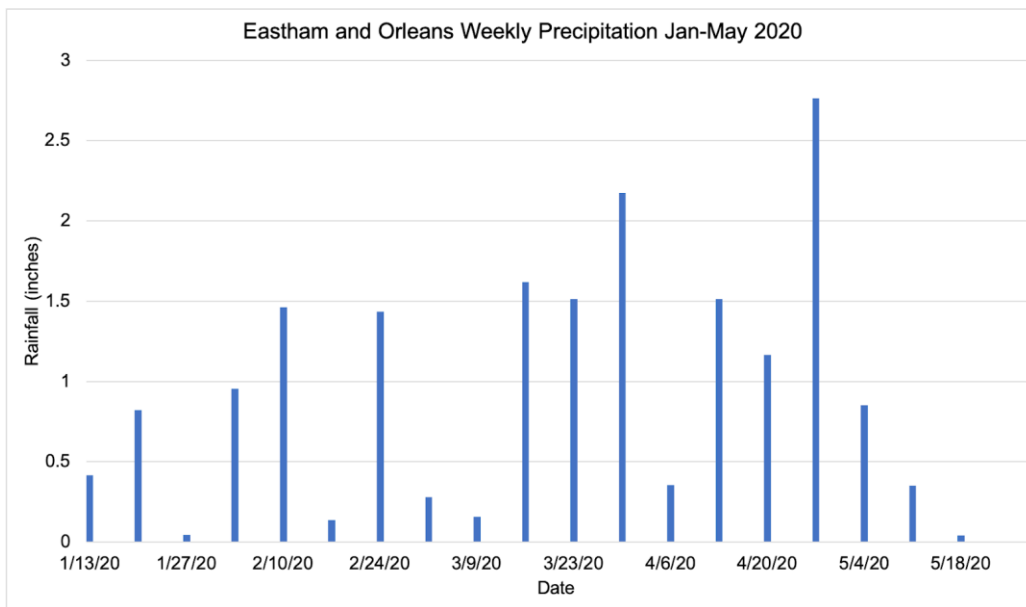


Figure 4. Weekly precipitation in Eastham and Orleans from January to May 2020 (<https://www.cocorahs.org/>).

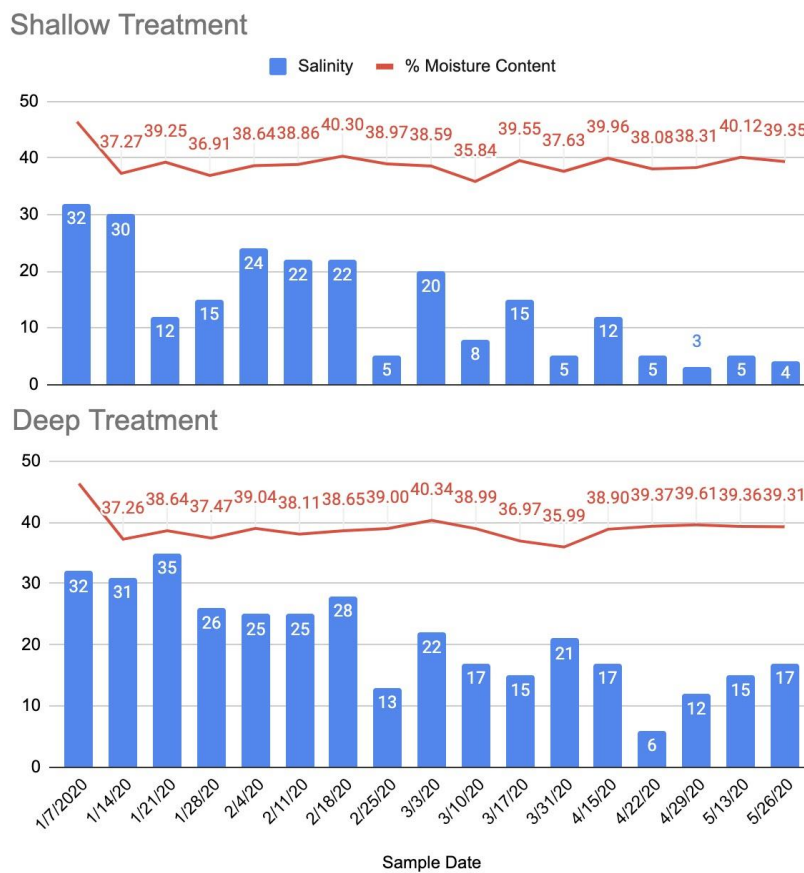


Figure 5. Percent moisture and salinity of shallow and deep dune treatments over time.

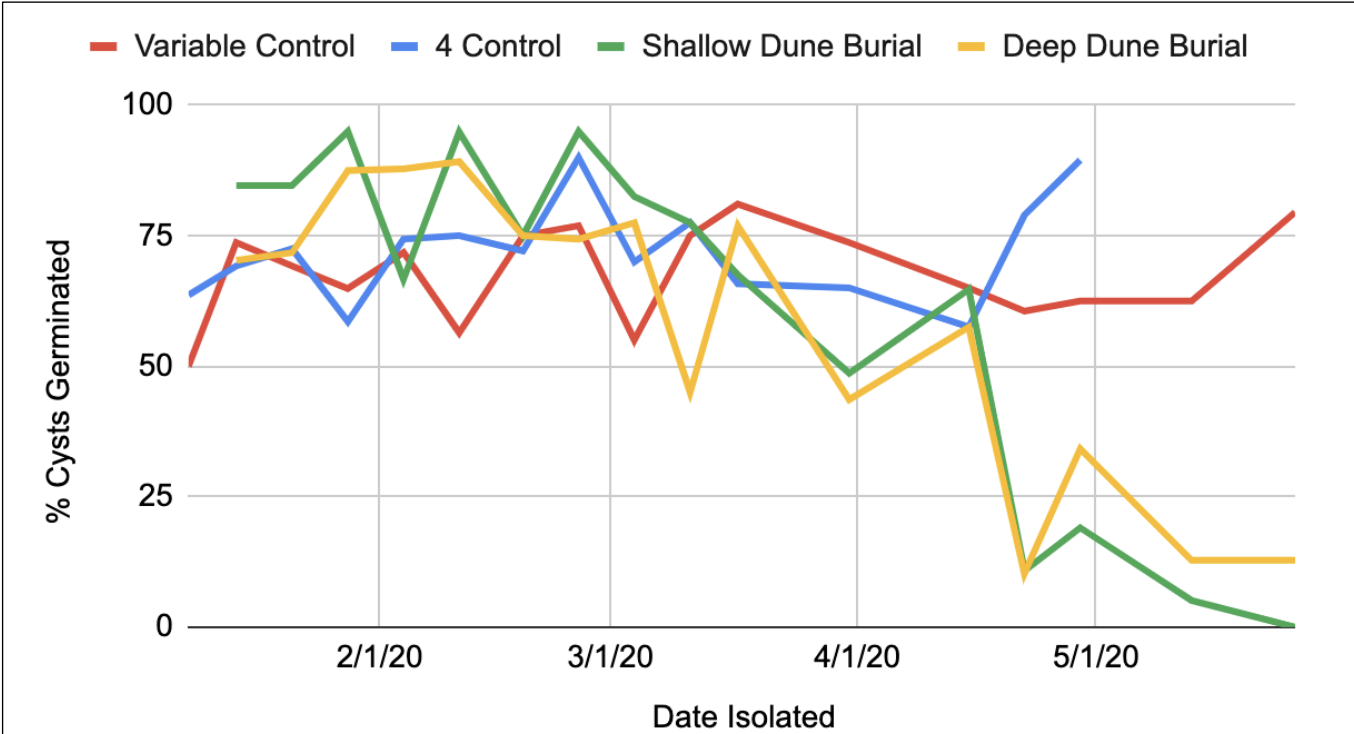


Figure 6. Percent cyst germination over time.

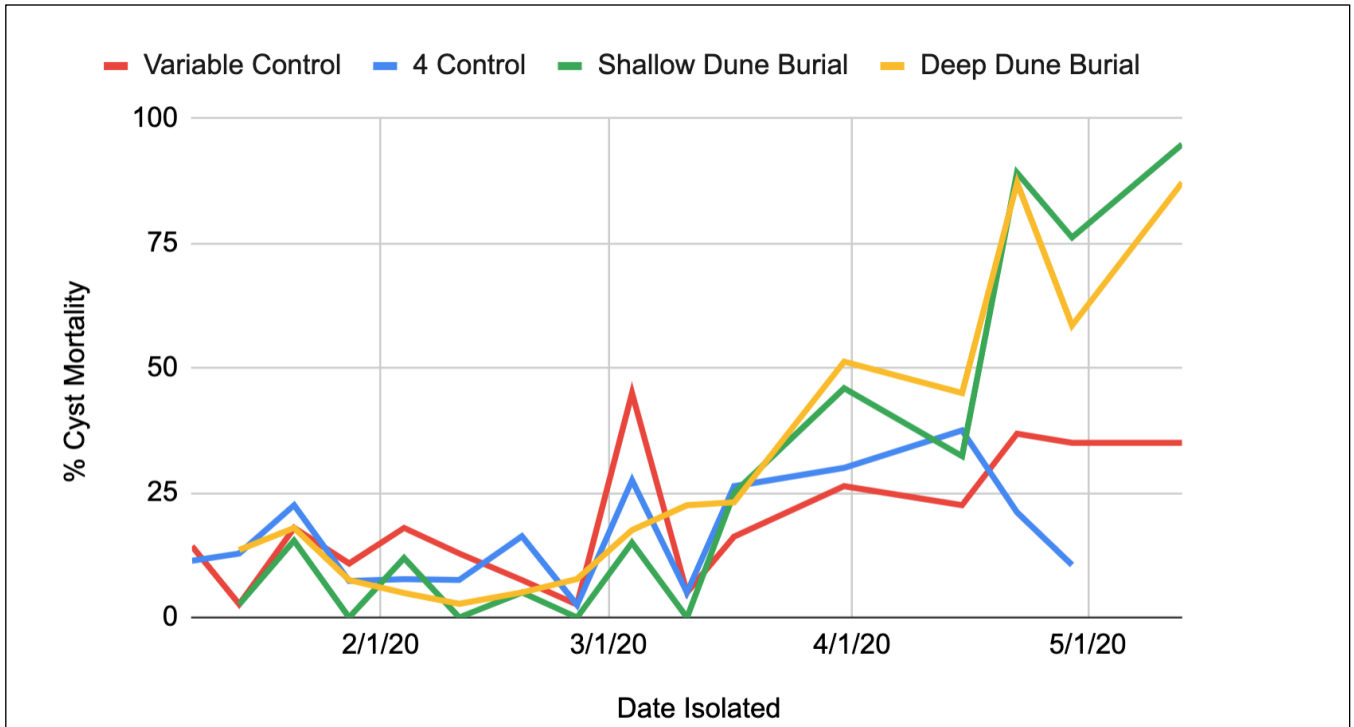
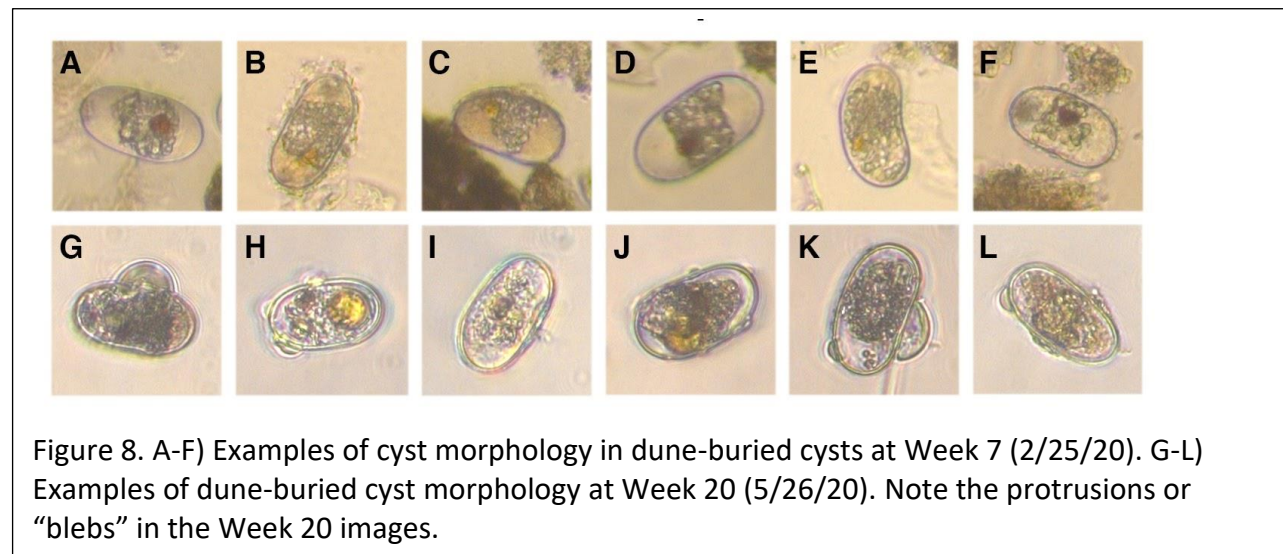


Figure 7. Percent cyst mortality over time.

4.4 Cyst Morphology

Cysts populations in the dune treatments maintained healthy appearances and overall morphological integrity for the first 10 weeks of the experiment. Starting on March 31, however, a large proportion (>25%) of dead cysts was observed in the shallow treatment for the first time. Thereafter, the relative proportion of dead cysts increased steadily in both treatments. In general, healthy cysts exhibited clear banding of internal contents and defined cell walls. As cysts began to exhibit higher incidence of death, internal contents became degraded in appearance and many displayed protrusions or “blebs” (Fig. 8). Morphological changes were similar in shallow- and deep-dune treatments.



4.5 Cyst autofluorescence

Throughout the study, cysts in the field treatments consistently exhibited high levels of red chlorophyll autofluorescence, while autofluorescence was rarely observed in cysts maintained in both control conditions (Fig. 9). The lack of autofluorescence in the latter reflects the effects of anoxia during laboratory storage, as that is known to completely suppress germination in *Alexandrium* (Anderson et al. 1987). The autofluorescence observed in the field cysts indicates that oxygen was present in the dune micro-environment around the sachets.

Across the first 10 weeks of the experiment, the proportion of cysts displaying autofluorescence at a level of 2 or above in the field treatments averaged 47% in the shallow sachets and 52% in the deep sachets. Fluorescence in both field treatments began to decrease on March 31 (Week 12) as the relative proportion of dead cysts within the samples began to increase. A small number of cysts in the deep dune treatment (~10%) continued to display autofluorescence through the conclusion of the experiment, while the shallow treatment reached 0% red autofluorescence by the final sampling on May 26th, consistent with 100% mortality.

Overall, these data indicate that cysts within the dune were undergoing physiological preparation for germination while cysts in the control samples remained quiescent under their anoxic storage conditions. At the time of their isolation many of the cysts in the dune samples were already primed to produce vegetative cells.

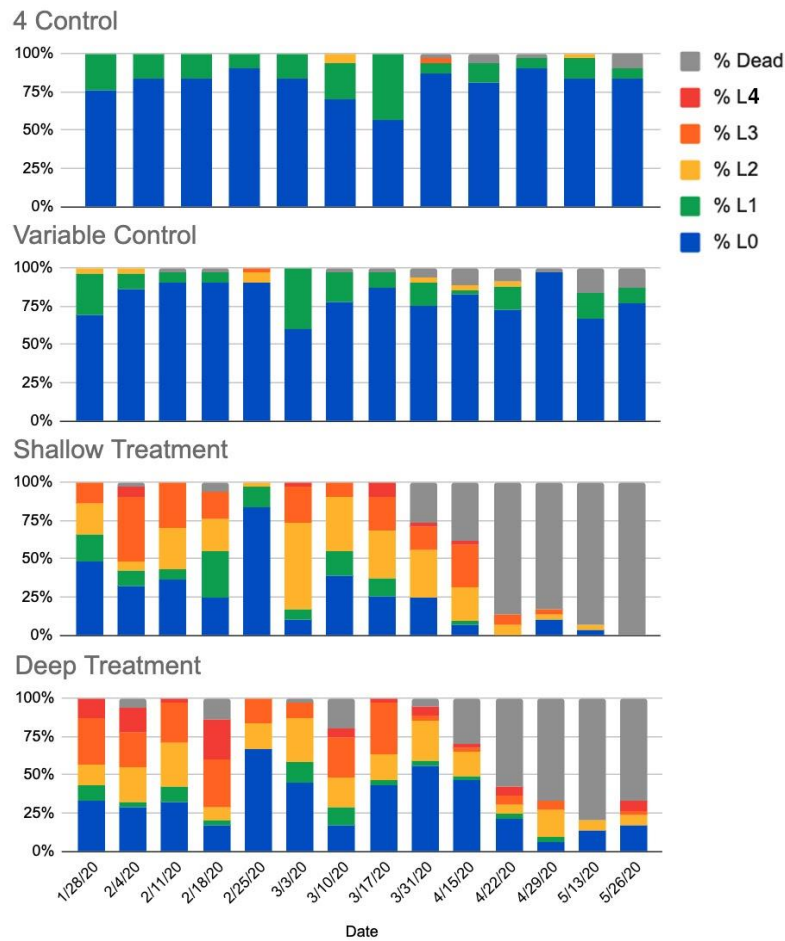
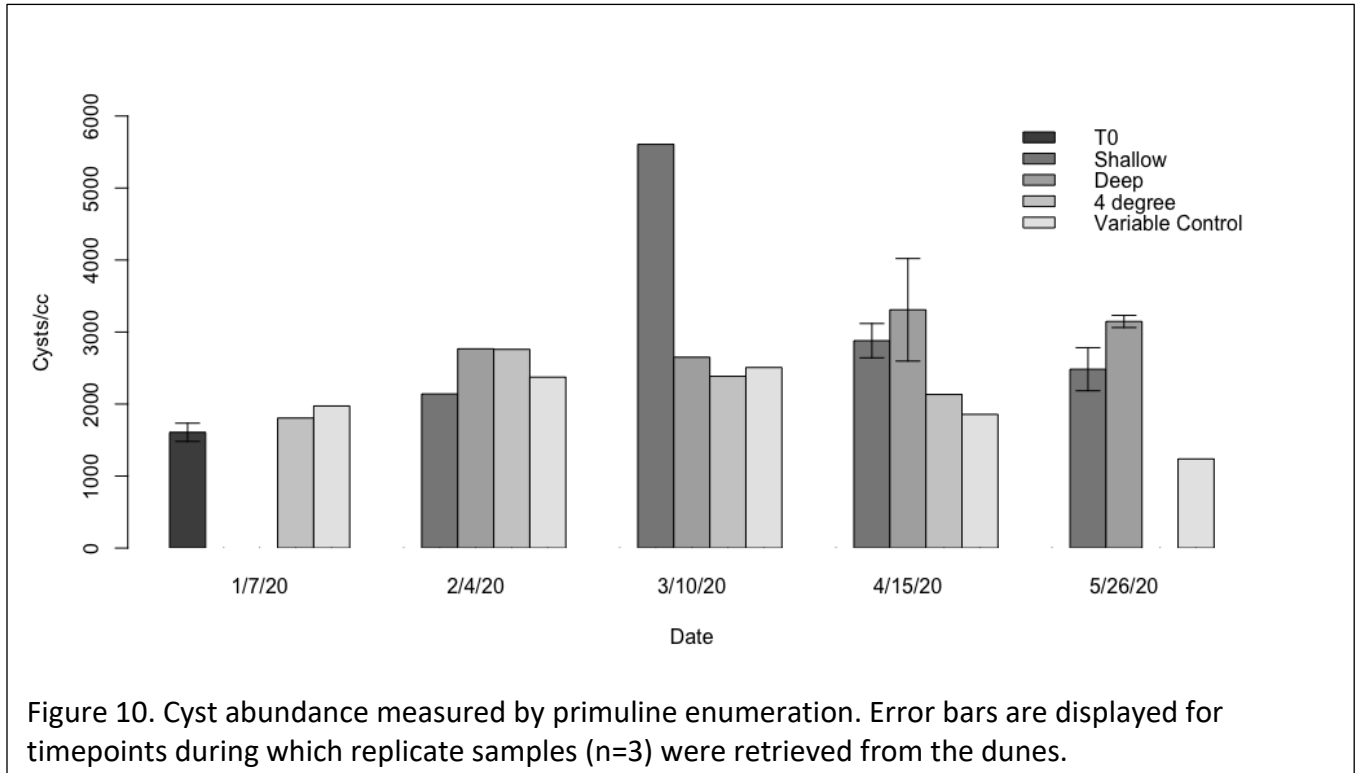


Figure 9. Proportional fluorescence of *Alexandrium* cysts in control and field treatments over time. Cysts were graded on a scale of 0-4, with an additional category included for dead cysts.

4.6 TOTAL CYST ABUNDANCE

At T0, the concentration of cysts within the sachets was $1,608 \pm 126$ cysts/cc. As the experiment progressed, cyst abundance in the sachet appeared to increase relative to the controls and T0. At Week 14, cyst concentration was $2,880 \pm 185$ cysts/cc in the shallow treatment and $3,309 \pm 552$ cysts/cc in the deep treatment. In comparison, the control values in the 4°C and Variable Control remained relatively constant at 2,133 and 1,857 cysts/cc respectively. At the final time point on May 26, cyst concentrations were $2,484 \pm 232$ cysts/cc in the shallow treatment and $3,147 \pm 65$ in the deep-dune treatment (Fig. 10).

In their natural habitat, *Alexandrium* cysts are unevenly distributed within sediments. Despite homogenization of sediments prior to aliquoting sachets, some variability in cyst concentrations is to be expected, making replication an important component of abundance analysis. For example, lack of replication and inhomogeneous distribution may explain the anomalously high



abundance recorded in the shallow sachet on March 10th. However, cyst abundances observed in treatment sachets were significantly higher by the conclusion of the experiment. We hypothesize that the higher cyst concentrations observed may result from a loss of fine sediments (<20 μm) from the sachets during storage in the dune. The gross wet weight of sediments within the sachets decreased 30% between T0 and the final time point in the shallow treatment, and 34% in the deep treatment. This loss of mass would concentrate the *Alexandrium* cysts into a smaller volume, increasing their abundance per cubic centimeter.

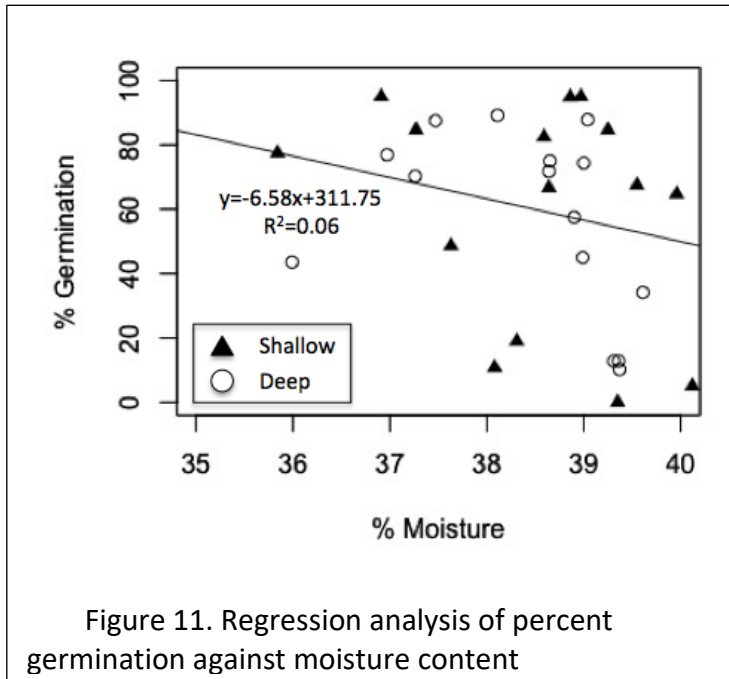
It should be noted that the primuline method detected cysts in high concentrations at the time of final sampling, but that simultaneous fluorescence data and morphological observations indicated that most cysts in the dune treatments were dead. Primuline staining does not distinguish between live and dead cysts.

5 SYNTHESIS

This was a successful experiment that provides useful information to guide dredging and dewatering activities in the Nauset Estuary and other areas where cyst-forming HAB species might occur. The only disappointment is that the winter was mild, so temperatures in the dune never dropped below 0.8 $^{\circ}\text{C}$ and the cysts never experienced freezing temperatures. A separate study conducted for Woods Hole Group indicated that *A. catenella* cysts stored at -20 $^{\circ}\text{C}$ for 8 days all died, and thus we would expect to have seen temperature-driven cyst mortality in the dune, had temperatures been a few degrees lower. The cysts survive very well at low, near-freezing temperatures and the same is true for temperatures in the 10 – 15 $^{\circ}\text{C}$ range observed in the dune at the end of the experiment (D. M. Anderson, pers. observation), so unfavorably low or high temperatures by themselves cannot explain the near 100% mortality observed in the dune cysts by the end of the 139 day experiment. Note also that the Variable

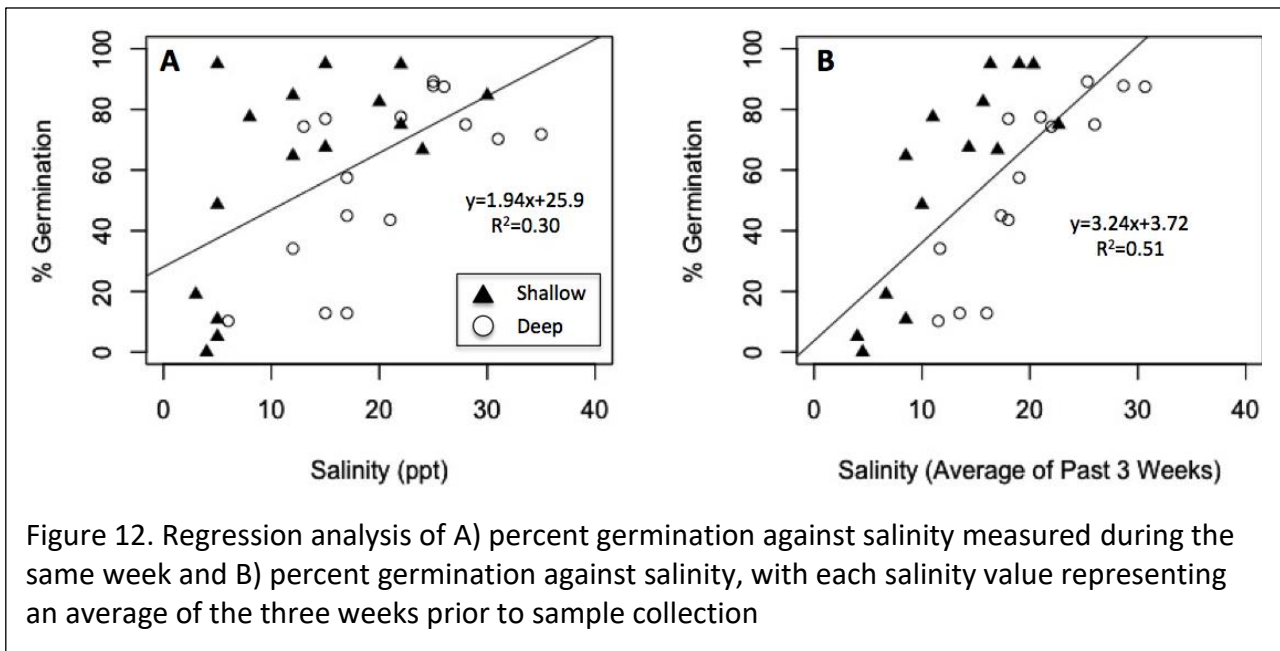
Control treatment did not experience mortality to any significant extent, so a temperature pattern similar to that observed in the field deep treatment did not cause mortality, in marked contrast to observations with the dune-stored cysts.

Additionally, the decrease in cumulative germination was not significantly correlated with the moisture content of the sachets (Figure 11, linear regression; $df=30$, $p=0.16$, $R^2=0.06$).



One possible conclusion is that cyst mortality was driven by prolonged salinity change rather than by desiccation or freezing. A regression analysis of germination against salinity for each sampling week revealed that the two factors were significantly correlated (Figure 12A, linear regression; $df=30$, $p=0.001$, $R^2=0.30$). However, experiments conducted for the Woods Hole Group prior to field deployment showed that cysts could survive and germinate when incubated in distilled deionized water for a week, indicating that *Alexandrium* cysts are tolerant of freshwater conditions for at least that long. To investigate the

impacts of prolonged exposure to low salinity conditions upon viability, percent germination was plotted against the salinity value for the three weeks leading up to sampling (Figure 12B).



This analysis showed that cyst germination was significantly correlated with sustained salinity (linear regression; $df=26$, $p<0.001$, $R^2=0.51$).

One argument against salinity-induced mortality is that the salinity of the deep treatment was generally above 17 ppt throughout the experiment. This is a moderate salinity similar to the conditions in many estuaries that are inhabited by *Alexandrium catenella*. The salinity was much lower in the shallow treatment where it was 5 ppt or less starting in mid February, but the lack of mortality in the deep treatment at higher salinities suggests that another factor caused the mortality.

The Variable Control tracked the temperature history of the deep cysts in the dune, but did not show similar mortality. The main differences between control and experimental cysts at that depth were thus the salinity and the oxygen levels. The salinity difference was not very large (32 versus 17 ppt), and spans the range of habitats where *A. catenella* thrives. We are left with the conclusion that the presence of oxygen may have expedited the mortality of cysts in the dune in some way. Why that might be lethal remains a mystery, however. Two possibilities are suggested. One relates to the ability of other organisms (e.g., bacteria, fungi, parasites) to survive in an oxygenated environment and kill the cysts. The unusual morphology of some of those dead or dying cysts (the blebs in Fig. 8) might be a clue to this underlying cause or mechanism. This will be explored in a subsequent academic study.

Another option is that the cysts were inhibited from germinating because of the combination of darkness and low, but non-zero oxygen, leading to oxidative stress in the cells that increased as temperatures rose. In a prior study, Anderson et al. (1987) showed that *A. catenella* (then called *Gonyaulax tamarensis*) cysts germinated in darkness, but very slowly compared to the light. After 7 weeks of incubation, roughly 50% germination occurred in that interval. These experiments were conducted in well-oxygenated laboratory culture flasks, whereas in the dunes, the cysts in the sachets had favorable temperatures and a positive but unknown amount of oxygen. Perhaps oxygen levels were sufficiently high to allow germination to proceed, (evidenced by the synthesis of chlorophyll), but low enough to slow germination. Combined with oxidative stress in the cysts as temperatures warmed, mortality ensued.

This scenario is consistent with what is known about factors that affect the viability of the seeds of terrestrial plants. As plant seeds age, their ability to germinate declines even if stored under optimal conditions. Reactive oxygen species (ROS), released during normal metabolism of oxygen, are known to have significant roles in the process of seed germination. However, ROS levels must be closely regulated in a relatively narrow range for germination to proceed. If ROS levels are too low seeds will never leave dormancy, and if they are too high then seeds will suffer excessive oxidative damage during seed storage and will be non-viable.

6 CONCLUSIONS AND RECOMMENDATIONS

- Under the natural experimental conditions of late winter 2019 - 2020, a significant number of cysts remained viable for at least three months., and therefore represent a potential

threat if they were washed away from the dewatering site. After that, mortality was quite rapid and was complete (i.e., near 100% cyst mortality) in five months. This was true at both shallow and deep positions within the dune.

- This is a “worst-case” scenario, due to the mild winter during the study. In a colder winter, assuming that freezing temperatures occur within the dune, ‘particularly in surface layers, mortality would be much faster, particularly in upper levels.
- Temperature and desiccation by themselves did not contribute to cyst mortality. It is possible that the sustained levels of low salinity as rainwater percolated through the sand was a lethal factor, but this does not explain mortality in the deep treatment, where salinity never dropped below 17, well within a range where *A. catenella* cells thrive. The effect of low salinity on cyst viability needs to be confirmed experimentally.
- One observation that might explain the mortality was that the dune treatments never went anoxic, evidenced by sustained levels of chlorophyll autofluorescence in the field cysts. This fluorescence was not observed in control samples stored in anoxic sediments. The observed mortality in the presence of oxygen might reflect the ability of other organisms (e.g., bacteria, fungi, parasites) to survive and kill the cysts. A more appealing option is that the oxygen levels were high enough to start the germination process, but that germination was slowed or delayed due to darkness. In the presence of oxygen, the cysts’ metabolism would have generated reactive oxygen species as temperatures increased, potentially leading to oxidative stress that led to the altered morphology and mortality. This is another process that needs to be explored in a subsequent academic study.
- Cysts were undergoing physiological preparation for germination within the dune but did not germinate there to any significant extent. This has significant implications for the risks associated with dredging operations and spoil dewatering, as premature dispersal of the dune material could result in a rapid, synchronized pulse of germination in receiving waters.
- A dredging operation in the early winter would be safest, as it would be three to four months before local water temperatures are warm enough to support a bloom if any of the cysts in the material being dewatered are dispersed by storms. If the dredged material is dewatered far from any area where a storm might wash sediment and cysts back into the ocean, then the dredging could be done at a different time of the year as long as the dewatered material is not used for beach nourishment for at least 5 months
- If a dredging and dewatering operation is conducted in the Nauset Estuary, the dewatered material should be monitored for cyst viability using methods described here. This would be a simple way to follow the mortality process and to assess the viability of cysts in material scheduled to be used for beach nourishment. It would also provide valuable scientific data to guide future dredging operations.

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Date: 7/19/2020

To: Leslie Fields, Woods Hole Group

From: David Ralston and Don Anderson

Re: Modeling impacts of dredging Mill Pond channel on *Alexandrium* cysts in Nauset estuary

This memo summarizes analyses of a numerical model to assess potential impacts of dredging in Nauset estuary on the distribution of cysts of *Alexandrium catenella*. *Alexandrium catenella* (formerly termed *A. fundyense*, and hereafter referred to as *Alexandrium*) is a dinoflagellate that causes an annually recurrent harmful algal bloom in Nauset estuary. *Alexandrium* blooms are associated with a family of toxins that cause paralytic shellfish poisoning (PSP) and can lead to closures of shellfish resources to protect public health, and thus are of significant economic and societal interest. This memo is supplementary to a previous report on the feasibility of dredging in Nauset estuary (Woods Hole Group, 2016). Here we focus on potential impacts of dredging of a channel to access Mill Pond, as a modification or alternative to the larger dredging plan for a channel from the Nauset inlet to Town Cove. The 2016 report provides a more comprehensive assessment of the potential impacts on the larger dredging plan, including potential impacts on *Alexandrium* blooms in the estuary.

As part of its life cycle, *Alexandrium* has a resting cyst stage. Cysts lie dormant in the bottom sediment until conditions are favorable for growth, at which point they can germinate into the water column and grow as vegetative cells into a bloom. Previous studies have found that the highest concentrations of cysts are located in the bottom sediments of the three drowned kettle ponds: Mill Pond, Town Cove, and Salt Pond (Crespo et al. 2011). These kettle ponds are also the locations in the estuary where the *Alexandrium* blooms are most intense. Cysts in bed sediments are typically associated with the fine particles (clays and silts) that collect in lower energy flow environments, as opposed to the sandy bed sediment in more energetic tidal flows of channels and shallow regions that are exposed to wind waves. Isolated cysts settle relatively slowly (about 0.1 mm/s), but when mixed with sediment the settling rates for cysts correspond to the settling velocities for the associated fine sediment (0.2-1 mm/s) (Anderson et al. 1985; Ralston et al. 2020).

To assess potential impacts of dredging on cyst distributions in Nauset estuary, we used an existing hydrodynamic model that has previously been used to characterize *Alexandrium* blooms in the system (Ralston et al. 2015). Model bathymetry was updated based on data collected by Woods Hole Group in November 2015, as described in the previous report (Woods Hole Group, 2016). Two diagnostic cases were created to represent a dredged channel from the inlet to Town Cove: one that has a dredged channel to Mill Pond and one without dredging to Mill Pond. The three cases are referred to as “baseline”, “dredged”, and “dredged Mill Pond”. The dredged channel dimensions were based on specifications from WHG. For the Mill Pond channel, the design dimensions were 2,530 ft long, 100 ft wide, and a dredge depth of -5 ft MLW. Figure 1 shows model bathymetry in the vicinity of Mill Pond for the three model configurations.

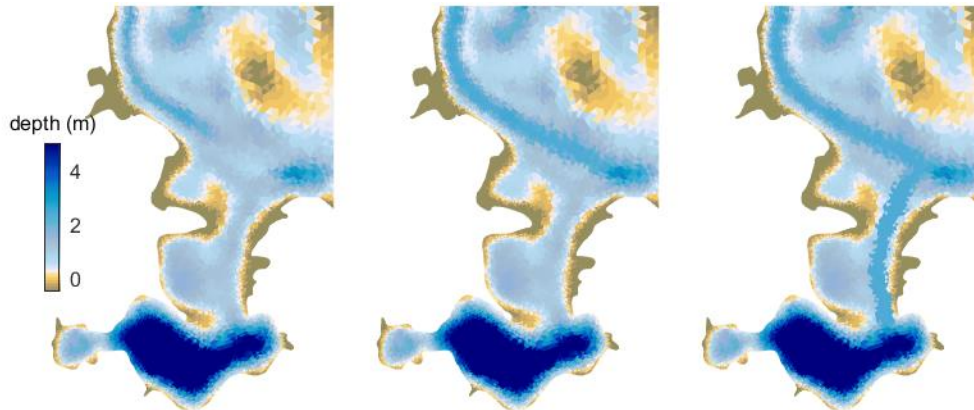


Figure 1. Bathymetry of three model configurations: (left) baseline, (middle) dredged, and (right) dredged Mill Pond.

In addition to tidal currents and water levels, the model included a sediment transport component to represent how cysts associated with bed sediments would be redistributed by the tidal currents. The diagnostic simulations were initialized with a uniform distribution of fine sediment (settling velocity of 0.3 mm/s) on the bed throughout the estuary. This is not meant to represent the present bed conditions in the estuary, in that many of the channels of the estuary are sandy and do not retain fine sediment. Instead, the modeling exercise is used to diagnose how the changes in hydrodynamics associated with the reconfiguration after dredging might change the transport and accumulation of the sediment size classes associated with cysts. The simulation does not directly address the resuspension and redistribution of cysts during dredging. It is not possible to accurately estimate the total number of cysts that will be resuspended during dredging, as this will not be constant across the marsh due to variable cyst abundances and sediment types in the areas to be dredged. In the previous report (Woods Hole Group 2016), it was estimated that the total number of cysts released during dredging would add approximately 0.03% to the cysts in the surface layer across the Nauset estuary. Presumably, the dredging will occur during cold, winter months when *Alexandrium* cyst germination will not occur. Cysts that are resuspended during those operations will thus have several months to be redistributed to the terminal kettle ponds before they begin to germinate. The eventual distribution of those cysts can be inferred from the modeling results reported here. Salt Pond, Town Cove, and Mill Pond are the likely sites for their eventual deposition, though the total number of cysts is likely to be quite small compared to the number already in those locations.

As noted in the previous report, the tidal amplitude in Nauset has been decreasing over the past decade or more as the inlet has migrated to the north and the tidal channel behind the inlet has shoaled (Woods Hole Group 2016). The Nauset system is also characteristically flood dominant, in that the shallow flows alter the tidal propagation such that flood tides have shorter duration and faster velocities than ebb tides (Aubrey and Speer 1985). This results in sediment transport that is preferentially in the flood direction, or landward. These characteristics of the estuary are important in understanding the modeled changes in Nauset in response to dredging.

The most notable differences in model results are between the baseline and dredged cases, and the Mill Pond dredging results very similar to the latter. The dredged case has greater tidal amplitude inside the estuary due to the reduction in drag and removal of shallow sills in the channel from the inlet. The

dredged case has tidal water level amplitudes that are about 20% greater than the baseline case. For the dredged Mill Pond case, tidal water levels are essentially the same as the dredged case. The increased tidal amplitude corresponds with greater tidal velocities inside the estuary. For example, maximum tidal velocities in the entrances to Town Cove and Mill Pond are increased by about 30% in the dredged case compared to the baseline case. The dredged Mill Pond case has similar velocities to the dredged case through most of the estuary. The exception is near the entrance to Mill Pond, where velocities are slightly reduced compared to the dredged case because of the increased channel depth (Figure 2).

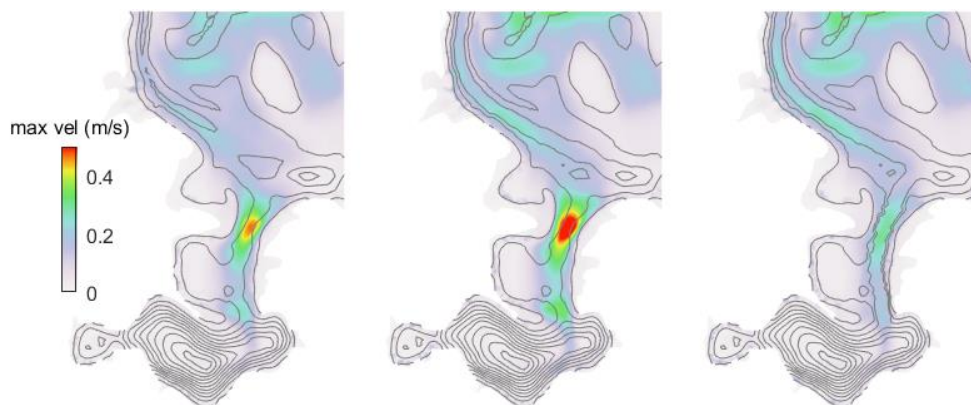


Figure 2. Maps of max tidal velocity near Mill Pond during a spring tide for three model configurations: (left) baseline, (middle) dredged, and (right) dredged Mill Pond.

Overall, the increased tidal amplitude and tidal velocities in the estuary result in greater sediment transport. The tidal velocities remain flood dominant in the estuary, so the transport of fine sediment toward the kettle ponds is enhanced. The accumulation in the kettle ponds of fine sediment, representative of how cysts in bed sediment would be redistributed, is greater in the dredged case than the baseline by 30-40%. Thus for example Town Cove would likely see an increase in cyst abundance, both due to the small number of cysts resuspended during dredging, and through the gradual accumulation of cysts from blooms due to the increased tidal amplitude and tidal velocities bringing cysts and fine sediment into the pond.

The accumulations of fine sediment in Town Cove and Salt Pond are similar in the dredged Mill Pond case as in the dredged case. However, the accumulation of sediment within Mill Pond is increased in the dredged Mill Pond case, about 40% greater than in the dredged case. Dredging of the channel to Mill Pond increases the connectivity to the rest of the estuary, and that results in more fine sediment transport into Mill Pond due to the overall flood dominance of the system. While the maximum velocities in the dredged channel to Mill Pond are slightly lower than without dredging, the tidal volume exchange is greater due to the deeper channel, leading to more tidal exchange. For example, during spring tides the tidal volume flux into Mill Pond is about 20% greater in the dredged case than the baseline due to the increased tidal amplitude, and that increases to about 25% greater tidal exchange than the baseline in the dredged Mill Pond channel case. The increased tidal exchange would also be expected to increase tidal flushing and reduce residence times of Mill Pond, potentially reducing the *Alexandrium* cell concentrations during bloom periods (Ralston et al. 2015).

In summary, the dredging of the channel to Mill Pond has minor impacts on the hydrodynamics and transport in Nauset estuary compared with the changes associated with the overall dredging project.

The dredged channel to Mill Pond increases connectivity with the rest of the system, but that does not necessarily increase transport of cysts out of Mill Pond. Instead, increased fine sediment transport in the estuary due to the increase in tidal amplitude after dredging results in more landward transport of fine sediment associated with cysts, and greater accumulation in Mill Pond. This is similar to the increase in cysts and fine sediment within Town Cove as a result of the dredging operation.

In terms of *Alexandrium* bloom dynamics and PSP toxicity within Nauset, an increase in tidal range could enhance flushing of the salt ponds, potentially reducing the accumulation rates of *Alexandrium* cells in the ponds and therefore bloom intensity and resulting shellfish toxicity as well (Ralston et al. 2015). As discussed above, larger tides will also increase bed stresses in the system, remobilizing and redistributing fine sediment and associated cysts back into Town Cove and the Salt Pond. This could increase the population of cysts that are available to germinate at those sites, although as with the sediment released during dredging operations, the expectation is that the fine sediment and cysts would accumulate in regions that already have high cyst concentrations. Furthermore, past studies have indicated that the magnitude of *Alexandrium* blooms and toxicity in the Nauset estuary are much more heavily influenced by growth conditions and population accumulation mechanisms as opposed to the size of the cyst inoculum (Anderson 1998; Ralston et al, 2015). Under the two dredging scenarios, population accumulation would likely be reduced due to increased flushing of the salt ponds, likely over-riding the small enhancement in population numbers from higher initial cyst abundance.

An important point in assessing potential effects of a change in tidal amplitude is that the model predicts a return to tidal conditions similar to that of several years ago rather than a significant increase over the historical range. As the Nauset inlet has migrated north and the entrance channel both extended and shoaled, the tidal channels have become more shallow and frictional, accounting for the decrease in tidal range. The proposed dredging would reverse some of that decrease, but the tidal regime and any effects on *Alexandrium* blooms and PSP toxicity would be similar to conditions from a few years ago.

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Nauset Estuary Dredging Feasibility Assessment



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February 2016

Nauset Estuary Dredging Feasibility Assessment

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1.0 INTRODUCTION

This report describes a study conducted for the Town of Orleans into the feasibility of developing a dredging program for improved navigation in Nauset Estuary. Significant shoaling has resulted in major changes to the channel and mooring areas, and navigation is typically restricted to several hours on either side of high tide. Commercial fishing boats have been forced to moor in deeper areas of the channel immediately behind the barrier beach, and offload their catch and crew to nearby landings via skiff. This is a less efficient alternative to prior practices, which afforded the fleet the opportunity to moor directly offshore Snow Shore, Priscilla and Goose Hummock landings. These difficulties with navigation and the concerns over public safety prompted the Town of Orleans to commission this study to evaluate a potential dredging program for the estuary.

The Town's conceptual dredge plan focused on portions of Nauset Estuary that provide boat access to the public landings and commercial boating facilities (Figure 1). This includes the main channel starting at the inlet to the Atlantic Ocean and continuing approximately 4.2 miles to Town Cove. The Town Cove area supports public facilities at Goose Hummock, Cove Road, and Asa's Landing, as well as private facilities at Orleans Yacht Club, Nauset Marine, and the Goose Hummock Shop. Areas of the estuary southeast of the main channel providing access to Snow Shore and Priscilla Road Landings were included in the plan. These areas of the estuary are located in the Towns of Orleans and Eastham and a portion of the study area is also located in the Cape Cod National Seashore (Figure 1).

The feasibility of a dredging program will depend on a host of factors including environmental impacts, project lifetime, costs and schedule for permitting, and costs for project construction. The purpose of this study is to develop the necessary information to reliably address these factors. Once this information is known, the Town will be in a position to make an informed decision as to the overall feasibility of the project.

This study takes advantage of existing information and studies, and also leverages the valuable experience of Town officials and other local stakeholders. New data collected as part of this study add to an improved understanding of the Nauset Estuary system, particularly as related to the engineering, environmental, financial, and practical aspects of a dredge program. Section 2.0 provides information on the existing physical and ecological environment in the estuary that influence the dredge and disposal plan formulation described in Section 3.0. The primary factors that determine project feasibility are included in Section 4.0, and recommendations for consideration by the Town if the project is pursued are described in Section 5.0.

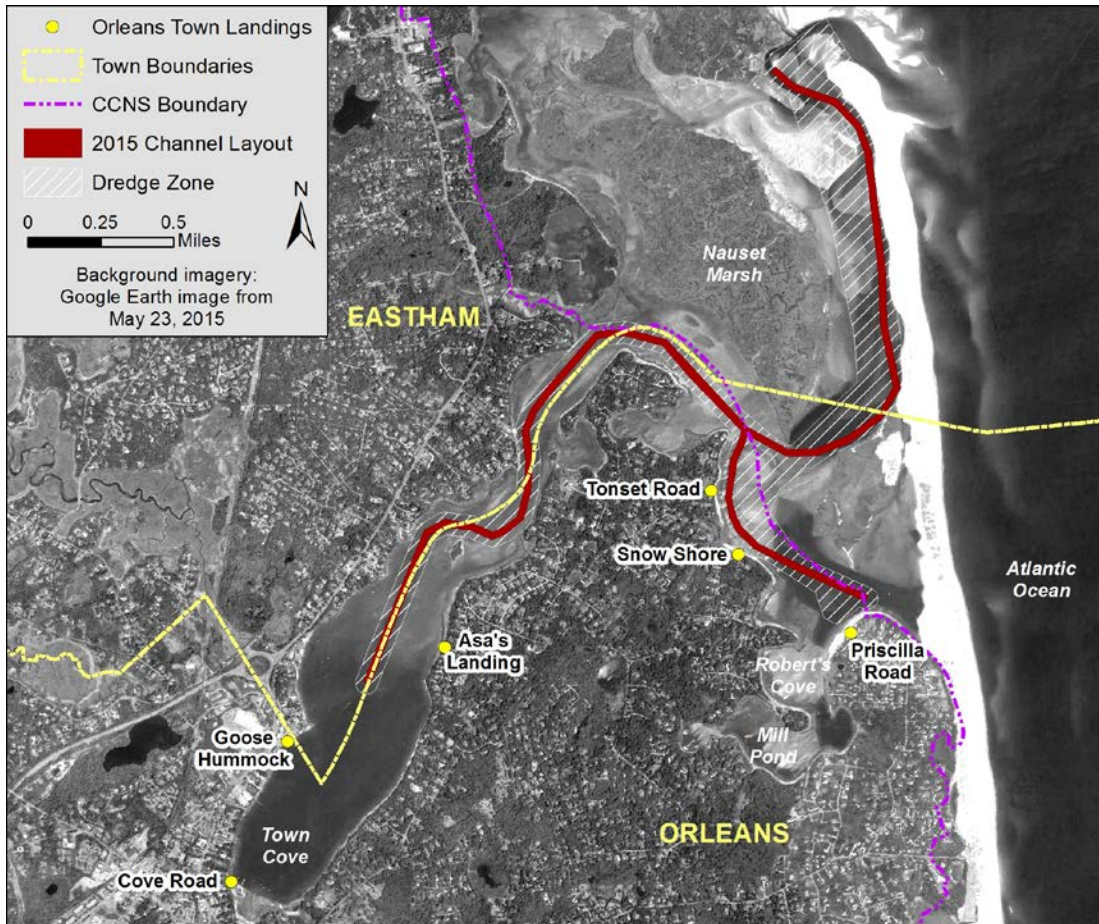


Figure 1. Nauset Estuary showing layout of conceptual dredge plan.

2.0 EXISTING ENVIRONMENT

An understanding of the existing environment in Nauset Estuary is critical to evaluating the feasibility of a dredging program. Data describing the quantity and type of sediment that will need to be dredged given current bathymetric and shoal conditions will control placement alternatives, construction methods, and also construction costs. A fundamental understanding of the changes in geomorphology of the barrier beach and Nauset Estuary inlet and the hydrodynamics of the system will provide valuable insight into areas of the channel that tend to shoal the fastest and will require frequent maintenance dredging. Information on ecological factors such as red tide cysts, shellfish, eelgrass, and other sensitive resources will help to identify potential environmental constraints on a dredging program.

For the purposes of this study the existing conditions of Nauset Estuary were documented through review of available information and limited collection and analysis of new data. The existing physical and ecological conditions of the estuary are described in the following report sections. Data sources are included and where new data were collected, the field and data analysis methods are described.

2.1 GEOMORPHOLOGY

This history of geomorphologic changes at Nauset Inlet was studied by Aubrey and Speer (1984) and more recently by Woods Hole Group (2006). Historical charts dating back to 1779 and aerial photography from 1938 and 1946, show the inlet to be located just north of Nauset Heights at the southeastern edge of the estuary. During the approximate 170-yr period that the inlet was located in the vicinity of Nauset Heights, spit formation extending to the north from the lower beach was non-existent (Figure 2). Although Aubrey and Speer (1984) agree that aperiodic coverage of historical maps may have undersampled previous episodes of inlet migration, they suggest that the persistence of a southern location suggests a historically stable inlet configuration at Nauset Heights.

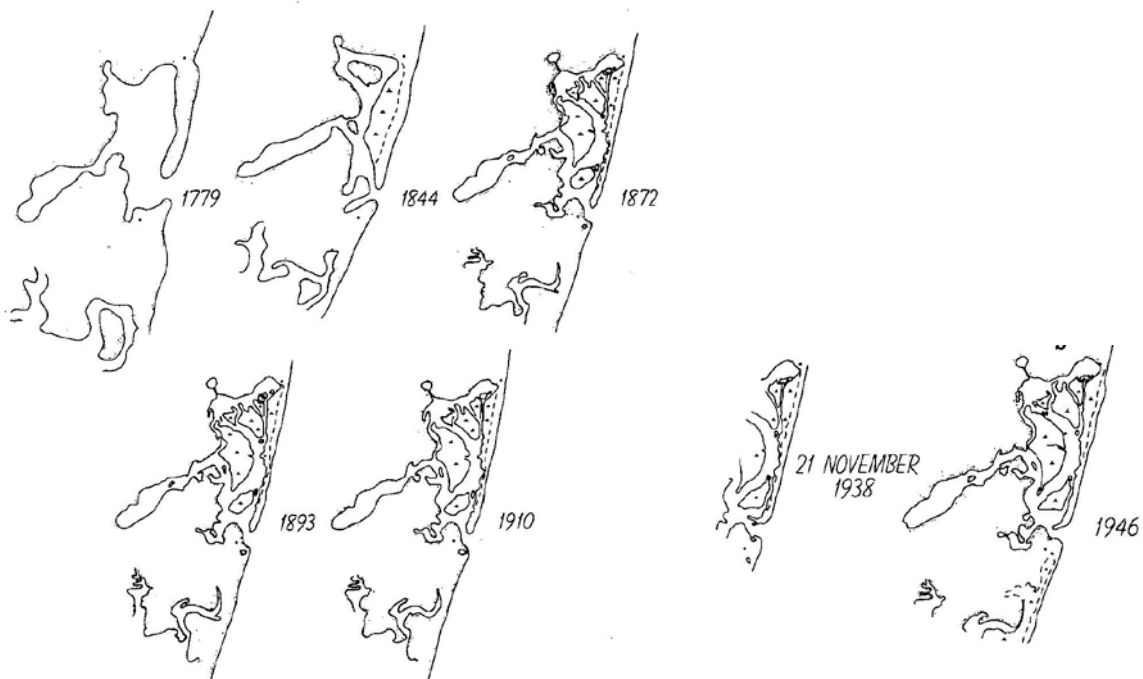


Figure 2. Representative charts and historical aerials from 1779 to 1946 showing stability of the Nauset Estuary inlet at Nauset Heights (Aubrey and Speer, 1984).

Inlet activity at Nauset Harbor has been distinctly more active during the last 70 years. Starting in the 1950s, the inlet experienced two distinct cycles of northward migration. During the first phase between 1950 and 1957, the length of the northern spit extending from Coast Guard Beach remained relatively stable, while the southern spit extending from Nauset Heights continually grew northward. A series of storms in the late 1950s and early 1960s re-established the inlet to its southernmost position immediately adjacent to Nauset Heights. The second cycle began in 1965 and lasted approximately 25 years until 1990. This period of northerly inlet migration was characterized by substantial

erosion of the north spit along with northward growth and extension of the south spit (Figure 3). The distance of northerly inlet migration during this period was about 1.3 miles.

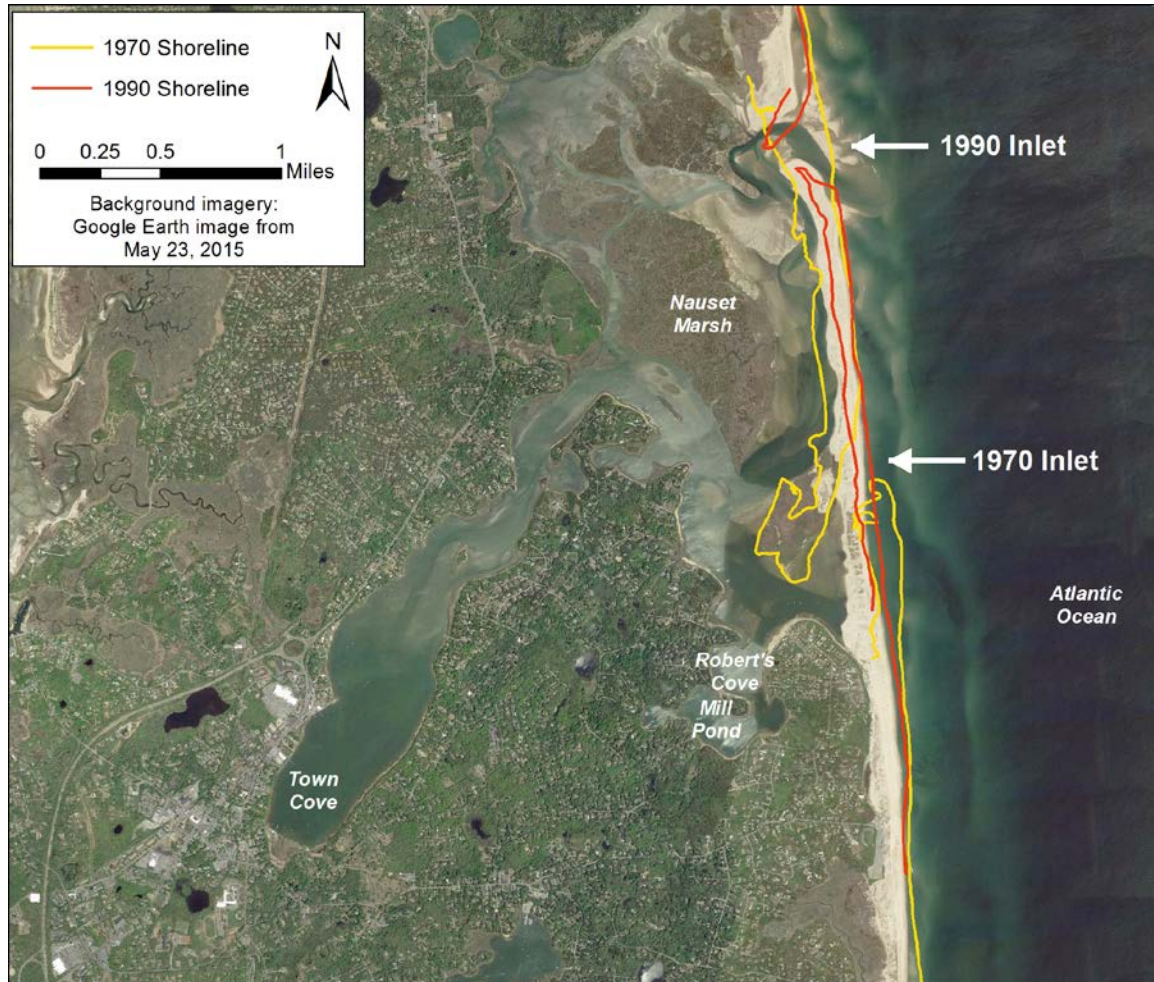


Figure 3. Northerly migration of Nauset Estuary inlet between 1970 and 1990.

Storm activity in the early 1990s caused a breach in the barrier beach near the north end of Tern Island. The system supported two inlets for a period of 2 to 4 years with a northern inlet in the vicinity of the 1990 opening, and a southern inlet at the location of the breach. Sometime after 1996 the northern inlet closed and the system began another cycle of northerly inlet migration. Between 1996 and 2015 the inlet migrated nearly 1.0 mile to the north, back to the location of the 1990 inlet (Figure 4). This represents the most northerly position of the inlet since the early record keeping in 1779.

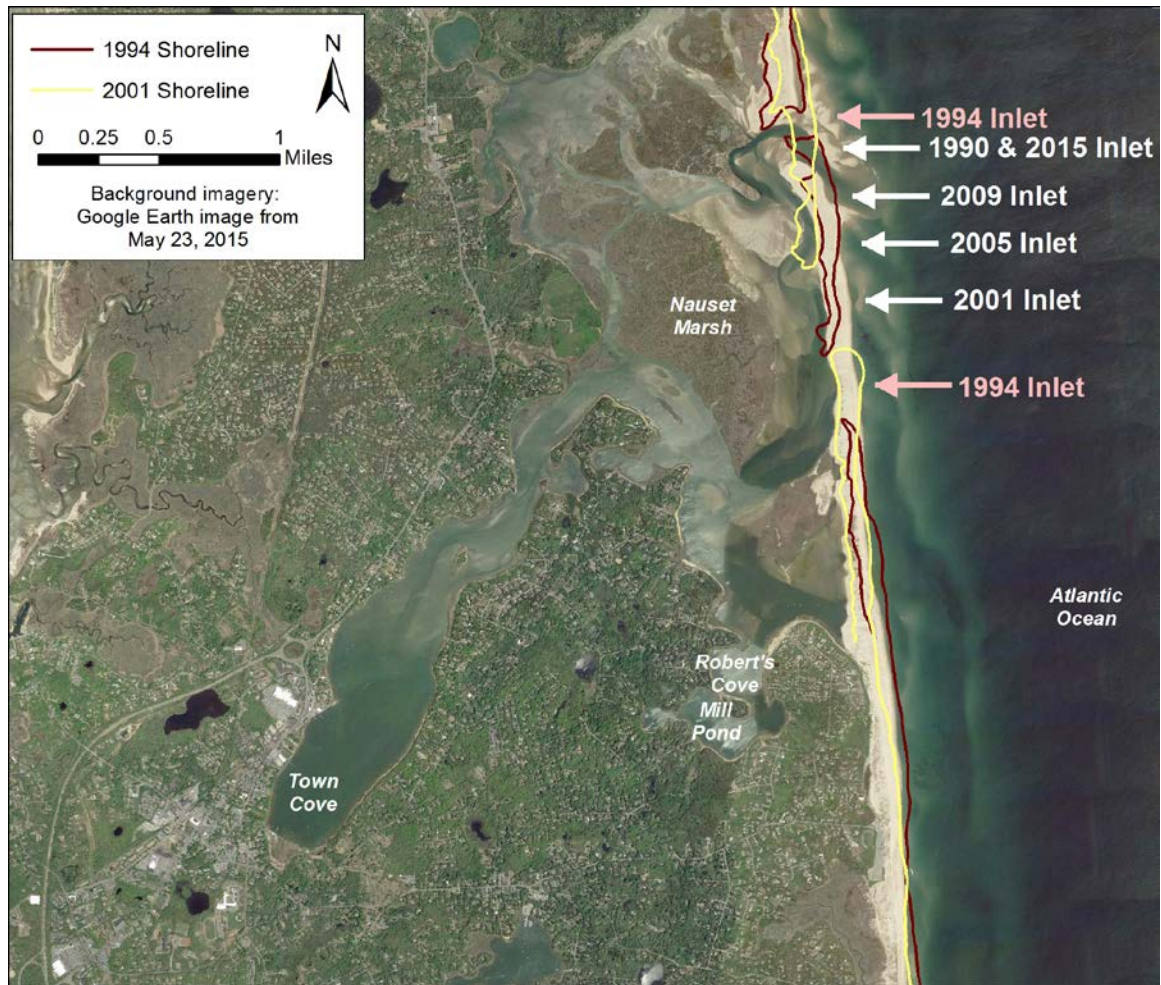


Figure 4. Nauset Estuary Inlet migration between 1990 and 2015.

These cycles of northerly inlet migration, punctuated by breaching to the south, have an influence on the location of the main channel in Nauset Estuary behind the barrier beach. As the spit lengthens to the north pushing the inlet further north, the channel becomes elongated and the hydraulic efficiency of the channel is reduced. Incoming tidal currents bring sediment from the ocean side to form flood shoals and overwash processes during storms deposit sediment in the channel along the west side of the barrier beach. These shoaling processes further reduce the efficiency of the channel. Eventually storms cause the formation of a new breach further to the south where the channel has a more direct link to the ocean. Historical breach locations just north of Tern Island are largely related to the location and orientation of the main channel which directs ebb currents towards the back side of the barrier beach. With enough hydraulic head between the estuary and the ocean, scouring on the west side of the barrier can result in the formation of a new breach from the estuary side. The scouring can also cause a thinning of the barrier beach just north of Tern Island, which weakens the barrier and increases the potential for overwash and breaching from the ocean side.

Historical data indicate that the Nauset Estuary channel between Tern Island and the current inlet location is highly dynamic and strongly influenced by the continuing geomorphologic evolution of the inlet and barrier beach. The data also suggest that a breach in the vicinity of Tern Island is likely to occur in the future. In fact, a washover just north of Tern Island was reported at high tide on February 9, 2016. Whether this develops into a full breach this winter is uncertain. What is clear however, is that a new inlet near Tern Island would allow the Town to temporarily abandon the northern section of channel behind the current barrier beach, in lieu of the more direct channel through the new inlet.

Longshore sediment transport rates and directions along the Eastham/Orleans ocean facing coastline have been studied by Zeigler (1954, 1960), US Army Corps of Engineers (1969) and by Geise (1988). The studies report a net southerly littoral drift with rates ranging between 230,000 and 250,000 cubic meters per year. Sediment is derived from erosion of coastal banks further to the north. The history of northerly inlet migration at Nauset Estuary, in a direction opposite the dominant longshore sediment transport, is contrary to patterns of migration at most other natural inlets. Aubrey and Speer (1984) analyzed historical charts, aerial photos, and storm histories from the area to develop a conceptual model that explains the inlet migration patterns.

The main channel in Nauset Estuary that runs along the west side of the barrier beach is the most dynamic part of the system and is subject to shoaling from inlet processes, barrier formation, and storm generated overwash. However, channel areas further inside the estuary are subject to shoaling as well. A qualitative assessment of channel shoaling was conducted using historical aerial photos from 1972 to the present. Areas of major shoaling were identified on the photos, digitized within a geographic information system (GIS), and then compared over time. This process is influenced by the stage of the tide at the time the photography was collected as well as the ability of the photo interpreter to utilize a consistent proxy for shoaling from one set of photography to the next. Despite these inaccuracies the method provides a reasonable first approximation of areas within the estuary that are prone to shoaling.

Results of the historical shoaling analysis are compared with shoal areas identified from a recent bathymetric survey conducted in November 2015 (Figure 5). The data show significant variability in channel shoaling immediately west of the barrier beach, caused by inlet and barrier migration and storm overwash processes. Patterns of channel shoaling are also evident further inside the estuary where the geometry changes from a narrow constricted channel to a wider configuration. This is consistent with typical flow dynamics where sediment moving with the higher velocity currents in the narrower channels, drops out of suspension when the channels widen and the current velocities decrease. In general the historical shoal locations correspond with current patterns of shoaling from the November 2015 survey, and also with problem areas identified by the Town of Orleans.

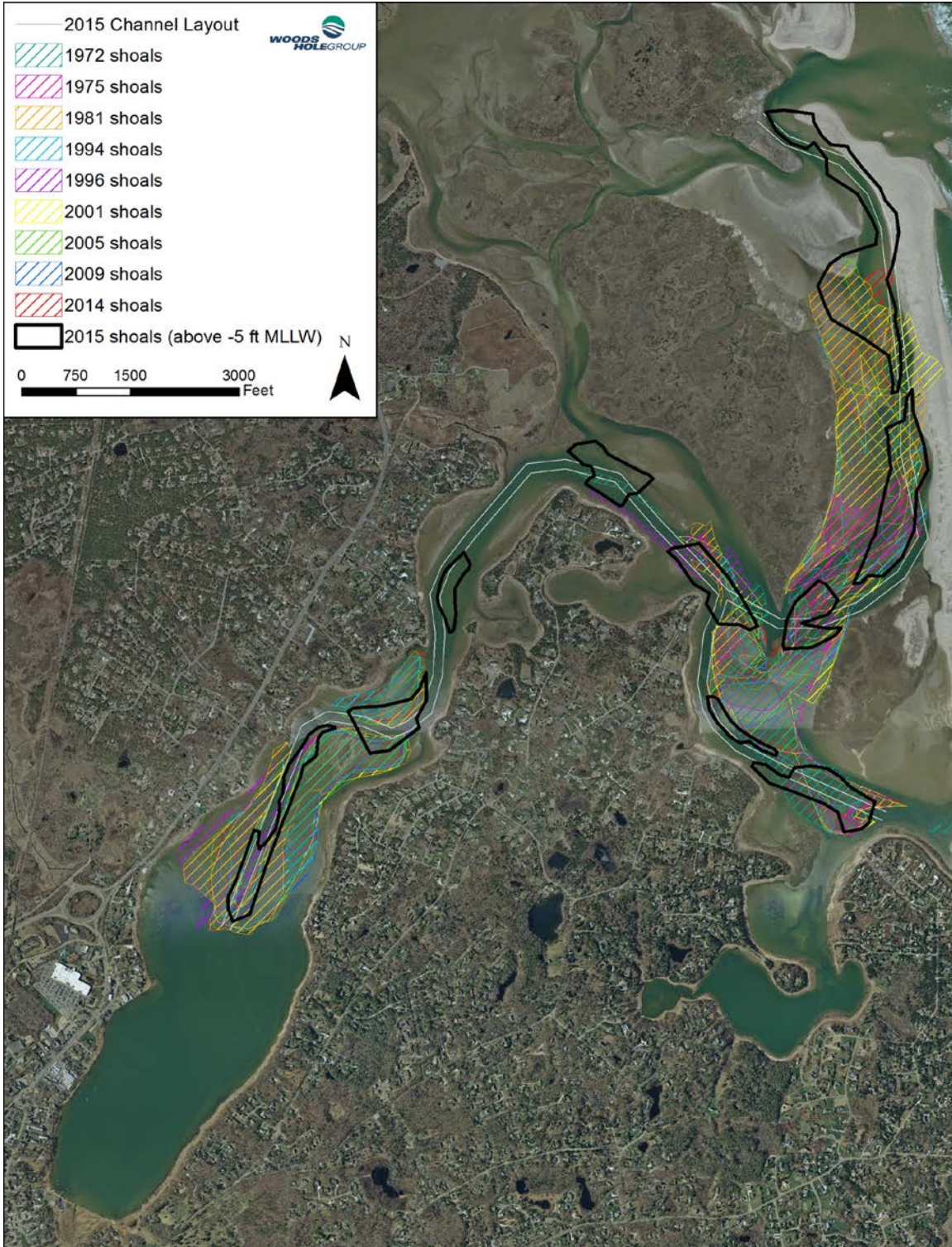


Figure 5. Patterns of historical shoaling in the Nauset Estuary channels compared with current shoal locations surveyed in November 2015.

2.2 BATHYMETRY

The current water depths and shoal locations in the Nauset Harbor estuary were documented via a bathymetric survey conducted on November 23 and 25, 2015. The purpose of the survey was to document existing conditions and to provide information needed to plan a dredge channel layout and compute dredge volumes.

The bathymetric survey was performed by a two-person survey crew including an ACSM/THSOA certified hydrographer. The crew was equipped with a Novatel RTK Global Positioning System with 20Hz update rate and an Innerspace Model “455” survey grade digital depth sounder with a narrow beach 200 kHz transducer and 20 depth/sec update rate. The Model 455 depth sounder incorporated transducer draft corrections, calibration for speed of sound through water and gain control. Calibration was accomplished by performing “bar checks” at the beginning and end of the survey day. Water level was continuously monitored during the survey using a VP electronic tide data recorder. As back-up the water levels were also monitored via the RTK GPS system. The recorded tidal data were used to correct the depth soundings to the NAVD88 vertical datum.

Since the bathymetric survey was collected to aid in channel design for navigation purposes, corrections from NAVD88 to the mean lower low water (MLLW) tidal datum were needed to compare with controlling water depths needed for safe navigation. Typically tidal datum corrections are derived from analyses of long-term tide gage data collected at nearby locations. However, in the case of Nauset Estuary, the closest long-term tide gage stations are in Boston Harbor and Chatham Harbor (Fish Pier), and these locations are not representative of tidal nonlinearities in the estuary. A 29-day tide gage deployment at various locations in the estuary in support of the Massachusetts Estuaries Program (MEP) during the fall of 2001 was identified as the best source of water level data for developing tidal datum corrections (Howes et al., 2012). The data show that MLLW in Nauset Harbor and Town Cove is approximately equal to zero NGVD29 (Figure 6). NOAA’s VertCon program was used to determine that NGVD29 is 0.9 ft lower than NAVD88, and therefore a correction of 0.9 ft was used to convert the NAVD88 bathymetry to MLLW (ex. -5.0 ft NAVD88 depth equals -4.1 ft MLLW depth).

A color shaded map of the November 2015 bathymetric survey, with depths referenced to MLLW, is shown in Figure 7. Depths in the main channel range from -32.5 to 0.7 feet (MLLW). The shallowest areas of the channel are west of the barrier beach. A number of isolated shoals with depths less than -5.0 MLLW are located along the channel. These shoal locations correspond closely with the locations of historical shoaling shown in Figure 5.

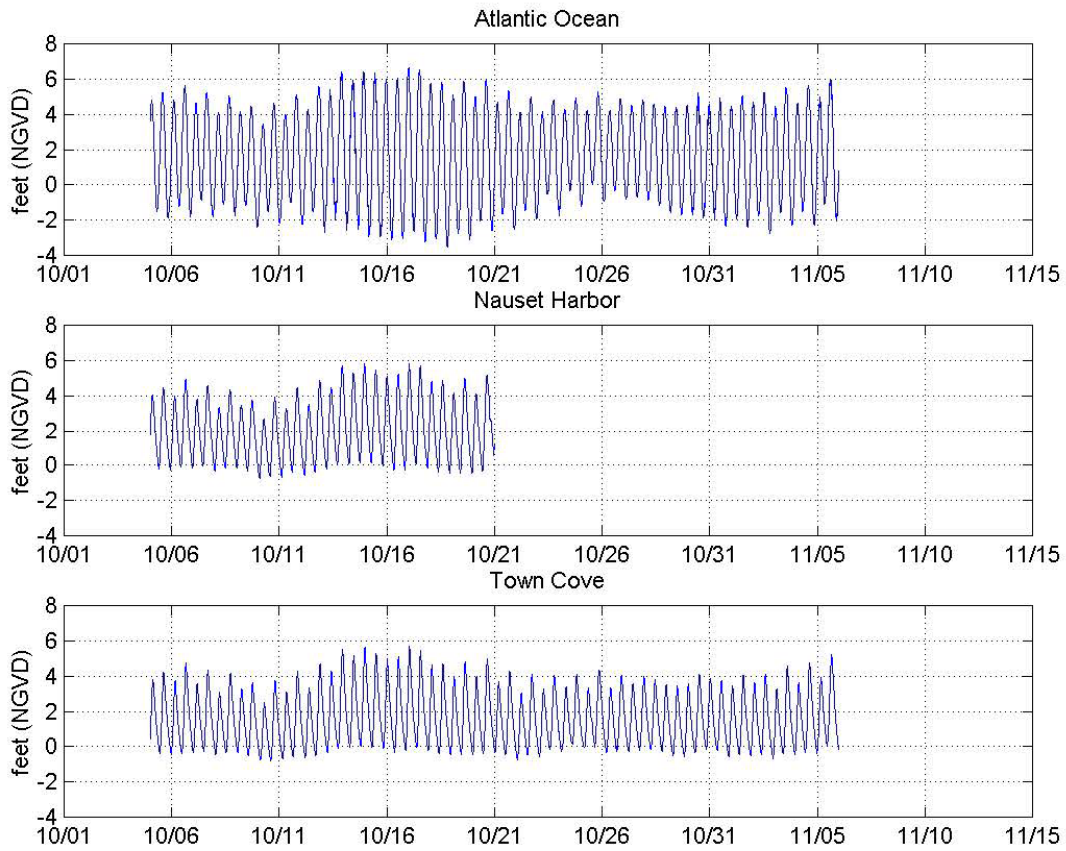


Figure 6. Water level measurements collected Nauset Estuary in support of the MEP in 2001 used to develop a tidal datum correction between NAVD88 and MLLW (Howes et al., 2012).

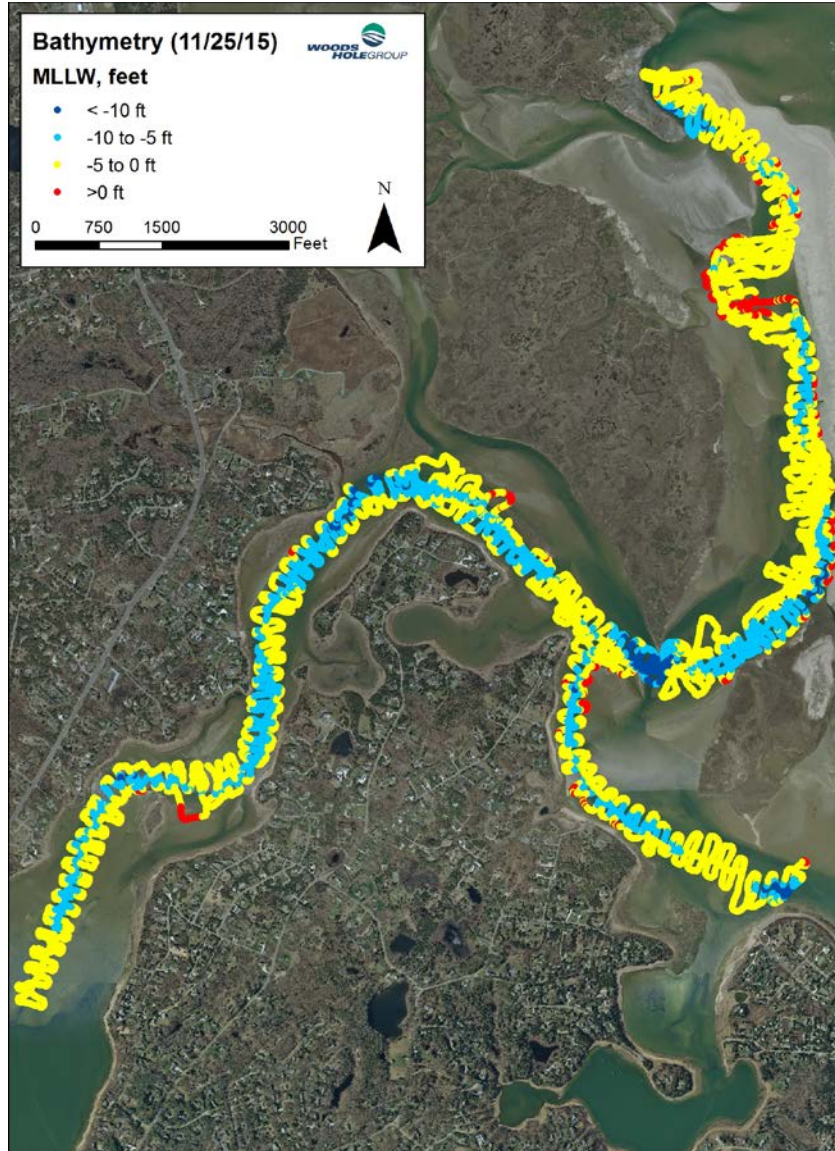


Figure 7. Color shaded map showing water depths referenced to MLLW from the November 2015 bathymetric survey.

2.3 HYDRODYNAMICS

A hydrodynamic model previously developed for Nauset Estuary was used to assess the current hydrodynamic conditions, as well as potential changes that may result from a dredging program. The Finite Volume Coastal Ocean Model (FVCOM) (Chen et al. 2003) used an unstructured grid with node spacing ranging from a minimum of less than 10 m in the estuary to 4 km on the open boundary (Fig. 8). High-resolution bathymetry was used for the model from LiDAR-derived topographic maps of Cape Cod National Seashore from the U.S. Geological Survey (USGS) (Brock et al. 2007). Bathymetry in subtidal regions too deep for LiDAR penetration was based on previous acoustic surveys and observations by investigators from the USGS (Cross et al. 2006) and Woods Hole Oceanographic Institution (WHOI) (Aubrey et al. 1997). The model was previously

evaluated against observations of water level, salinity, temperature, and velocity from moored sensors at multiple locations around the estuary (Ralston et al. 2015).

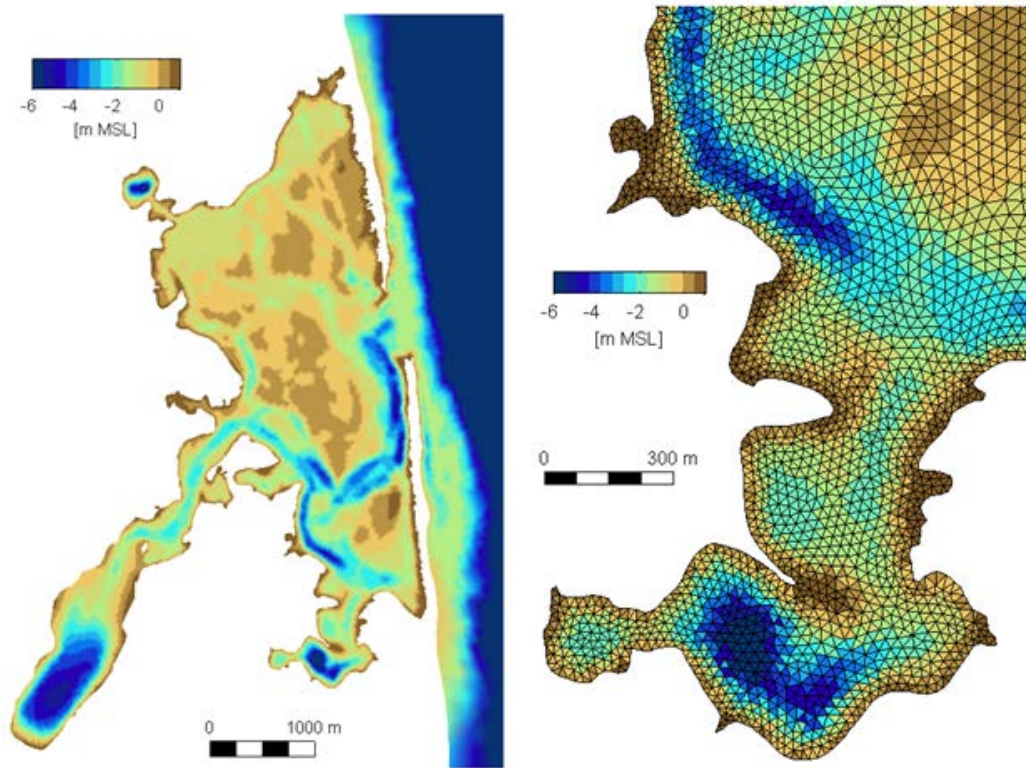


Figure 8. Model bathymetry, with a zoom on the unstructured grid configuration in the vicinity of Mill Pond. Model open boundaries (not shown) extend north, south, and offshore from the inlet approximately 15 miles in each direction.

For the current study the model grid bathymetry was updated based on data collected during the November 2015 bathymetric survey in the vicinity of the planned dredging program. Note that the 2015 configuration of the south spit is approximately 660 ft north of the previous model grid based on the inlet position in 2007. For this study no attempt was made to change the model grid to reflect the more northerly inlet location because the model was being used in a diagnostic sense to evaluate relative changes in flow patterns between the no dredge/dredge condition. Modeling shows that Nauset Estuary is a flood dominated inlet, meaning that peak incoming flood currents are stronger than peak outgoing ebb currents. Flood dominated systems tend to be sediment sinks, as more material is transported in during the flood tide than can be exported on the ebb tide.

2.4 SEDIMENTS

Sediment characteristics and distributions throughout Nauset Estuary were evaluated as part of this study to determine the quality of sediment required for dredging and to evaluate the feasibility of different placement alternatives. Two phases of sampling were conducted to help characterize the site and maximize use of available resources. The sampling methods and results are described in the following report section.

Initial confirmatory grab sampling was conducted within the planned dredge area to validate sediment characteristics documented by previous studies. The purpose of the confirmatory sampling was to gather information to identify targeted areas for subsequent vibracore sampling, with specific emphasis on identifying boundaries between sandy and fine-grained sediments. Confirmatory sediment grabs were collected at sixteen (16) sites on November 30, 2015. A Van Veen grab sampler was used to collect samples from the upper 6-12 inches of the sea floor. Sediment characterizations were conducted by a trained sedimentologist based on visual and textural observations. Results of the qualitative assessment shown in Figure 9 indicate that sediments in the main channel were mostly sand and silty sand. Samples from Town Cove and the southeast oriented channel leading to Priscilla Road Landing contained finer-grained materials characterized as sandy silt. While the confirmatory samples provided a qualitative measure of sediment characteristics at the near surface, core samples were subsequently collected to identify sediments at depth that would be more representative of the entire volume of material potentially removed via dredging.

Results of the confirmatory sediment sampling and the bathymetric survey were used to develop a plan for sediment coring at six (6) locations to quantify material that would need to be dredged from the primary shoal areas. The coring was conducted on December 10, 2015 using a shallow draft pontoon boat specially equipped with an A-frame, winch, anchoring spuds, and a vibracore unit. The coring was conducted to an approximate depth of -6.0 ft MLLW determined based on water depth, tide elevation and time of coring. The cores ranged in length from 2.7 to 6.6 ft depending on water depth at each site. Sample locations were recorded using a RTK GPS. The cores were collected in clear polycarbonate liners and transported to the Woods Hole Group office where they were split, photographed, described, and sub-sampled. The sub-samples were shipped to GeoTesting Express, Inc. in Acton, MA for grain size analyses. Results of the laboratory analyses show the sediments to be sand or silty sand (Figure 9). The only samples containing higher percentages of silt were in Town Cove and near Priscilla Road Landing where the upper 0.2 to 0.6 ft of sediment contained in excess of 30% silts and clays. The core log descriptions and photographs are provided in Appendix A and the laboratory grain size testing results are provided in Appendix B.

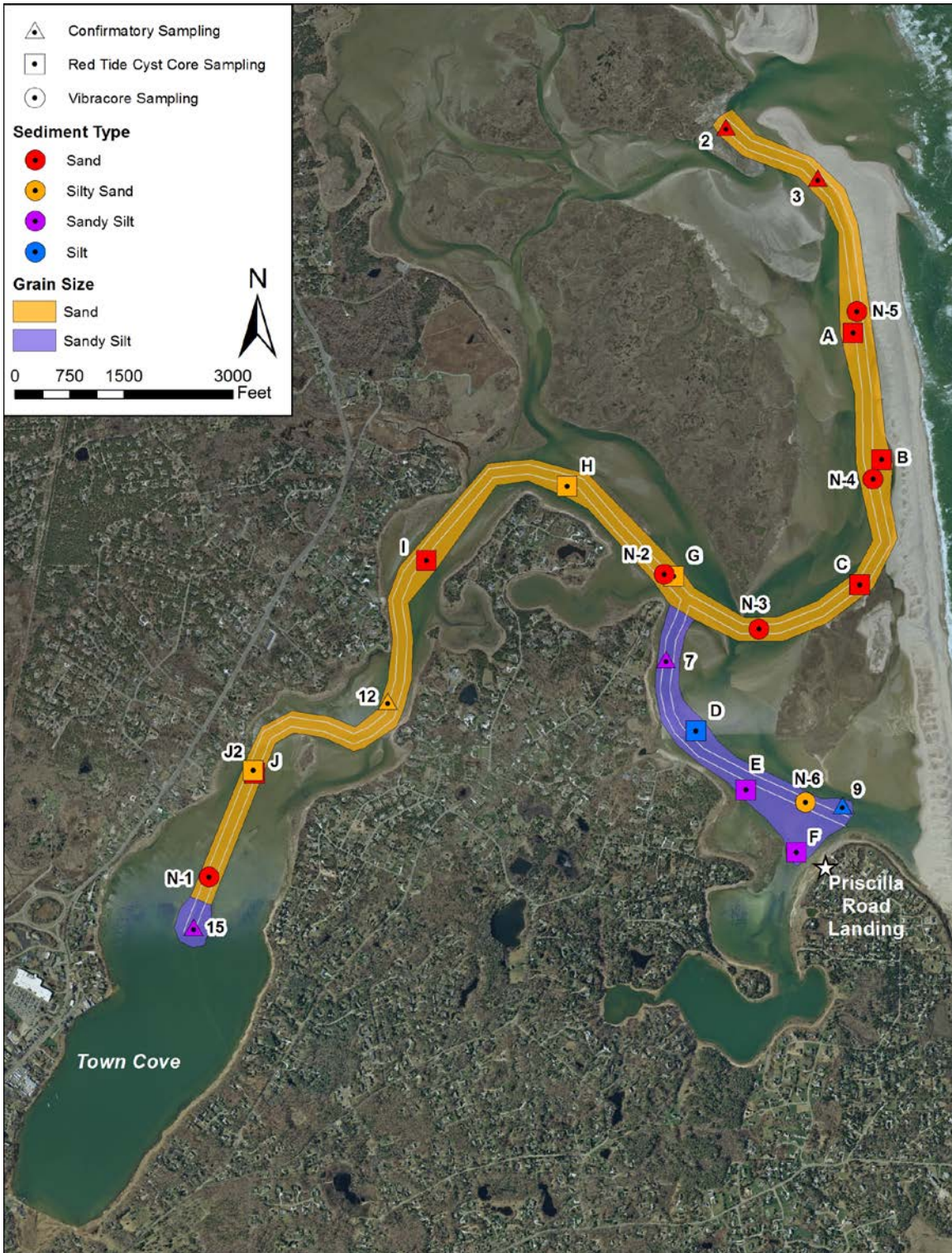


Figure 9. Sample locations and sediment characteristics from 2015 based on a combination of qualitative assessment and laboratory analyses for grain size.

2.5 ECOLOGICAL RESOURCES

SAV Resources

An eelgrass survey was performed at the same time as the confirmatory sediment sampling on November 30, 2015 (Figure 10). A video camera mounted atop the Van Veen sediment sampler was used to survey the bottom. Eelgrass surveys were conducted via passive drifting transects at approximately one foot above the seafloor. Due to decreased sunlight towards the end of the day, camera exposure caused a “washing out” effect of the image. However this did not significantly affect the ability to interpret the imagery. An example of the estuary bottom observed during the video surveys is presented in Figure 11.

Eelgrass video transects were analyzed for eelgrass presence or absence. Despite limitations in video quality, the presence of eelgrass was not observed at any of the sixteen site locations. This finding supports previous mapping efforts that have reported there was no eel grass in the study area.

An analysis of historical eelgrass data for Nauset Harbor was conducted by the Massachusetts Estuaries Project (MEP) (Howes et al. 2012). This analysis incorporated mapping done by the MassDEP Eelgrass Mapping Project, as well as aerial photographs from 1951 used to reconstruct the eelgrass distribution prior to substantial development in the Nauset Estuary watershed. At the time of the study, MassDEP’s most recent year of eelgrass mapping was 2001. The 1951 data from the aerial photograph analysis were only anecdotally validated, while the 2001 map was field validated. The goal of the MEP analysis was to determine the stability of the eelgrass community in Nauset Estuary over time. Howes et al. (2012) found that by 2001, eelgrass had nearly disappeared from the Nauset Estuary, with most of the remaining eelgrass patches located just north of Tonset Road (Figure 12). The loss was found to be consistent with the level of high nitrogen concentrations in the water and the tidal flows within the system. Nutrient enrichment is known to cause a loss of eelgrass habitat in tidally restricted basins, such as Town Cove. Such areas also tend to be the main discharge points for watershed nitrogen inputs, which further exacerbate the problem. That high nitrogen levels and reduced tidal flushing have contributed to the loss of eelgrass is further supported by the fact that the only location observed to have eelgrass in 2001 was adjacent Tonset Road where these impacts are mitigated by high tidal exchange (Howes et al. 2012).

It should be noted that subsequent sampling in Nauset Estuary by MassDEP in 2012 did not observe the presence of eelgrass. This is supported by the field surveys conducted in 2015 as part of this study, which also found no evidence of eelgrass beds.

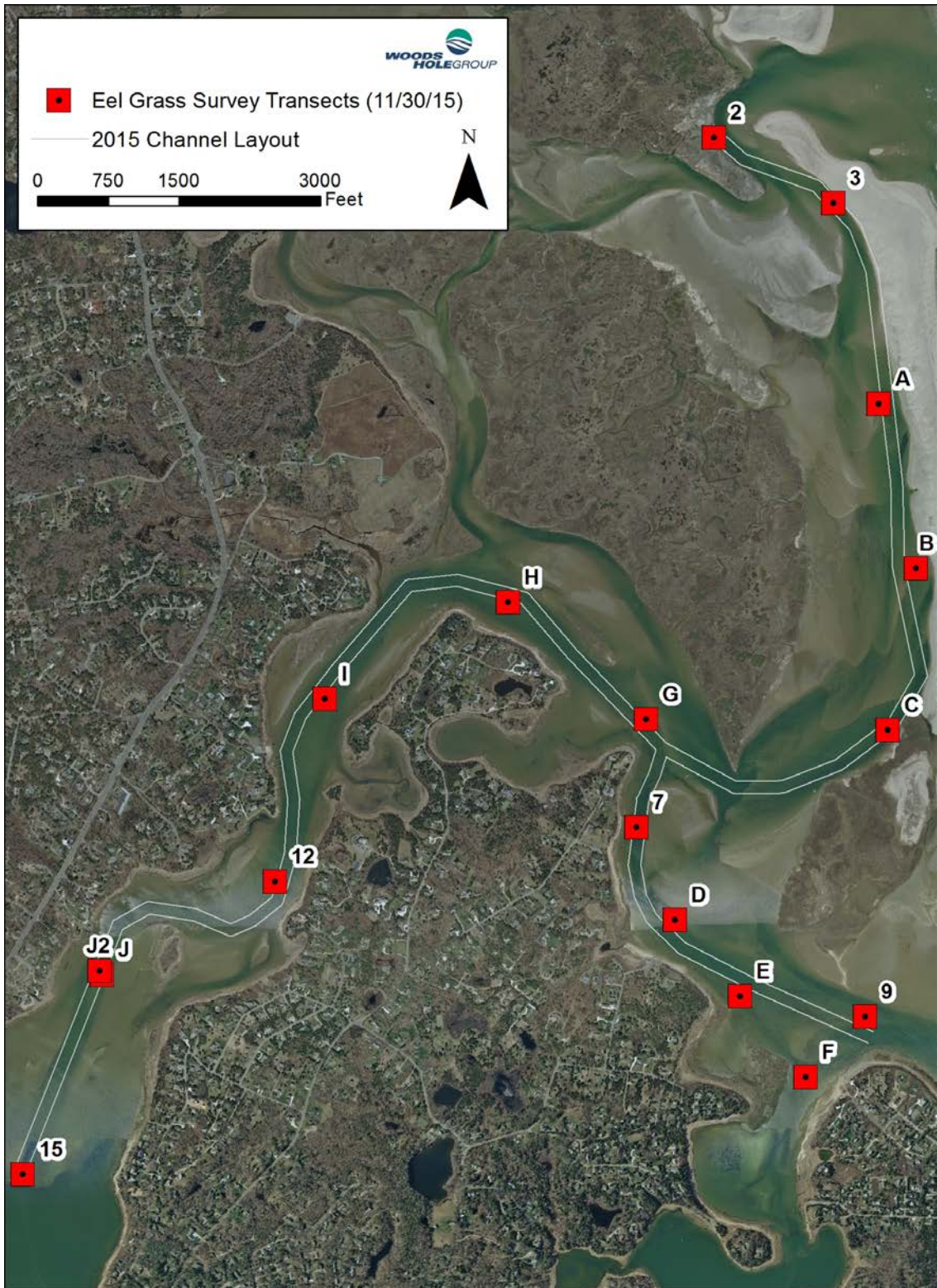


Figure 10. Eelgrass survey transect locations evaluated in November 2015.

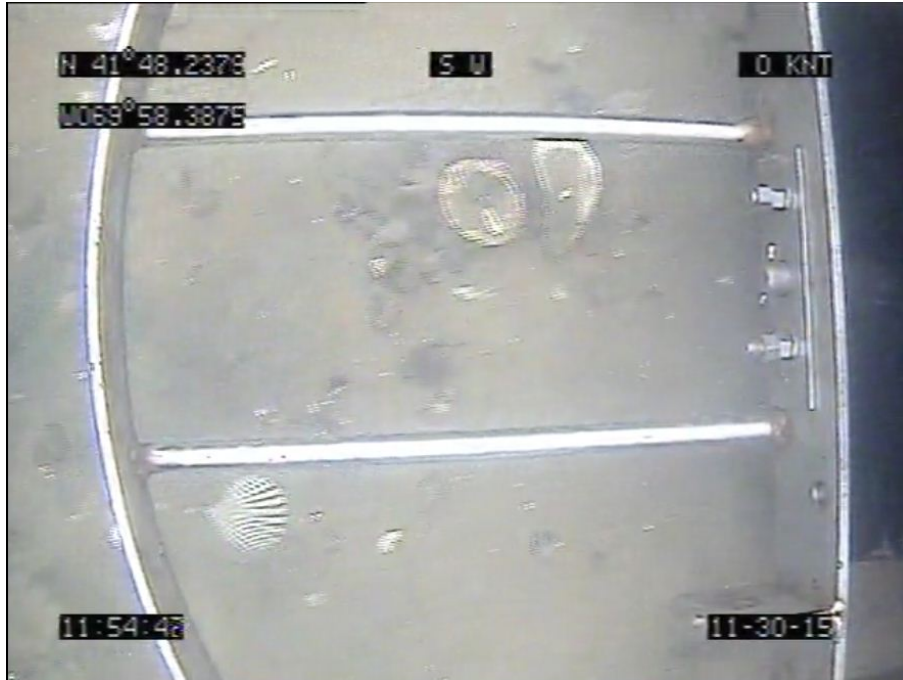


Figure 11. Example image from the November 2015 eelgrass video survey. Bottom cover was mostly sand with shell fragments.



Figure 12. Historical eelgrass mapping results from MassDEP's Eelgrass Mapping Project.

Shellfish Resources

The Massachusetts Division of Marine Fisheries (DMF) has produced a map outlining areas that are believed to be suitable for specific types of shellfish, such as blue mussel, quahog, and soft-shelled clam. These areas are delineated based on the expertise of the DMF staff, in conjunction with input from local shellfish constables, commercial fishermen, and information contained in maps and studies of shellfish in Massachusetts. These areas include places where shellfish have been observed since the 1970s, and have a habitat that is suitable to support that particular type of shellfish, but there may not be any shellfish present at this time. Therefore, these shellfish suitability maps represent *potential* habitat areas. A map of the DMF shellfish suitability areas in Nauset Estuary is shown in Figure 13.

Although no field surveys were done as part of this preliminary assessment, shellfish constables from both the Town of Orleans and the Town of Eastham were interviewed to identify current locations of important shellfish populations. In Orleans, there are high densities of quahogs along the eastern shoreline of Town Cove, north to the area of Hopkins Island. There is also a set of blue mussels that establishes around the channel near Hopkins Island each year; however, the population has not been able to survive the winter during the last few years, either getting scoured by ice or predated by eiders, but has regularly recolonized the area each year. Most recently this blue mussel set was observed on the Eastham side of the channel.

Shellfish constables from both towns noted a high density of shellfish in some of the shoals that have developed. In Orleans, there have been significant quahog, soft-shell clam, and razor clam populations recently in the sandy shoals near Priscilla Road and Snow Shore Landings. While in Eastham, soft-shell clam and surf clam have been observed in the tidal flats near Nauset Inlet. In general, both shellfish constables noted no significant populations of shellfish within the majority of the historic navigation channel.

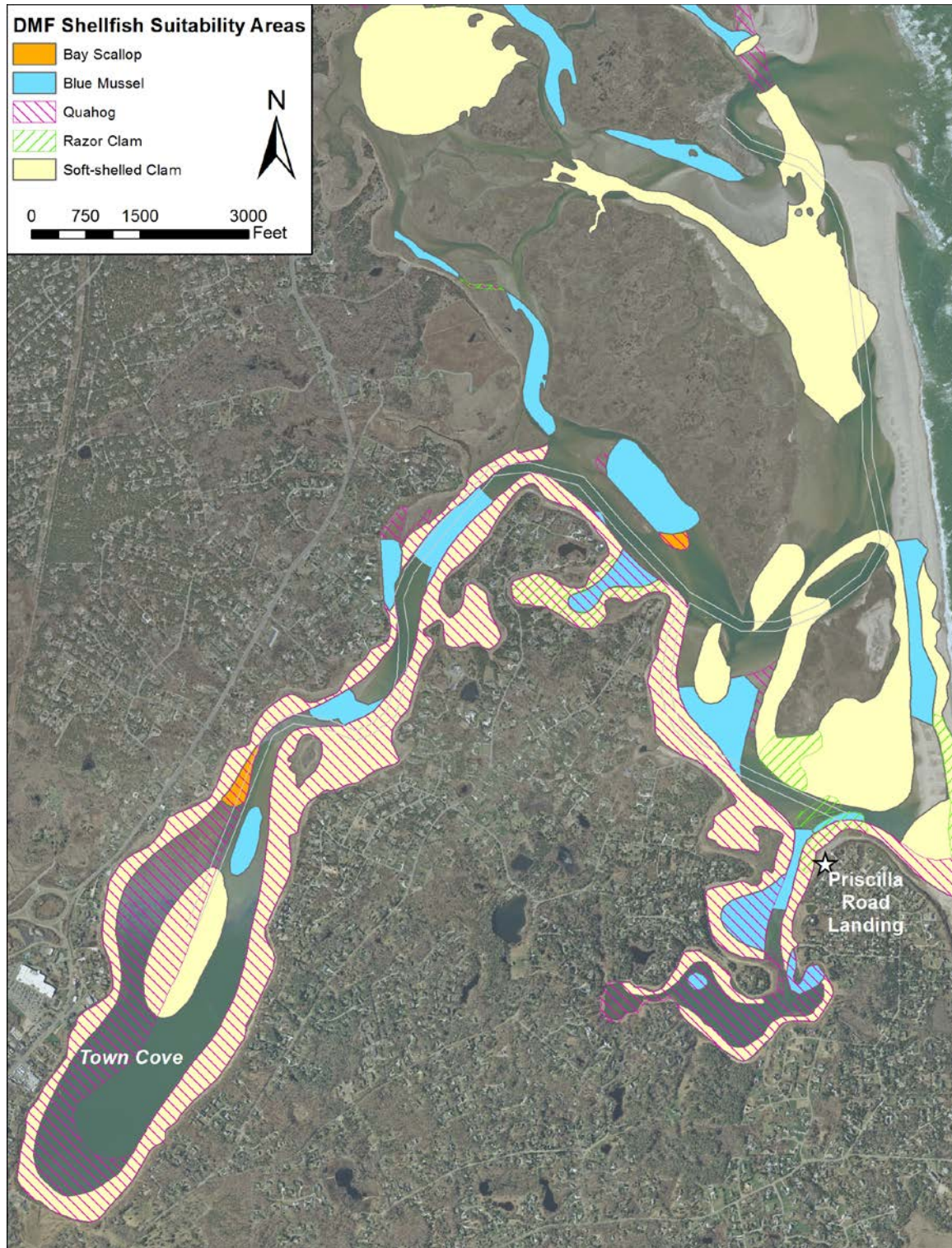


Figure 13. Mass DMF shellfish suitability map for Nauset estuary.

Endangered Species

The Estimated and Priority Habitats of rare species mapped by the Natural Heritage and Endangered Species Program (NHESP) represent the geographic extent of state-listed rare species in Massachusetts based on observations documented within the NHESP database. Estimated Habitats are a subset of the Priority Habitats, which do not include areas delineated for rare plants or wildlife with strictly upland habitat requirements. The Estimated and Priority Habitats within and around Nauset Estuary are presented in Figure 14. When a project falls within Priority Habitat and does not meet a Massachusetts Endangered Species Act (MESA) filing exemption (321 CMR 10.14), it is necessary to file directly with the NHESP pursuant to MESA. For projects within Estimated Habitats that require a Notice of Intent (NOI), a copy of the NOI must also be sent to NHESP.

While specific species driving the habitat designations shown in Figure 14 are not currently known because a MESA information request has not been submitted, other reports produced by NHESP provide some indication of which species might be present. Although, the Natural Heritage BioMap2 program serves only as a conservation tool, without any regulatory significance, and does not supplant the Estimated and Priority Habitats which do have regulatory significance, it does combine decades of documented rare species data, and can provide useful insight into species of concern that might be found in a particular area. For example, the entire ocean-side shoreline of the outer cape is identified as important nesting and foraging habitat for Piping Plovers and Least Terns, as well as an important staging area for Common and Roseate Terns (NHESP 2012). Additionally, the BioMap2 report indicates that American sea-blite is a species of concern along the eastern shore of Town Cove.

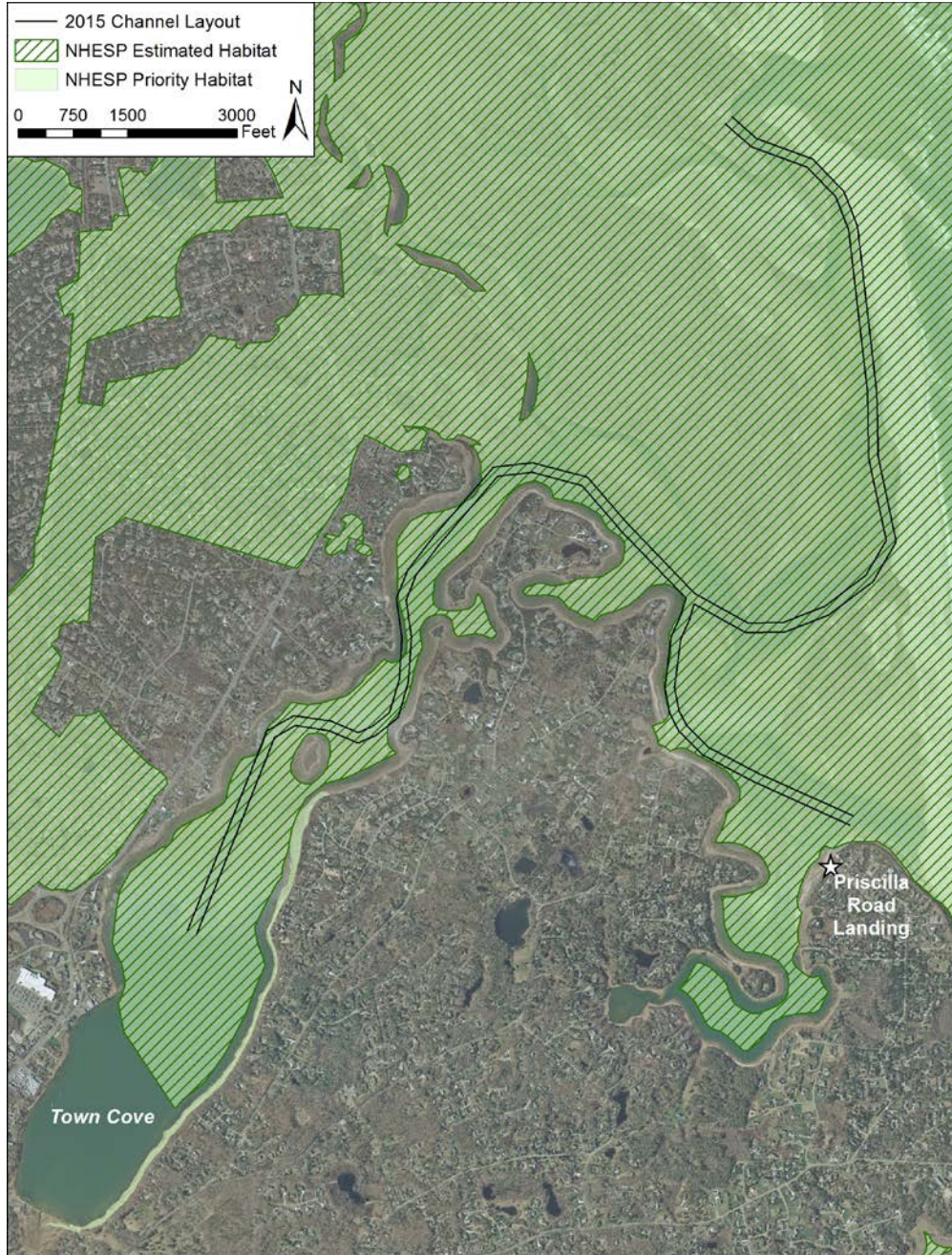


Figure 14. Natural Heritage and Endangered Species Program Estimated and Priority Habitats in Nauset Estuary.

2.6 RED TIDE

Background and past studies

Harmful algal blooms (HABs, commonly called “red tides”) are a serious economic and public health problem throughout the world. In the U.S., the most serious and widespread manifestation is paralytic shellfish poisoning (PSP), a syndrome caused by human ingestion of shellfish that accumulate toxins from dinoflagellates, predominantly in the genus *Alexandrium*.

In many parts of the world, PSP is a recurrent and serious problem associated with blooms of toxic dinoflagellates in the genus *Alexandrium*. The potent neurotoxins produced by these organisms are accumulated by filter-feeding shellfish and other grazers and are passed on to humans and other animals at higher trophic levels, leading to illness, incapacitation, and even death. *Alexandrium* species cause toxicity in many different hydrographic and climatic regimes, from temperate to tropical. One reason for growth success across such a variety of habitats is that many species have a cyst stage in their life histories. This allows the organism to remain dormant in bottom sediments through temperature extremes (e.g., winter), with seasonal germination inoculating vegetative cells into the water column only during intervals where temperature and light are suitable for growth (Anderson et al., 2012). Population development is thus possible in more locations than would otherwise be the case if year-round persistence in the water column were the only means for survival.

There are two types of *Alexandrium* blooms in the New England region, both caused by the species *A. fundyense* (hereafter referred to simply as *Alexandrium*). One occurs along the open coast of the Gulf of Maine from the Bay of Fundy to Massachusetts and outer Cape Cod, and on rare occasions, this distribution stretches to the islands of Nantucket and Martha’s Vineyard and occasionally, to Rhode Island (i.e., Anderson et al., 2005a; Anderson et al., 2005b; Borkman et al. 2014). Blooms in the coastal region of the Gulf of Maine can stretch over hundreds of miles and last for several months.

The second type of *Alexandrium* bloom in the region is much smaller in scale and is representative of the blooms that occur in the Nauset Estuary system. *Alexandrium* blooms occur, but those episodes are sporadic and highly independent of each other or of the large-scale coastal blooms described above. Instead, isolated and localized blooms occur in those areas, with very tight linkage in time and space to cyst populations in bottom sediments of the areas where toxicity occurs. These locations can be viewed as self-seeding “point sources”, in that *Alexandrium* populations originate within the embayments or estuaries, with no input of cells from coastal waters, and they deposit cysts after those blooms, to “seed” future blooms. These “localized” or “point source” blooms have been well studied by D. M. Anderson and colleagues (e.g., Anderson et al. 1983; Anderson and Stolzenbach 1985; Crespo et al. 2011; Ralston et al. 2013, 2015; Brosnahan et al. 2014).

The distribution of the *Alexandrium* blooms within Nauset Estuary is not uniform. It has been well established that the hot spots of toxicity occur at the three distal end points of the system - namely Salt Pond, Town Cove, and Mill Pond (collectively termed salt

ponds hereafter). Although the central marsh does occasionally show dangerous levels of toxicity, the highest and earliest levels are always recorded within these salt ponds, with the toxicity in the central marsh delivered there from the localized blooms. In all cases, the salt ponds have deeper central portions (kettle holes), with water exchange with the central marsh limited by shallow, restricted inlet channels. Figure 15 shows the distribution of cysts in Nauset Estuary in 2008, 2009, and 2011. Figure 16 shows a time series of *Alexandrium* cell abundance between March and May 2009. Clearly, there is a strong linkage between the location of the cyst accumulations and the origins of the Nauset blooms, with cells first appearing in Mill Pond, then Town Cove and Salt Pond, with low abundances observed in the central marsh, and no connectivity between the three salt ponds.

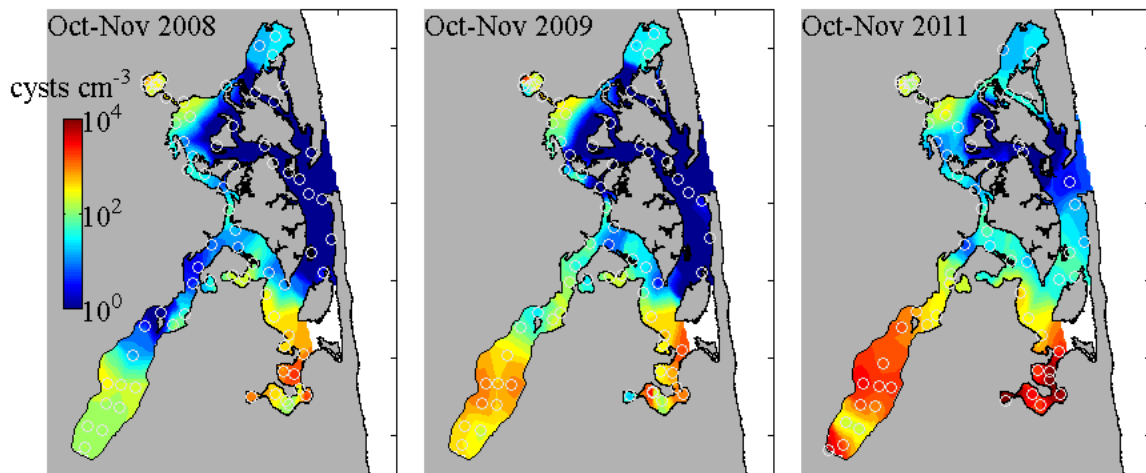


Figure 15. Contour maps of Nauset Estuary mean *A. fundyense* cyst concentrations (cysts/cm³) in: (left) 2008, (center) 2009, and (right) 2011. Gray circles indicate sample sites (From Ralston et al., 2015).

There are two reasons why these three locations are persistent hot spots for *Alexandrium* and toxicity. The first is that they are accumulation zones for the cysts of *Alexandrium* because of their bathymetry and hydrography. As flood tide-dominated systems, Salt Pond, Mill Pond, and Town Cove accumulate fine sediments year after year, and cysts behave like that fine sediment fraction. Cysts that are formed within the central marsh tend to be disbursed with other fine sedimentary material, much of which ultimately accumulates in kettle holes like the salt ponds and the areas that have silted in near their inlets. The bulk of the *Alexandrium* cysts formed within Nauset Estuary are thus retained within the salt ponds.

The second mechanism that leads to the hotspots results from a combination of the bathymetry and configuration of the salt ponds and the behavior of *Alexandrium*. *Alexandrium* swims vertically in the water column, seeking the appropriate amount of sunlight for photosynthesis in surface waters, while also swimming downward to access nutrients that are often found in deeper waters. This is termed diel vertical migration. *Alexandrium*, however, does not swim to the very surface of the water, but instead finds

suitable sunlight 1.5 - 2.5 meters deep (Anderson and Stolzenbach 1985). This means that the top of the vertical ambit of *Alexandrium* tends to be below the depth of the shallow inlet channel. Thus the water that leaves the salt ponds on ebb tides contains few cells compared to those retained within the ponds. The population is thus retained within the ponds, dividing and accumulating, and reaching dangerous levels of toxicity. For example, Salt Pond has had closures due to toxin levels above quarantine action limits in 23 of the past 26 years. Similar numbers hold for Mill Pond and Town Cove.

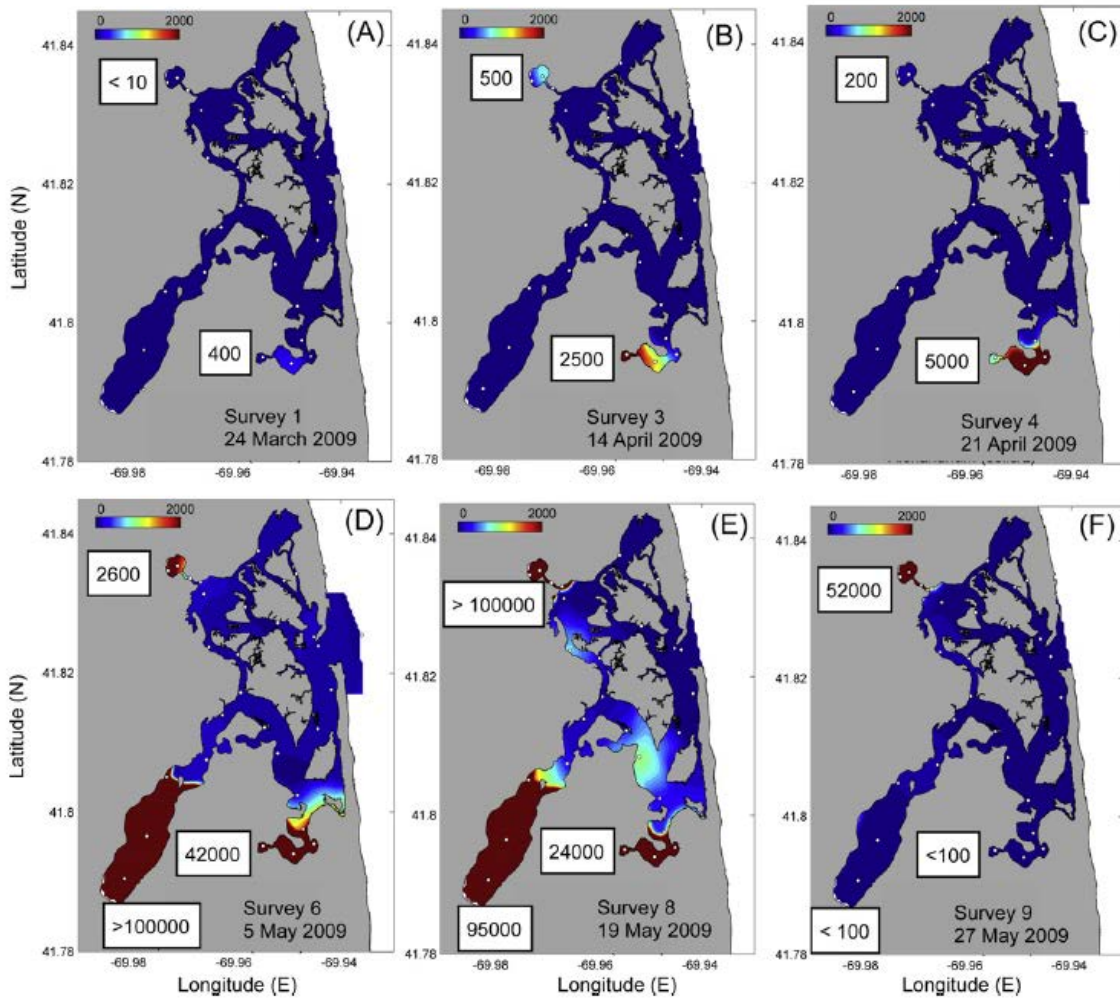


Figure 16. Distribution of Nauset Estuary *A. fundyense* cells (cells L⁻¹) between March 24 and May 27, 2009. Maximum number of cells for Mill Pond, Town Cove and Salt Pond indicated in the white squares. White dots indicate sample sites (From Crespo et al., 2011).

Another important feature of the *Alexandrium* bloom dynamics is that the cysts in bottom sediments do not just sit at the surface of those sediments. Bioturbation (i.e. mixing by worms and other bottom-dwelling animals) as well as physical mixing from storms and

currents can bury the cysts. It is common to find more cysts a few centimeters below the surface than there are at the surface, as shown in a core profile taken in Roberts Cove, immediately adjacent to Mill Pond (Figure 17). However, dinoflagellate cysts require oxygen for germination (Anderson et al. 1987), and typically oxygen is only found in the top centimeter or less of bottom sediments. This means that cysts that are buried below that layer typically do not germinate and participate in the bloom formation in the spring. Instead, they remain dormant and either eventually die, or are mixed to the sediment surface or the water column by storms, bioturbation, or other disturbances. There are reports that *Alexandrium* cysts can live in anoxic sediments for decades (Keafer et al. 1992); there are even reports of successful cyst germination that were over 100 years old (Ribeiro et al. 2011). Clearly, activities that might resuspend deep cyst deposits (i.e., dredging) have the potential to introduce cysts that otherwise would not have germinated, into conditions that would be favorable for germination.

One important conclusion from Figure 17 and from many other cyst profiles in sediment cores is that in Nauset Estuary, *Alexandrium* cysts are quite low in abundance below 10 cm (D. M. Anderson, unpub. data). For this reason, the cyst abundance in the top 0-10 cm layer is most important when considering the impacts of dredging operations.

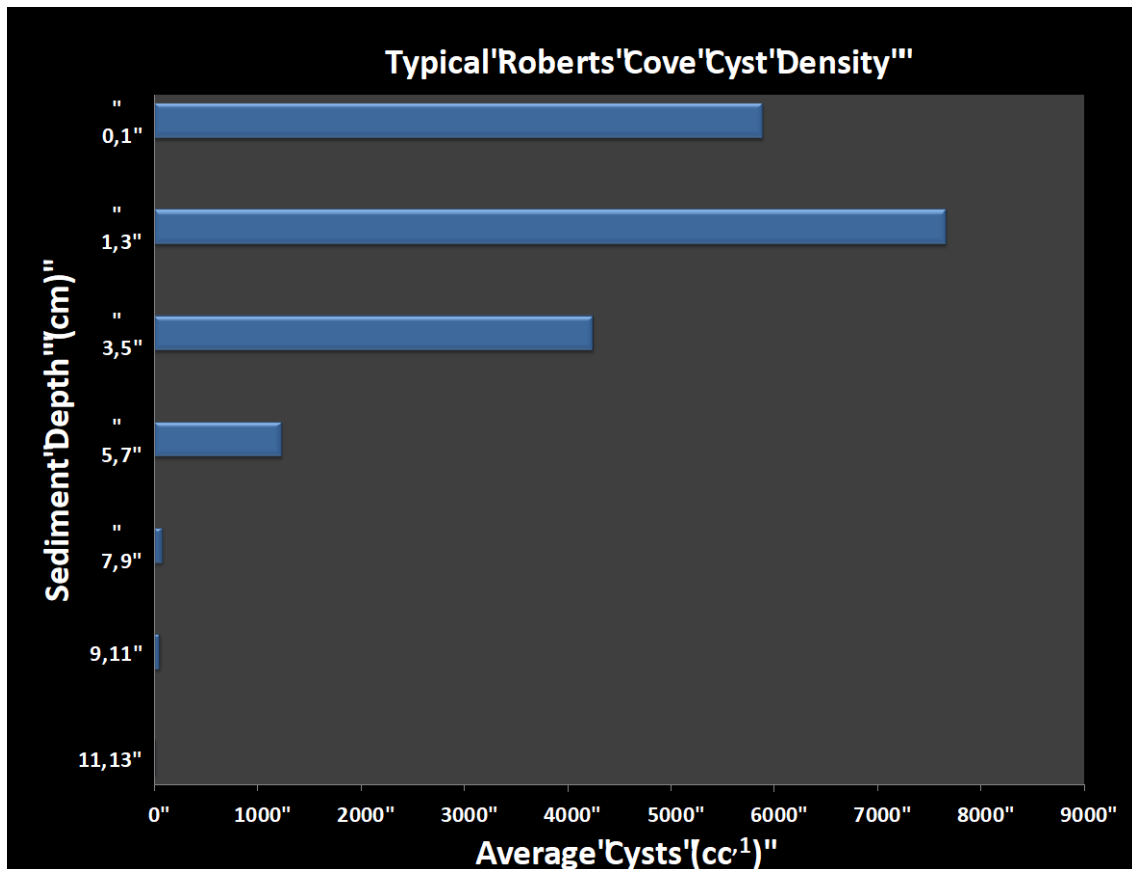


Figure 17. Vertical profile of *Alexandrium* cyst abundance (cysts/cm³) from Roberts Cove in the Nauset Estuary.

It is also important to recognize other factors that regulate the timing and extent of *Alexandrium* cyst germination. Foremost among these is seasonality in germination that is internally controlled by a “clock” mechanism. The timing or phasing of this “endogenous clock” is in turn regulated by temperature. It is a complicated process that is still under active investigation, but for the purpose of this discussion, suffice it to say that most newly formed cysts that are deposited in the summer or fall from *Alexandrium* blooms typically cannot germinate during the early winter because of a combination of maturation processes and clock regulation. Germination is typically possible beginning in January or early February, but the rate of that germination is controlled by ambient temperatures. In very cold winters, germination is delayed until waters reach 4-6 °C. At those temperatures, the cysts can germinate, but the *Alexandrium* vegetative cells that are produced grow very slowly, if at all, again because of non-optimal temperatures. An indication of the growth potential of *A. fundyense* from Roberts Cove is described in a study by Watras et al. (1982). In general, a temperature range for survival and growth between 5.5 and 24 °C was observed. There was no growth at 5.5 °C, but the cells did not die. At 8.5 °C, the rate ranged from 0.08 to 0.2/day depending on salinity. The maximum growth rate was 0.44/day, at 22.5 °C. A broad optimum for growth occurred between 13 and 22.5 °C.

Interestingly, *Alexandrium* cells also do not germinate or grow when it becomes too warm (Anderson 1998). Typical summer temperatures of 23-28 °C are inhibitory in this regard.

Some useful information is presented in Figure 18, which shows multiple blooms of *Alexandrium* in Roberts Cove from 2009 to 2015, as well as the bottom temperature, and the rate of cyst germination at ambient temperatures. Bloom initiation tends to vary interannually, with the earliest cells seen in February, but more often, March. Peak motile cell concentrations occur in April and May, and the blooms terminate in late May and early June. Anomalous years like 2012 (yellow curve in Figure 18) show a shifted bloom dynamic, but otherwise the same general shape.

The middle panel of Figure 18 shows the germination success of cysts at ambient temperatures. This would be analogous to the situation if sediments containing cysts were resuspended or dumped into the oxygenated surface waters during a dredging operation. The pattern indicates that germination does occur in the fall and early winter, but is generally near zero in January and February, increasing thereafter. Note that the lack of germination in the mid- and late-summer months (June – September) is due to newly deposited cysts being immature at the time of the incubation. Cysts that were mature but buried in anoxic sediment layers would be expected to germinate at those times.

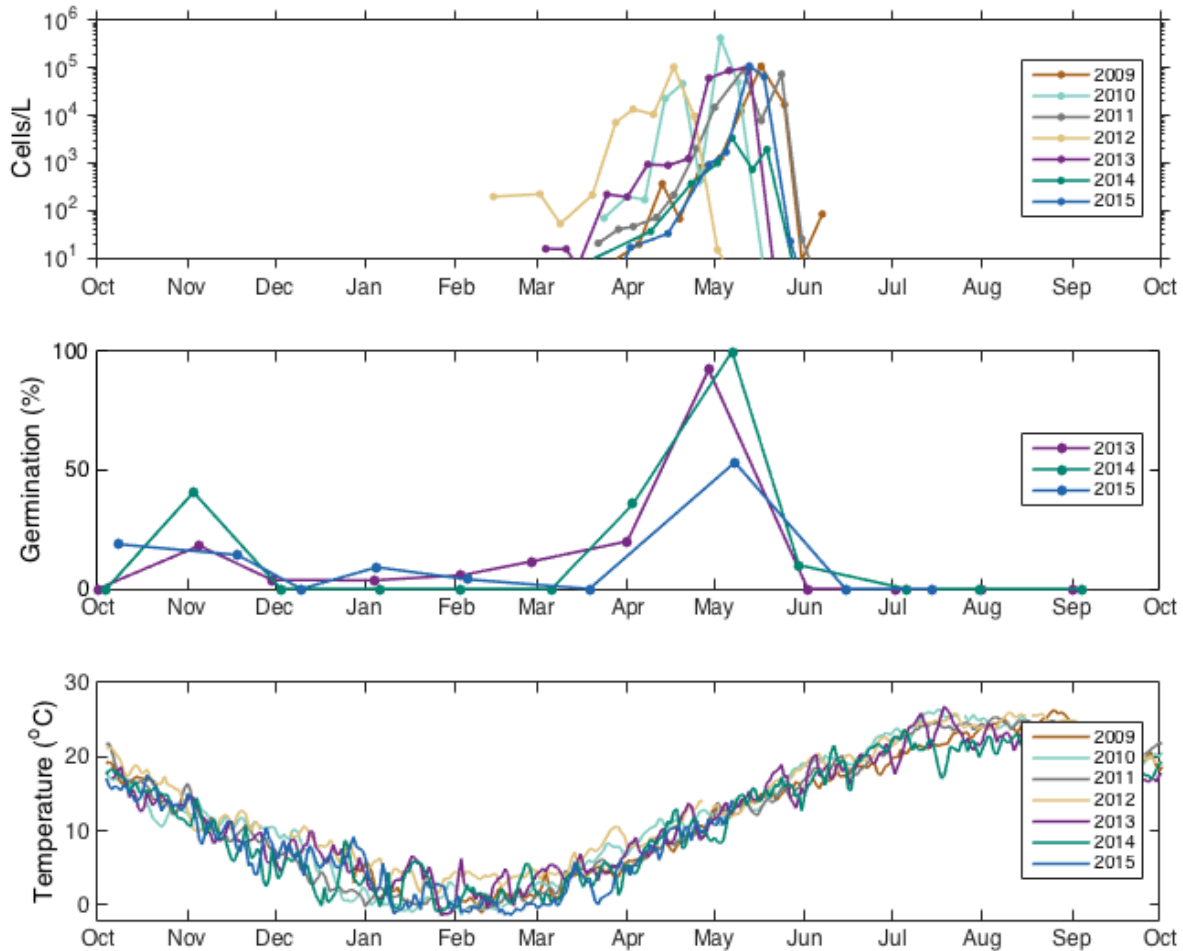


Figure 18. *Alexandrium* motile cell and cyst dynamics from Roberts Cove in Nauset Estuary. Top panel: *A. fundyense* cell abundance by month. Middle panel: Cyst germination success in surface sediment samples collected and incubated at the ambient water temperature. Bottom panel: temperature (°C). (From A. Fischer, unpub. data).

2015 red tide cyst assessment

To evaluate current red tide conditions in Nauset Estuary sediment cores were collected at 10 sites on December 10, 2015 for analysis of red tide cysts (Figure 19). The sample locations were planned to coincide with previous red tide cyst analyses conducted by others. A push-core sampling device equipped with a 2 5/8 inch inner diameter clear polycarbonate barrel was used to collect the cores. To ensure sufficient retrieval depth, the cores were pushed to a penetration depth of 1.5 feet. A piston assembly inside the core barrel was used to create suction, thereby preventing excessive compaction during core barrel penetration, and loss of sediment from the bottom of the barrel during recovery. This method provided an undisturbed sediment core of at least 10 cm in length. Upon collection, the cores were packed in ice and stored at 4 °C in the dark for a maximum of 36 hours prior to processing using standard techniques (Anderson et al., 1982, 2005a).

In brief, the cores were extruded such that the 0-1 cm sediment layer was carefully retained, and the 1–10 cm layer was collected into a plastic basin and completely homogenized by hand. From each layer, a well-mixed 5 cm³ wet volume sediment subsample was taken and resuspended to 25 mL with filtered seawater. A 10 mL subsample of the 25 mL sediment slurry was sonified using a Branson Sonifier 250 affixed with a 1.25 cm disruptor horn at a constant 40-W output for 1 min, and sieved to yield a clean, 20–80µm size fraction (Anderson et al., 2005).

Alexandrium fundyense cysts were counted in a 1-ml Sedgewick Rafter slide according to standard methods for cyst identification and enumeration (Anderson et al., 2003) using primulin to stain the cysts (Yamaguchi et al., 1995). For this, 10 mL of processed sediment was preserved by the addition of 0.75 mL, 100% ACS grade formalin and returned to 4 °C for at least 60 min. This sample was then centrifuged for 10 min at 3000xg, the overlying water aspirated, and the sediment pellet was resuspended in 10 mL ACS grade methanol and stored at 4 °C for at least 48 h. The sample was centrifuged and aspirated as before, and resuspended in 10 mL Milli-Q water. Following centrifugation and aspiration, 2 mL of primuline stain (2 mg mL⁻¹) was added. The sample was incubated in the dark at 4 °C on a rotating mixer, centrifuged and aspirated, and washed with 10 mL Milli-Q water, centrifuged and aspirated again, and the stained sediment pellet was brought up to 3 to 14 mL with Milli-Q water depending on the volume of the stained sediment pellet. A one mL subsample was enumerated using a Zeiss Imager microscope at 100X total magnification under blue light epifluorescence (Chroma filter set 19002, Chroma Corp, Bellows Falls, VT).

Table 1 shows the results of the sediment coring and cyst analysis, and Figure 19 shows the location of the samples and the distribution of cyst abundance. Cyst concentrations ranged from 0 (central marsh sites) to values as high as 2,446 cysts/cm³ in the top cm of sediment. The latter site was near Mill Pond and Roberts Cove. Other high values were also in the areas closest to the mouths of the salt ponds. Concentrations in the 1-10 cm fraction were generally much lower than the surface counts at each station, except at station F near Roberts Cove, where 2,941 cysts/cm³ was measured. Note that these values represent the average cyst abundance over that 9 cm layer.

These 2015 cyst samples were collected and analyzed to allow comparisons between the limited number of samples collected now, and those collected in more extensive, marsh-wide system surveys in 2008, 2009 (Crespo et al., 2011) and 2011 (Ralston et al. 2015). Figure 20 compares cyst abundance at sampling sites from 2008, 2009, 2011, and 2015. It is immediately apparent that the general distribution of *Alexandrium* cysts in the area to be dredged has not changed over these years, and it is also clear that cyst abundance has a similar range to that measured in other years. This is an important observation, and the main justification for taking the samples, as it demonstrates that cyst abundance and distribution within the estuary are generally similar among years. Since the dredging program, if found feasible by the Town, will likely be several years from now, there is confidence that these measurements, and those in the recent past, are a realistic representation of the situation at the time the dredging may eventually occur.

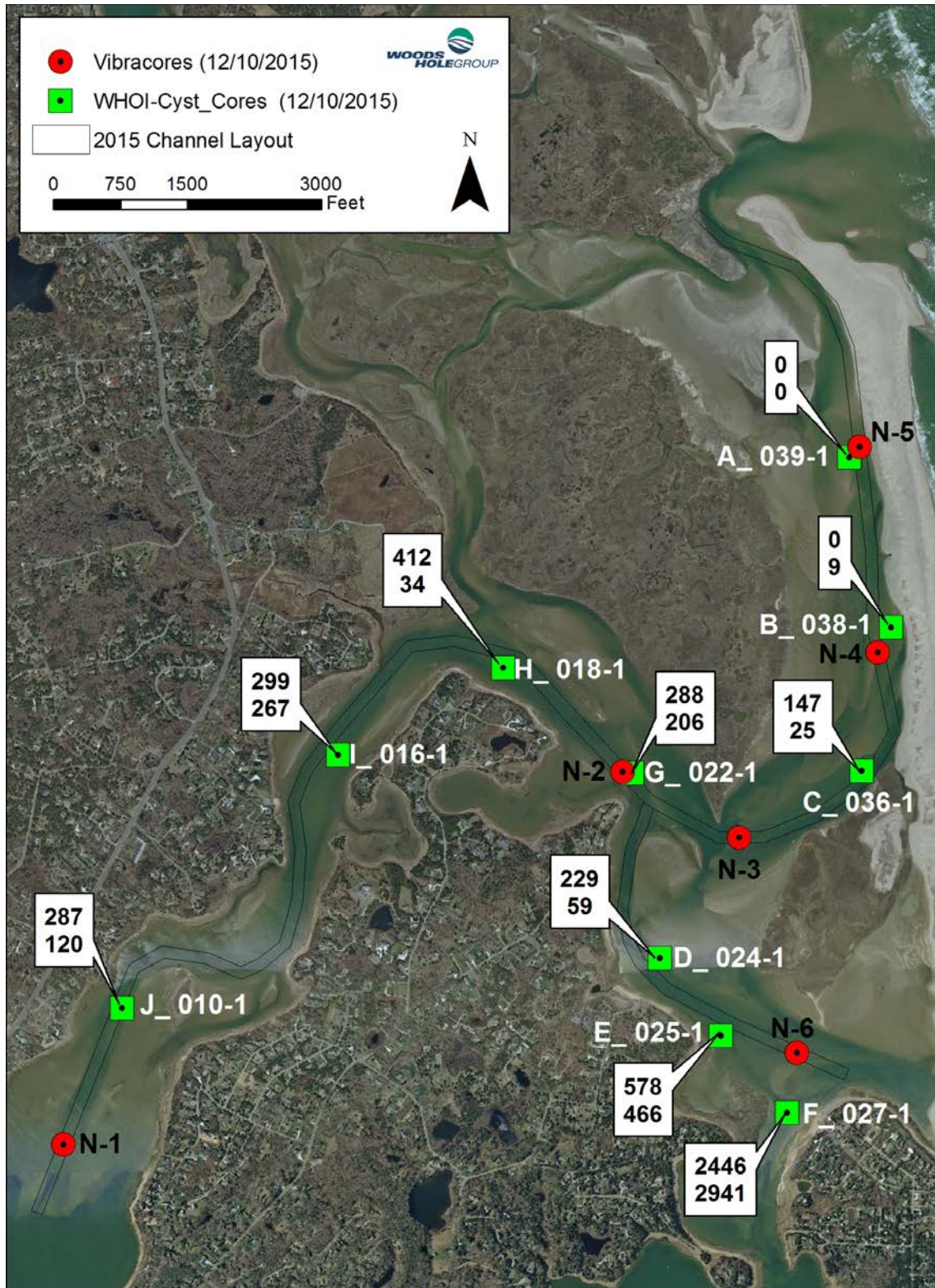


Figure 19. Map showing cyst coring locations and cyst counts. White boxes near each station show the *Alexandrium* cyst abundances (cysts/cm³) in the top cm (top line) and 1-10 cm layer (bottom line).

Table 1. Summary of 2015 red tide cyst sampling and analysis.

Core ID	Latitude	Longitude	Core Recovery (ft)	Collection Date & Time	0-1 cm <i>Alexandrium</i> cysts/cm ³	1-10 cm <i>Alexandrium</i> cysts/cm ³	Sediment Type (visual)
A_039-1	41°49.256	69°56.544	1	12/10/15 11:30	0	0	Sandy
B_038-1	41°48.876	69°56.504	0.4	12/10/15 11:05	0	9	Course sand
C_036-1	41°48.657	69°56.556	1.2	12/10/15 12:22	147	25	Light sand to dark black
D_024-1	41°48.32	69°57.059	0.8	12/10/15 12:51	229	59	Dark silt
E_025-1	41°48.175	69°56.911	1	12/10/15 13:04	578	466	Mud
F_027-1	41°48.031	69°56.756	0.9	12/10/15 13:40	2446	2941	Light sandy silt
G_022-1	41°48.668	69°57.143	1.2	12/10/15 10:21	288	206	Sandy silt
H_018-1	41°48.86	69°57.437	0.8	12/10/15 14:07	412	34	Dark silt
I_016-1	41°48.709	69°57.841	0.8	12/10/15 14:22	299	267	Sandy silt
J_010-1	41°48.247	69°58.384	0.9	12/10/15 14:40	287	120	Sandy silt

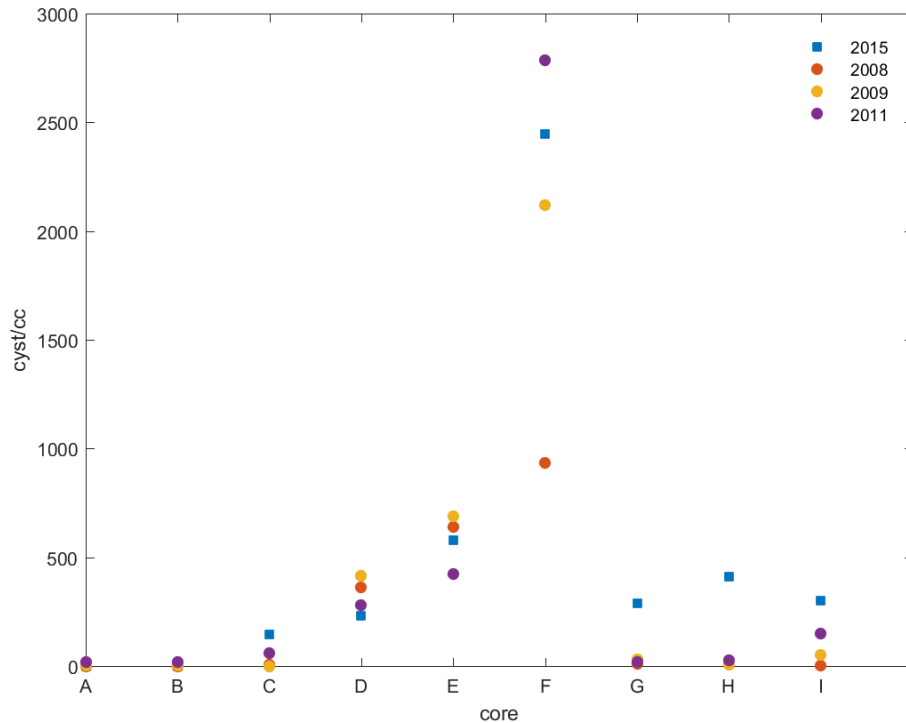


Figure 20. Comparison of cyst abundance at the 2015 core locations with data from previous cyst surveys in 2008, 2009, and 2011.

Red tide cysts in dredged sediments

Observed sediment cyst concentrations and information on the Town’s conceptual dredging plan were used to estimate the abundance of red tide cysts in the dredge sediment. The FVCOM model grid bathymetry was used as the basis for the calculations. Cyst concentrations observed at the sample locations were interpolated to the model grid using an inverse-distance weighting approach. The near-surface (0-1 cm) cyst concentrations were used for the spatial distribution. To augment the 10 stations sampled in November 2015, additional near-surface samples (0-1 cm) from the most recent cyst survey of the full estuary during Nov 2011 were utilized (Figure 15). The approach is reasonable given the strong similarities in spatial distributions of cyst abundance across the multiple years of surveys, including those from November 2015 (Figure 20).

The total volume of dredged sediment was calculated by comparing the model grid for the 2015 bathymetry with the grid representing the dredged channel. The amount of material to be removed during the dredging was calculated to be about 73,000 cubic yards, similar to the volume calculated from the bathymetric surveys. The cysts associated with the dredged material were assumed to decrease linearly from the near-surface abundance mapped to the model grid to 0 cysts at 10 cm depth, and equal to 0 in any material below 10 cm. Cyst abundances typically decrease rapidly in the bed over depths of about 10 cm (Figure 17).

Assuming that the cyst concentrations decrease linearly from the surface concentration to 0 at 10 cm depth, and that there are no cysts below 10 cm, the total number of cysts to be removed during dredging was calculated to be 2.2×10^{12} . Dividing that by the dredge volume, an average of concentration in the dredged material of 40 cysts/cm³ was determined.

2.7 PAST DREDGING ACTIVITIES

Information on past dredging activities in Nauset Estuary was obtained from the Massachusetts Department of Environmental Protection (DEP) and the Division of Conservation and Recreation (DCR). A total of four (4) permits were identified with issue dates between 1924 and 1974. Table 2 provides a summary of the relevant permit information and Figure 21 shows the locations of the specific activities.

Table 2. Historical permits for Nauset Estuary dredging and associated placement.

Permittee	Permitted Activities	Permit/License No.	Issue Date
Mass DPW/ Waterways	Dredging at 3 sites with placement at 4 in-harbor sites	Contract No. 97	May 24, 1924
Town of Orleans	Maintain bulkhead, piers, dredged & fill	License No. 6256	Aug. 1, 1974
Goose Hummock Shop	Maintain bulkhead, piers, dredge & fill	License No. 5853	Dec. 22, 1971
Esther & Melville Richardson	Dredge & fill	License No. 4844	Jul. 28, 1964

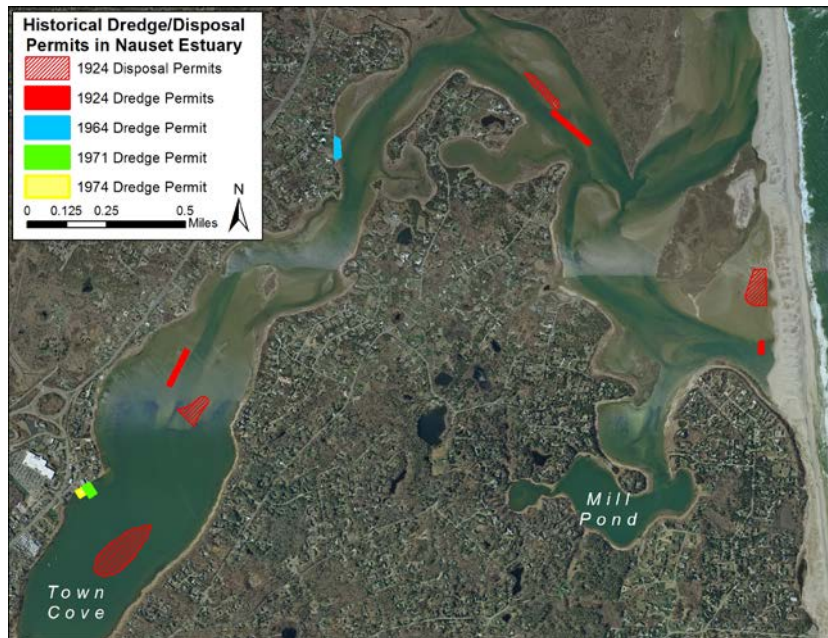


Figure 21. Historical dredging and disposal activities in Nauset Estuary.

3.0 DREDGE AND DISPOSAL PLAN FORMULATION

3.1 TOWN DREDGE CONCEPTUAL PLAN

The Town of Orleans is investigating the feasibility of a dredging program in Nauset Estuary that would improve navigation and public safety. Current shoaling in the channel makes access to the Town landings difficult and dangerous during certain tides. The conceptual channel layout, seen in Figure 1, would facilitate safe passage for navigation not only through the inlet and behind the barrier beach, but also to the key Town landings, such as Priscilla Road, Snow Shore Road, Tonset Road, Asa's Landing, Goose Hummock, and Cove Road, as well as other locations in Town Cove.

To accommodate local boating needs, the Town is investigating a channel design that is 100 feet wide at the base, with 1V:3H side slopes extending an additional 15 feet on each side. The main stem of the dredge channel would extend just over 4 miles from Nauset inlet to Town Cove. A secondary channel, approximately 4,500 feet long would extend south from the main channel towards Robert's Cove, to provide access to Tonset Road, Snow Shore Road and Priscilla Road Landings. The channel would be dredged to a depth of -5 ft at MLLW.

3.2 DREDGE ZONE LAYOUT

The conceptual layout takes advantage of the existing channel and will require significant sediment removal in only a few locations. Figure 5 shows the existing shoals, according to the 2015 bathymetric survey. The major shoal locations are near the inlet and behind the barrier beach, at the first bend in the channel to the south of Nauset Marsh, and towards the upstream end of the channel in Town Cove. However, due to the dynamic nature of the shifting inlet and the resulting change in currents, the exact locations of these shoals changes from year to year. Consequently, the specific areas that need to be dredged today may be different than the areas that need to be dredged a year from now. Given the current bathymetry an estimated total of 80,600 cubic yards of material would need to be removed from the channel to meet the conceptual design described in Section 3.1 (Figure 22). This includes approximately 68,000 cubic yards from the main channel and approximately 12,600 cubic yards from the southern channel.

Due to the dynamic nature of the estuary, the Town is considering an adaptive management approach that would permit a larger dredge zone, rather than a specific channel. This zone is wider than the specific channel layout, and allows flexibility in the future for choosing the optimum dredge route along the deepest part of the natural channel to minimize the volume of dredge material. As part of this feasibility study, a potential dredge zone was developed for Nauset Estuary based on historical variations in the natural channel (Figure 22). At minimum the dredge zone is 300 feet wide near the entrance to Town Cove, and increases to nearly 1,500 feet wide near the inlet. In total, the dredge zone covers approximately 390 acres. However, despite the much larger size of this zone, any particular dredge project would be limited to a 100-foot wide channel within that zone. The total area of dredging in the main channel would not exceed 66 acres and the total area in the channel leading to Priscilla Road Landing would not exceed 13.2 acres. This adaptive management approach would allow the Town to select

a slightly different path for the dredged channel in order to capitalize on the existing channel thalweg, and to minimize costs by removing as little sediment as required.



Figure 22. Extent of dredge zone and 2015 channel layout.

3.3 POTENTIAL ALTERNATIVES FOR PLACEMENT

As with all dredge projects, one of the major factors in determining a project's feasibility is where to place the dredged material. Where material can be placed is driven by a number of factors, including distance from the dredging site, characteristics of the sediment being dredged, natural resources, such as eelgrass, shellfish, and salt marsh, feasibility/need to dewater the material, and ownership/size of the potential disposal site(s).

These factors were used as a guide to evaluate the range of possible placement alternatives for the Nauset Estuary dredge program. Unfortunately, the dense residential development, the paucity of shorefront public-owned parcels, and the close proximity to the Cape Cod National Seashore (CCNS) limited the available options for placement. Five potential placement sites/alternatives were identified; however, two of the alternatives are considered experimental due to the need to collect additional information regarding impacts, suitability, and regulatory review. Descriptions of the placement options are provided in the following section.

Dune restoration at Nauset Beach

Use of Nauset Beach as a dredged material placement site would be optimal for the Town, since the beach is currently experiencing significant erosion and the resilience of the site could be enhanced through dune restoration. In fact, in a study recently completed for the Town by Woods Hole Group (2016), a plan of phased retreat for Nauset Beach that included dune enhancement was recommended to protect valuable resources and extend the lifetime of the public beach. Beneficial reuse of sediment dredged from Nauset Estuary for dune enhancement at the public beach would result in a significant cost savings for the Town as the plan of phased retreat for Nauset Beach is implemented.

The most efficient method to use this site would be to contract with the Barnstable County dredge and hydraulically pump the sediment from the estuary directly to Nauset Beach. Because the beach is approximately one mile to the closest part of the estuary, it would be necessary to incorporate use of a booster pump to transport the material. The maximum pump distance for the County dredge with a booster pump is 11,000 ft. This distance would allow portions of Nauset estuary to be hydraulically dredged and the material directly pumped to Nauset Beach, but the ends of the dredge project near the inlet and towards Town Cove would still be too far (Figure 23). Dredge volume estimates from this section of the channel that could be pumped to Nauset Beach are approximately 45,100 cubic yards (channel area 1 in left panel of Figure 23).

It is estimated that Nauset Beach could hold approximately 80,000 cubic yards, and would likely be available for reuse as a placement site within 5 to 10 years if the estuary required maintenance dredging. A preliminary compatibility assessment indicates that the Nauset Estuary sediments have a median grain size between 0.2 and 0.6 mm (fine to coarse sand) and would therefore be suitable for use as dune enhancement at Nauset Beach.

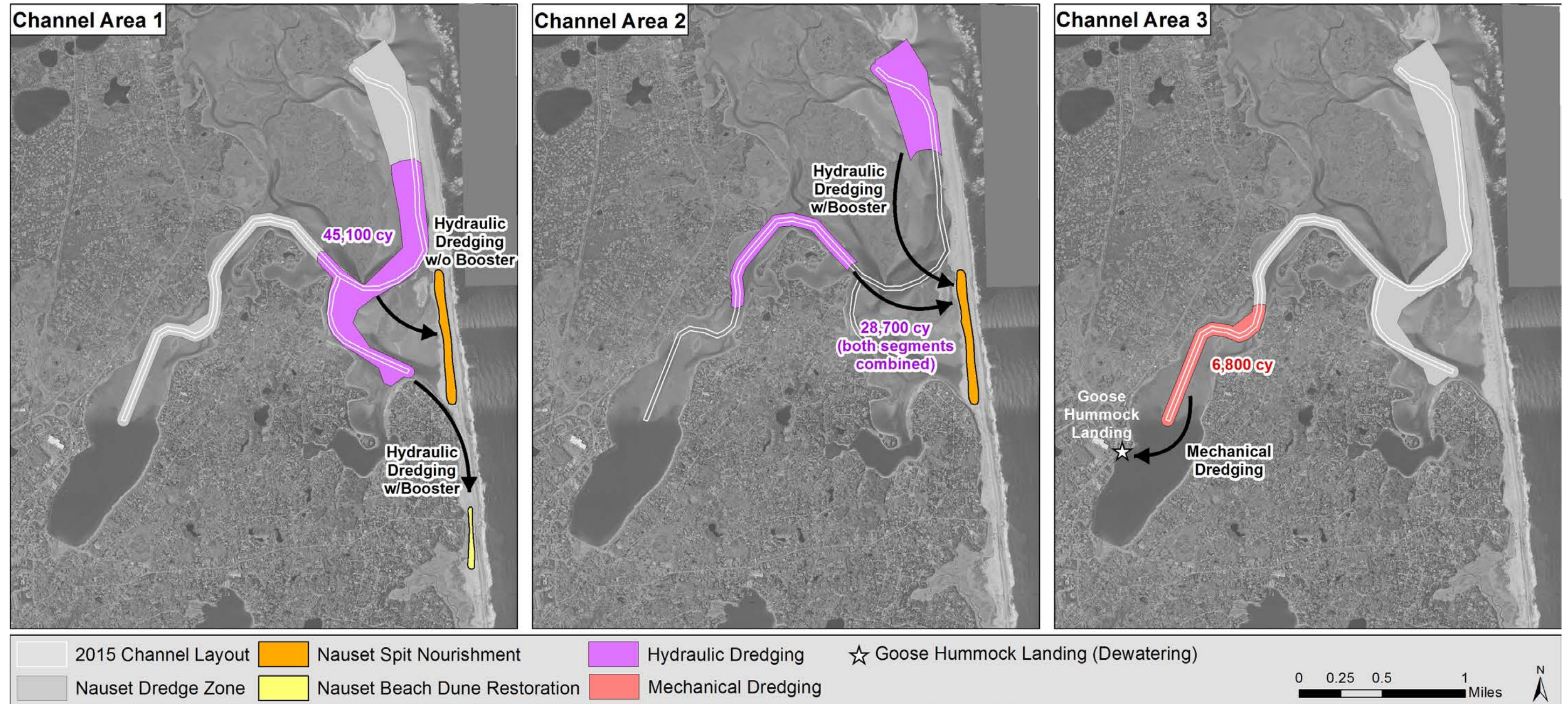


Figure 23. Dredging and placement options for Nauset Estuary.

Dune enhancement along Nauset Spit

The Town-owned portion of Nauset Spit could also be used as a placement site, and could accommodate material acquired through hydraulic dredging. Because of its proximity to the estuary, a good portion of the channel could actually be dredged and the material transported to Nauset Spit without a booster. The left panel of Figure 23 shows approximately 45,100 cubic yards from channel area 1 could be placed on Nauset Spit without the use of a booster pump. With the notable exception of the last mile of channel leading to Town Cove, the remaining portions of the channel would be within reach of Nauset Spit using a hydraulic cutterhead dredge equipped with a booster pump. Approximately 28,700 cubic yards of sand from channel area 2 could be used to enhance Nauset Spit if a booster pump is utilized (channel area 2 in center panel of Figure 23).

Capacity of this site is estimated at more than 100,000 cubic yards, and the site would likely be available for reuse as a placement site within 5 to 10 years. As with the Nauset Beach site, the dredged sediments would be compatible with existing material at Nauset Spit.

Upland/coastal beneficial reuse

There is also the option to beneficially reuse the dredged material at an upland site, or at a site farther away than a hydraulic dredge can pump the material. This option would likely require mechanical dredging with temporary storage, dewatering, and trucking of the dredged material. However, because there is very little upland open space around the estuary, options for dewatering locations are limited. This method is less efficient than hydraulic dredging and would only be recommended for the furthest upstream portion of the channel leading to Town Cove, where even hydraulic methods with the Barnstable County dredge are not feasible. This section of the channel currently requires dredging of approximately 6,800 cubic yards (channel area 3 in right panel of Figure 23).

One potential shorefront staging area in Town Cove is Goose Hummock Landing (Figure 23). In this scenario the material would be mechanically dredged and transported via small barge to Goose Hummock Landing. The sediment would be partially or totally dewatered in the barge (depending on the grain size), and then off loaded at the public bulkhead where it would be temporarily stored for further dewatering (if necessary) and then trucked to a pre-selected beneficial reuse site.

Subaqueous placement

An interesting option that might be considered is to spread sandy dredge material over the surface of the salt ponds, thereby burying the *Alexandrium* cysts that are present in these areas. Calculations performed as part of this study suggest that the dredged sediments will contain very few *Alexandrium* cysts (see Section 4.2 below). If a layer only a few cm thick were dispersed in this manner, and if this were done in the late winter, just before the time when the cysts begin germinating, the inoculum for that year's bloom could be substantially reduced. Not only will sediments quickly become anoxic below

the sand layer, inhibiting germination, but the sand grains would make it very difficult for any germinated cells to successfully swim to the overlying water column.

This placement alternative would accommodate only a small fraction of the dredged material and should be considered experimental at this point. Further discussion with the stakeholders and regulatory officials would be required to evaluate the methods, sites, and potential benefits.

Marsh restoration

A second interesting option for beneficial reuse of dredged material would be to place the sediment in a thin layer over portions of the salt marsh to allow the marsh to keep pace with rising sea levels. This too should be considered experimental, since further data would be needed investigate response of the Nauset Estuary marshes to sea-level rise to see if the alternative is warranted. Additional discussions with the CCNS would be required since the large marsh areas in the estuary are owned by the National Park Service (NPS). The enacting legislation for the CCNS appears to prohibit this type of activity on the salt marsh; however, similar projects under consideration elsewhere may help to demonstrate important benefits of this approach that may allow its use.

4.0 PROJECT FEASIBILITY

The feasibility of establishing a dredging program in Nauset Estuary is described in the following sections in terms of potential environmental impacts, engineering constraints, regulatory requirements, and construction costs.

4.1 ENVIRONMENTAL FEASIBILITY

A dredging program in Nauset Estuary has the potential to have both positive and negative impacts. If the Town decides to pursue the project further it will be necessary to conduct more in-depth environmental impact analyses than were achievable with resources available for this study. However, data and tools developed for this project were used to the extent possible to evaluate potential impacts of the project.

Impacts on hydrodynamics

The FVCOM model described on Section 2.3 was used to evaluate potential changes to the estuary hydrodynamics caused by the dredge plan. The model grid was updated to reflect the 100 ft wide channel dredged to a depth of -5 ft MLLW (Figure 24). To allow comparison with previously validated model results, the model simulations were forced with conditions corresponding to a previous observational period in April 2011.

One of the more notable differences between model simulations with the current 2015 bathymetry and the proposed dredged channel was an increase in tidal amplitude. As the channel has shoaled in recent years and the inlet location has migrated to the north, the channel has become shallower and longer, and therefore more frictional. The added bottom friction causes a reduction in the amplitude of the tide propagating into the estuary from the ocean. Measured water level data from moorings deployed in Town Cove at various times since spring 2009 demonstrate that the tidal amplitude has been

decreasing as the channel has lengthened and the friction increased (Figure 25). The data show a 20% decrease in tidal amplitude over the 5 year period of observation. A similar decrease in water level was observed in measurements from Salt Pond.

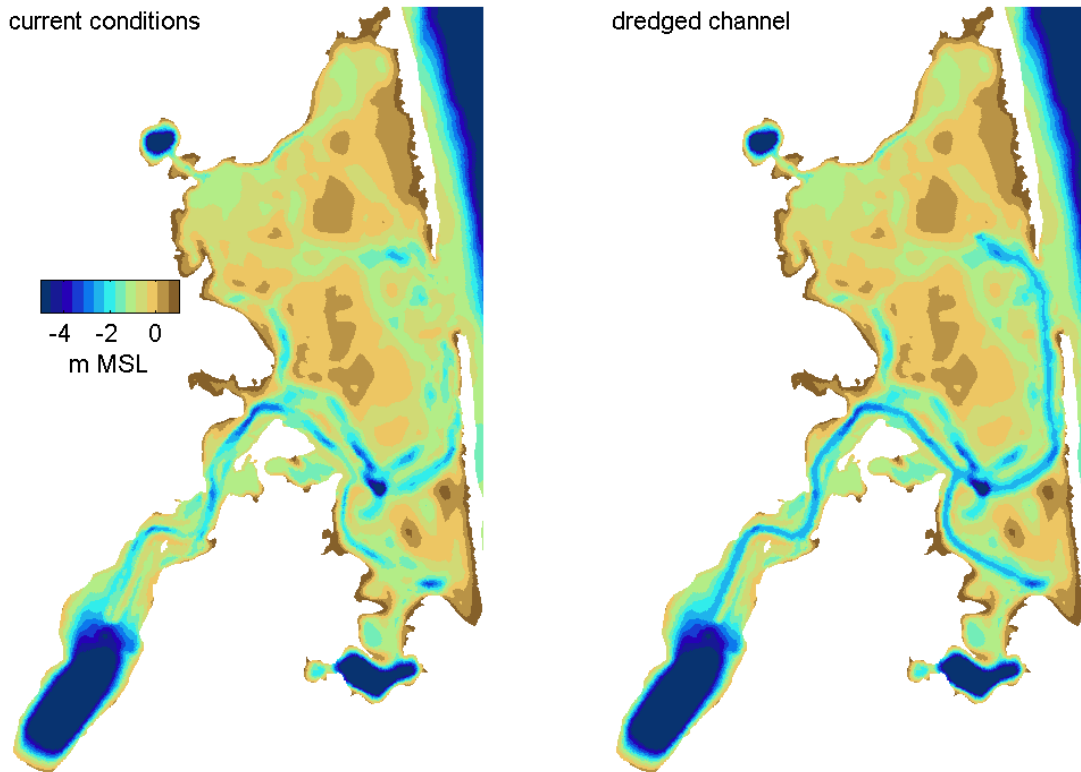


Figure 24. Model bathymetry based on (left) 2015 bathymetric soundings, and (right) channel dredged to -5 feet MLLW.

Model simulations are generally consistent with the observed trends. For example, simulations with the current 2015 bathymetry have a lower tidal amplitude in Town Cove (and the other ponds) than the previous model simulations based on bathymetry surveys through 2009 (Figure 25). In the model, the effect of dredging is to make the tidal flow less frictional, increasing conveyance into the ponds and increasing the tidal amplitude. Therefore, expected effects of the dredging are to restore tidal amplitude to values similar to the model results using the older bathymetry and the observations from 2009-2011.

In the model, tidal velocities and bottom stresses increase modestly in the vicinity of the proposed dredging (Figure 26). The changes in bottom stress, which are important for determining sediment transport, are due both to the increase in water depth and the increase in tidal amplitude. The estuary remains strongly flood dominant, continuing to favor sediment import and accretion. Bed stresses with the proposed dredging are greater in the current configuration only in a few locations, which likely correspond with regions that are currently depositional. In general, the dredging project is not expected to result in increased shoreline erosion within the estuary as the system is expected to return to conditions that existed previously. Longer term, shifts in tidal amplitude, bottom stress,

and sediment transport depend as much on inlet position and dynamics as on the channel depth.

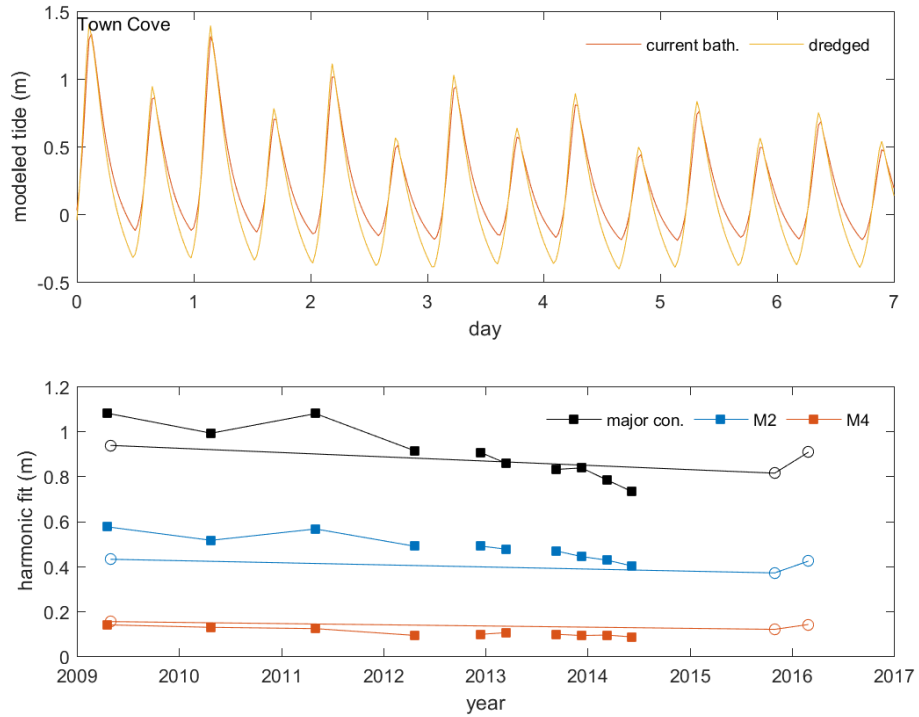


Figure 25. Modeled and observed tidal amplitudes in Town Cove. (top) Modeled water level using 2015 bathymetry vs. the dredge configuration. (bottom) Tidal harmonics based on observations (filled squares) and model results (open circles). Model results are based on simulations using bathymetry from 2009, 2015, and the dredged channel.

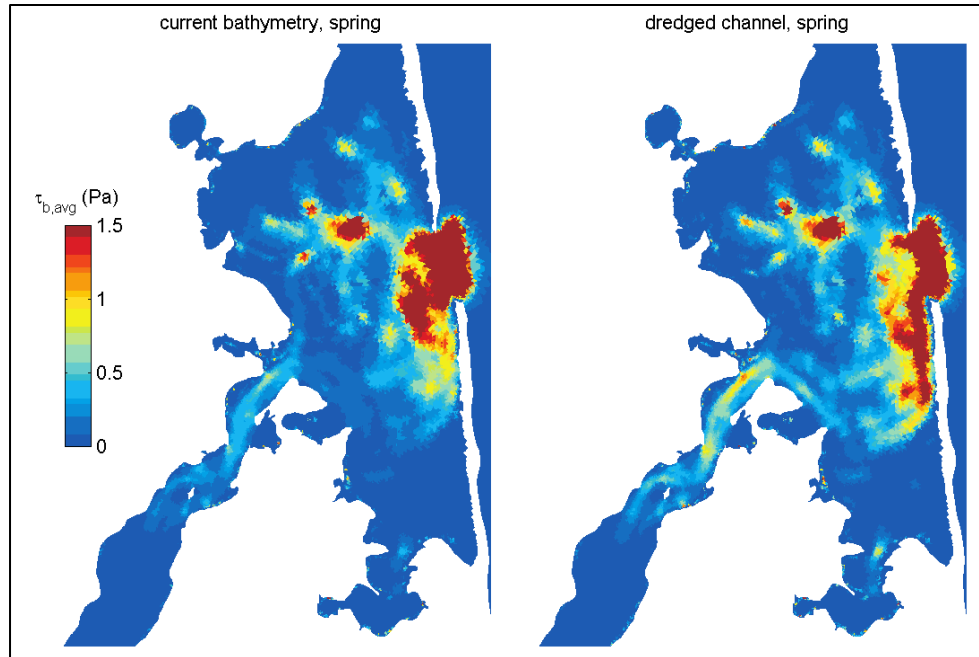


Figure 26. Modeled bottom stresses (average over 2 days) for the current bathymetry (left) and bathymetry with the proposed channel (right).

Impacts on distribution of red tide cysts

There are several ways that the dredging might alter the dynamics and distributions of *Alexandrium* blooms within Nauset Estuary. One is that the mechanical or hydraulic dredging operations will resuspend sediments that contain *Alexandrium* cysts, redistributing those cysts within the marsh, and, depending on the timing of the dredging, provide conditions that are suitable for germination. The latter concern can be eliminated by dredging between December and February when the cysts are generally incapable of germination.

The redistribution of cysts is also not a major concern based on the following reasoning. The estuary is strongly flood dominant and retentive, so resuspended sediment and cysts will likely deposit within the estuary, either on the marsh platform or in regions of lower velocity like shoals at the channel edges or in the salt ponds. It is, however, not possible to estimate the total number of cysts that will be resuspended during dredging, as this will not be constant across the marsh due to variable cyst abundances and sediment types in the areas to be dredged. Previous coring data have shown that cysts are most concentrated in the top few cm of the bed, and that concentrations decrease rapidly within about 10 cm from the surface. The dredging depth would generally be much deeper than 10 cm, and thus the cysts in the surface layer will be mixed and diluted with the deeper bed material. The calculation described in Section 2.6 estimated an average of 40 cyst/cm³ in the dredged material, and it is reasonable to assume that the sediment and cysts released to the environment during dredging will have a similar average concentration. Resuspension experiments in test plots in Roberts Cove found that cysts settled at rates similar to silt-sized sediment (Anderson and Ralston, unpublished data), so the cysts and silt can be expected to be transported in the estuary similarly. Silt is most commonly

found in the lower energy regions of the system, including the salt ponds and shallow side embayments, and in these regions the background cyst concentrations range from several hundred to several thousand cysts/cm³. The addition of newly remobilized material with an average concentration of around 40 cyst/cm³ would not increase the cyst abundance at the bed surface in these depositional areas, nor would it be expected to increase the magnitude of *Alexandrium* blooms.

Alternatively, the total number of cysts in the dredge material is estimated to be 2.2×10^{12} . Using a similar approach, the total number of cysts in the estuary in the top 1 cm of the bed is estimated to be 6.6×10^{13} , and the total number in the top 10 cm of the bed as 3.3×10^{14} . Estimating that the loss rate of resuspended material during dredging operations to be 1% (Palermo, et al., 2008), the total number of cysts released during dredging would represent an addition of about 0.03% to the cysts in the surface layer. Again, this would not be expected to increase the magnitude of *Alexandrium* blooms.

The changes in tidal amplitude in the estuary associated with dredging that were calculated by the model may have impacts on red tide cysts that are difficult to quantify. An increase in tidal range could enhance flushing of the salt ponds, potentially reducing the accumulation rates of *Alexandrium* cells in the ponds and bloom intensity (Ralston et al. 2015). Larger tides may also increase bed stresses in the system, remobilizing and redistributing fine sediment and associated cysts. This could increase the population of cysts that are available to germinate, although as with the sediment released during dredging operations, the expectation is that the fine sediment and cysts would accumulate in regions that already have high cyst concentrations. An important point in assessing potential effects of a change in tidal amplitude is that the model predicts a return to tidal conditions similar to that of several years ago rather than a significant increase over the historical range. As the Nauset inlet has migrated north and the entrance channel both extended and shoaled, the estuary has become more frictional, accounting for the decrease in tidal range. The proposed dredging would reverse some of that decrease, but the tidal regime and any effects on the harmful algal bloom would be similar to conditions from a few years ago.

Red tide impacts associated with the various placement alternatives shown in Figure 23 present no major concerns or negative impacts. For the dune enhancement alternatives, most cysts in the sand will be buried in the dune, such that few, if any, will be washed back into the water. As the sand dries out, the cysts will desiccate and die. With the upland/coastal beneficial reuse alternative the primary concern with respect to *Alexandrium* cysts is that during the dewatering process, cysts might be carried into Town Cove with the water that drains from the sediment pile. But, sand and silt act as filters when piled in the holding area, so most cysts will be strained from the water as it drains through the tortuous path of the sand, silt, and clay particles. With the marsh restoration option, the dredged sediment and associated *Alexandrium* cysts will be trapped by the *Spartina* and other marsh grasses. The cysts will thus be placed in an environment where they are likely either to die, due to repeated cycles of inundation and drying with the tides, or to be buried into anoxic sublayers of sediment, where they will remain dormant until they die. The subaqueous placement alternative has considerable promise to be effective and

environmentally benign, but it should be pursued as a pilot research study first to demonstrate the principle of using sand deposition to suppress cyst germination.

Impacts requiring further study

Given that FVCOM shows changes in tidal amplitude with the dredging project, it is likely that the project would also result in changes to tidal flushing and water quality. However, these impacts are not expected to result in significant harm since the system will be returning to conditions that existed previously. If the Town proceeds with the project it will be important to quantify these potential impacts. In terms of sediment transport and shoreline erosion, the dredging is not expected to result in significant differences. However, one area that requires further examination is the southern channel leading to Priscilla Road Landing. While the FVCOM model does not indicate significant changes to hydrodynamics in this area caused by dredging, the potential for an increased risk of breaching at the historical 1930's location near Nauset Heights should be evaluated further. If adverse impacts are noted, it may be possible to evaluate different dredging scenarios (narrower, shallower) that would reduce the potential for a breach in this location. If the Town proceeds with the project, it will also be necessary to evaluate potential impacts to existing resources such as shellfish, wetlands, shorebirds, etc. through more detailed surveys.

4.2 ENGINEERING FEASIBILITY

The engineering feasibility of the project was evaluated by looking at two primary aspects of the project. The first was the ability to maintain a dredged channel to the desired width and depth without frequent maintenance dredging. The second included an evaluation of viable construction methods given the dredge channel layout and available placement options. Although determining specific time frames for the former is difficult, based on preliminary hydrodynamic modeling and long-term knowledge of the geomorphology of Nauset Inlet and Nauset Estuary, rough projections of the lifetime of the dredged channel can be made. Because of the dynamic nature of the inlet and barrier beach, the portion of the channel immediately behind the barrier beach and near the inlet would likely require maintenance dredging every 1 to 3 years to maintain the channel design. In the event that a new breach forms to the south near Tern Island, the channel area behind the barrier beach would be abandoned, and maintenance dredging would only be required in the channel leading to the breach. Post-dredge shoaling rates in the interior channels are difficult to predict without a detailed sediment transport model; however, it is likely that these areas would receive small volumes of sedimentation and would require infrequent maintenance dredging.

The second engineering consideration involves which construction methods are viable given the channel layout, available placement options, and equipment limitations. Because there are technical limitations to how far dredged material can be hydraulically pumped, the limits on appropriate placement sites were assumed to be 4,000 and 11,000 ft from the dredge locations. These two distances coincide with the Barnstable County Dredge capabilities to pump dredge material without and with a booster pump. Because Nauset Beach is approximately one mile south of Nauset Estuary, material can only be hydraulically pumped there with a booster pump attached to

the pipe (Figure 23). Alternatively, Nauset Spit is much closer to the proposed dredge areas, and could be used as a placement site for material pumped from within 4,000 feet using a hydraulic dredge, even without a booster. By adding a booster pump, material from much of the proposed dredge area could be pumped to this location.

Finally, due to the length of the dredging project, areas of the channel in the vicinity of Town Cove are more than 11,000 feet from either beach/dune disposal site. As such, the distance limitations of the County Dredge, even with an attached booster pump, rule out the possibility of utilizing a hydraulic dredge to remove the material from this portion of the channel (Figure 23, right panel). Instead, the material will need to be mechanically dredged, and barged to a shorefront location for offloading and trucking to an approved site. Water depths in the estuary would not allow for a fully loaded barge to be towed to the eastern side of the system so the material could be used on Nauset Spit. Instead, the likely destination for any mechanically dredged material, regardless of grain size, from the Town Cove portion of the channel would be Goose Hummock Landing. There, it could be offloaded at the existing bulkhead, dewatered in the parking lot if necessary, and then trucked to Nauset Beach for dune enhancement or some other approved location.

4.3 REGULATORY FEASIBILITY

Any dredging project in Massachusetts requires certain permits and certificates. Based on the 2015 channel layout, which includes removal of approximately 80,600 cubic yards of sediment from over 79 acres, regulatory review will be required by the Massachusetts Environmental Protection Act (MEPA) and the Cape Cod Commission in the form of an Environmental Impact Report (EIR) and District of Regional Impact (DRI). The current plan exceeds the regulatory threshold for the EIR, which is alteration of ten or more acres of a wetland (11.03(3)(a)1a). It may be possible to file an Expanded Environmental Notification Form (ENF) with MEPA requesting a waiver from the requirements of an EIR. This would reduce permitting costs and timing, but at this point it is unclear if MEPA would accept this request. It may also be possible to scale the project back so the EIR threshold is not triggered, but this would require a significant reduction in project scope which may not meet the objectives of improving navigation and public safety.

Since the channel layout includes sections in both the Town of Orleans and the Town of Eastham, a separate Notice of Intent will need to be filed with each town's Conservation Commission. In addition, other standard permits for dredge projects, such as a Massachusetts DEP Water Quality Certification, Chapter 91 Permit, Coastal Zone Consistency, and a USACE Individual Permit will also be required.

Although certain activities are prohibited or more strictly regulated within the Cape Cod National Seashore (CCNS), this dredge plan would not require additional federal permitting because of its location within the CCNS. However, close communication with the CCNS will be important if the project proceeds. Placement options on Town owned land, shown in Figure 23 in Section 3, also do not trigger the need for permitting with the CCNS.

Table 3 summarizes the list of permits that would be required to implement the dredge plan. The table details the type of application, agency responsible for issuing each

permit, the duration of the permits, and the estimated cost associated with preparing and applying for each permit. Combined, the cost for all permits necessary for this project is estimated to be approximately \$141,000. If the requirement for an EIR/DRI can be waived the cost for permitting could be reduced to approximately \$75,400. Although an exact time line for applying for and receiving all the permits is not possible to develop at this time, it is likely to take between 2 and 3 years.

This feasibility study collected a limited amount of data, to help evaluate the feasibility of the project, but more detailed data will be required for actual permitting. Based on past experience from similar projects, a list of additional data needed to support the permit applications has been developed and is summarized along with associated costs in Table 4. To complete all the additional data collection would cost approximately \$195,900 and would take approximately 1 year to complete.

Combined the cost of permitting and additional data collection would range between \$271,300 and \$336,900 depending on whether or not an EIR/DRI review is required.

Table 3. Required permits for the Nauset Estuary dredge project.

Application	Agency	Permit Duration	Cost
Expanded Environmental Notification Form	MEPA	Not Applicable	\$17,400
Environmental Impact Report/ Development of Regional Impact Joint Filing	MEPA/ Cape Cod Commission	Not Applicable	\$65,600
Notice of Intent	Orleans Conservation Commission	3-Years, possibly up to 10-Years	\$15,000
Notice of Intent	Eastham Conservation Commission	3-Years, possibly up to 10-Years	\$15,000
401 Water Quality Certification	MADEP Wetlands & Waterways	5-Years	\$8,000
Chapter 91 Waterways Permit	MADEP/ Waterways	10-Years	\$8,000
MCZM Federal Consistency Determination	MA Coastal Zone Management	Not Applicable	\$5,000
MA Individual Permit	Army Corps of Engineers	10-Years	\$7,000

Table 4. Data collection activities and estimated costs to support permit applications.

Data Collection Activity	Estimated Cost
Resource area surveys (wetlands, shellfish, eelgrass, shorebirds)	\$23,000
Beach and dune topographic surveys	\$7,800
Bathymetric surveys (Pre- and Post-Dredge)	\$18,400
Placement site Monitoring	\$9,100
Vibracoring and beach sampling for grain size	\$42,500
Refined hydrodynamic modeling	\$77,700
Engineering design and plans	\$17,400
Total	\$195,900

4.4 CONSTRUCTION COSTS

Construction costs are contingent on a number of factors, including mobilization costs, dredging costs, disposal costs (in the case of mechanical dredge), and whether or not a booster is utilized (in the case of hydraulic dredging). Mobilization costs to get the County Dredge to Nauset Estuary are approximately \$25,000 per dredge event. The cost for actual dredging, however, depends on whether a booster pump is utilized. Without a booster pump, dredging costs \$9 per cubic yard. With a booster pump, dredging costs \$13 per cubic yard. There are no specific disposal costs associated with hydraulic dredging because the material is pumped to the placement site as it is being dredged, although some land-based, mechanical equipment such as bobcats and bulldozers may be required to spread and grade the material, which would add additional costs to this method.

Mechanical dredging is more costly. The mobilization cost for a mechanical dredge is approximately \$150,000. The cost of actual dredging is \$43 per cubic yard. Unlike hydraulic dredging, the mechanical dredging would also incur a rehandling and trucking fee of approximately \$43 per cubic yard. If the material was not reused beneficially, and taken to a landfill for use as daily cover there would also be a tipping fee of about \$37 per cubic yard.

Given the volumes of sediment present in different areas of the channel layout (Figure 22), and the limitations of what dredge method and placement site can be utilized for each of the areas (Figure 23), the cost of dredging each channel area has been calculated (Table 5). Assuming that the entire 80,600 cubic yards of material is dredged from all three channel areas in Nauset Estuary, the costs would range between \$1.5 and \$1.7 million. If sediment dredged from channel areas 1 and 3 (Figure 23) is used beneficially for dune restoration at Nauset Beach, it could save the Town between \$900,000 and \$1,200,000, which is the estimated cost for purchasing and spreading sand to restore the dune (Woods Hole Group, 2016).

Table 5. Estimated construction costs for dredging Nauset Estuary.

Dredge Method	Channel Area 1¹	Channel Area 2¹	Channel Area 3
Hydraulic w/o Booster	\$430,900		
Hydraulic w/ Booster	\$611,300	\$398,100	
Mechanical			\$734,800

1: Includes \$25,000 mobilization/demobilization fee

4.5 SUMMARY OF FEASIBILITY FACTORS

Sections 4.1 to 4.4 describe the various feasibility considerations for the Nauset Estuary dredging project. These considerations encompass environmental, engineering, regulatory, and financial concerns involved with this project. To better facilitate an understanding of all these project components, the major findings from each feasibility category are summarized below in Table 6. The Town can use this summary, as well as the detailed information presented in this report, to determine the overall feasibility of this project, based on their needs, available funding, and required time frames.

Table 6. Summary of project feasibility.

Feasibility Category	Summary
Environmental	<ul style="list-style-type: none"> • No adverse impacts are expected due to dredging in areas with red tide cysts provided the work is done between December and February. • Potential impacts to shellfish and water quality will require further study to be determined. • Because no eelgrass is present in Nauset Estuary, no impacts are expected to this resource.
Engineering	<ul style="list-style-type: none"> • Combination of hydraulic and mechanical dredging • Placement can be through nearby beneficial reuse and offsite upland transport • Lifetime estimates for the dredged areas range from a low of 1 to 3 years immediately behind the barrier beach to higher lifetimes with infrequent maintenance dredging elsewhere.
Regulatory Constraints	<ul style="list-style-type: none"> • The total cost to complete all necessary additional data collection and prepare and submit all required permits is estimated to be \$336,900. • It will take approximately 1 year to complete all additional necessary data collection, and an additional 2 to 3 years to apply for and acquire all permits necessary to commence work
Construction Costs	<ul style="list-style-type: none"> • Construction cost for the entire project range from \$1.5 to \$1.7 million. • Beneficial reuse of the dredged sand could offset the costs of dune enhancement and phased retreat at Nauset Beach by approximately \$900,000 to \$1,200,000.

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APPENDIX A. CORE LOG DESCRIPTIONS

APPENDIX B. LABORATORY GRAIN SIZE RESULTS

Section M

Dredge Sediment Grain Size & Chemistry Data

Section M

Phase 2 Core Logs & Lab Data from Sampling on 12/10/2015

Section M

Request for Approval of SAP to ACOE & DEP - 6/7/2017

Section M

SAP Supplemental Information to ACOE – 7/27/2017

Section M

Approved SAP from ACOE – 8/18/2017

Section M

Phase 3 Core Logs & Lab Data from Sampling on 10/3/2017

Section M

Phase 4 Core Logs & Lab Data from Sampling on 7/29/2019

Section N

Shorebird Monitoring Reports

Section O

Support Letters

Section P

Public Notice and EENF Distribution List

Section Q

Project Map & Plans

Dredge Plans are Currently Under Development