

# **Massachusetts Estuaries Project Marine Benthic Monitoring Laboratory Standard Operating Procedures**



**Prepared for:**

Watershed Planning Program  
Division of Watershed Management, Bureau of Water Resources  
Massachusetts Department of Environmental Protection

CN 510.7



**Prepared by:**

Normandeau Associates, Inc.  
141 Falmouth Heights Rd.  
Falmouth, MA 02540

**January 2025**

# **Massachusetts Estuaries Project Marine Benthic Monitoring Laboratory Standard Operating Procedures**

January 2025

## **Suggested Citation**

MassDEP. 2025c. Massachusetts Estuaries Project Marine Benthic Monitoring Laboratory Standard Operating Procedures. CN 510.7. Massachusetts Department of Environmental Protection, Bureau of Water Resources, Division of Watershed Management, Watershed Planning Program. Worcester, MA. In cooperation with Normandeau Associates, Inc.

## **Acknowledgements**

This Quality Assurance Project Plan and associated appendices were funded by the Watershed Planning Program (WPP) within the Division of Watershed Management, Bureau of Water Resources, Massachusetts Department of Environmental Protection, via a contract (BWR-DWM-2018-14-CW TECH SERVICES) with Normandeau Associates, Inc.

Contributors from Normandeau Associates, Inc. included the primary authors: Deborah A. Rutecki and Mindy Sweeny.

## **Contact Information**

Watershed Planning Program

Division of Watershed Management, Bureau of Water Resources

Massachusetts Department of Environmental Protection

8 New Bond Street, Worcester, MA 01606

Website: <https://www.mass.gov/guides/watershed-planning-program>

Email address: [dep.wpp@mass.gov](mailto:dep.wpp@mass.gov)

## **Cover Photo**

Photos by Normandeau Associates, Inc. Images of benthic habitat from Pleasant Bay 2020 survey, including eelgrass, a horseshoe crab, and quahog shell rubble. *Massachusetts Estuaries Project-Benthic Monitoring Report: Pleasant Bay 2021*. MassDEP. June 2021.

## **Disclaimer**

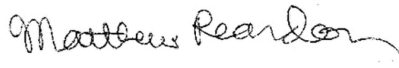
References to trade names, commercial products, manufacturers, or distributors in this report constituted neither endorsement nor recommendation by MassDEP. All applicable federal, state, and local laws and regulations are to be followed when conducting activities described in this Quality Assurance Project Plan. MassDEP and the Commonwealth of Massachusetts accept no responsibility and no liability for loss of any kind, including personal injury or property damage due to the work and/or activities described in this Quality Assurance Project Plan.

**Massachusetts Estuaries Project  
Marine Benthic Monitoring  
Laboratory Standard Operating Procedures**

CN 510.7

7/30/25-7/30/27

**Review and Approvals**



7/30/2025

**Matthew Reardon**

Date

Total Maximum Daily Load Section Chief  
Watershed Planning Program  
Massachusetts Department of Environmental Protection



7/30/2025

**Holly Brown**

Date

TMDL Analyst  
Watershed Planning Program  
Massachusetts Department of Environmental Protection



7/30/2025

**Jasper Sha**

Date

Quality Assurance Analyst  
Watershed Planning Program  
Massachusetts Department of Environmental Protection

## List of Revisions

[illegible]

## TABLE OF CONTENTS

	PAGE
I. GENERAL INFORMATION.....	1
1.0 Introduction .....	1
2.0 Technical Approach.....	1
3.0 References.....	2
II. LABORATORY STANDARD OPERATING PROCEDURES FOR BENTHIC MACROFAUNA SAMPLES.....	3
1.0 Health and Safety .....	3
2.0 Laboratory Equipment .....	3
2.1 Sample Preparation – Sorting .....	3
2.2 Sample Preparation - Taxonomy Identification .....	4
3.0 Sample Receipt .....	4
4.0 Sample Preparation – Sorting.....	5
5.0 Taxonomic Identification .....	6
6.0 Data Entry .....	10
7.0 Sample and Record Retention .....	12
8.0 Sample QC.....	13
9.0 Storage .....	14
10.0 Disposal .....	15
11.0 References.....	15
III. LABORATORY STANDARD OPERATING PROCEDURES FOR SEDIMENT ANALYSIS .....	20
1.0 Health and Safety .....	20
2.0 Laboratory Equipment .....	20
3.0 Sample Receipt .....	20
4.0 Analytical Procedures.....	21
4.1 TOC.....	22
4.2 Grain Size Analysis .....	22
5.0 Data Entry .....	23
6.0 Sample QC.....	27
7.0 Sample Record Retention.....	27
8.0 References.....	27
IV. LABORATORY STANDARD OPERATING PROCEDURES FOR UNDERWATER STILL IMAGES AND/OR VIDEO .....	28

1.0	Digital Still Images .....	28
1.1	Laboratory Equipment.....	28
1.2	Procedure.....	28
2.0	Digital Video.....	31
2.1	Laboratory Equipment.....	31
2.2	Procedure.....	31
3.0	Data Entry .....	32
4.0	Image Analysis QC .....	35
5.0	Sample Record Retention.....	36
6.0	References.....	36
V. LABORATORY STANDARD OPERATING PROCEDURES FOR SEDIMENT		
	PROFILE IMAGING (SPI; OPTIONAL) .....	37
1.0	Laboratory Equipment .....	37
2.0	Procedure .....	37
3.0	Data Entry .....	38
4.0	Analysis QC .....	41
5.0	Sample Record Retention.....	42
6.0	References.....	42

## **I. General Information**

### **1.0 Introduction**

The Massachusetts Department of Environmental Protection (MassDEP) established the Massachusetts Estuaries Project (MEP) to monitor and protect estuarine ecosystems in southeastern Massachusetts embayments. MEP's goal is to assess the conditions of these embayments and to develop critical site-specific nitrogen thresholds that could be used as a management tool by communities to identify needed corrective and protective measures for both now and in the future.

Benthic infaunal communities are a good indicator of embayment conditions and are used to assess the level of habitat health from healthy (low organic matter, high dissolved oxygen (DO)) to highly stressed (high organic matter, low DO). Communities in benthic assemblages respond to a variety of stressors in different ways allowing the type of stress affecting the assemblage to be identified. As many macroinvertebrates have relatively long life cycles of a year or more and are relatively immobile, the structure of the assemblage is a response to past and/or present conditions (Howes et al. 2003, US EPA 2020). MEP uses the approach, which is accepted by the regulatory community, that the pollution tolerance of individual species allows their use as indicators in relation to pollution effects on estuarine and marine habitats.

The objectives of the MEP benthic monitoring program are to assess embayment ecological health and to determine if long term changes are occurring in southeastern Massachusetts estuaries that may indicate stress from nutrients and other factors including invasive species and climate change. Additional information can be found in the MEP Benthic Monitoring Quality Assurance Project Plan (QAPP; MassDEP 2025a).

This document constitutes the Standard Operating Procedures (SOP) manual for the laboratory tasks of benthic monitoring for the Massachusetts Estuaries Project. The goals of this SOP are to (1) provide sufficiently detailed instructions to enable laboratory technicians to follow consistent and technically valid protocols, and (2) record the laboratory results from these surveys in a consistent manner.

### **2.0 Technical Approach**

MEP benthic monitoring will include laboratory analyses to support sediment and benthic macroinvertebrate community characterization. This SOP manual contains detailed procedures for analysis of the following types of benthic samples:

- Benthic Macrofauna
  - Soft bottom samples using a Van Veen grab sampler
  - Hard bottom/riprap samples using a suction sampler
- Soft Bottom Sediments

- Grain size
- Total Organic Carbon (TOC)
- Underwater Digital Still Images and/or Video
- Soft Bottom Sediment Profile Imaging (SPI)

### **3.0 References**

- Howes, B.L., R. Samimy, and B. Dudley. 2003. Massachusetts Estuaries Project. Site-Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Critical Indicators. Interim Report. Prepared for Massachusetts Department of Environmental Protection. 25 pp.
- MassDEP. 2025a. Massachusetts Estuaries Project Marine Benthic Monitoring Quality Assurance Project Plan. CN 510.5. Massachusetts Department of Environmental Protection, Bureau of Water Resources, Division of Watershed Management, Watershed Planning Program. Worcester, MA. In cooperation with Normandeau Associates, Inc.
- US EPA (U.S. Environmental Protection Agency). 2020. National Coastal Condition Assessment 2020 Field Operations Manual. April 2020. EPA- 841-F-19-005. U.S. Environmental Protection Agency, Office of Water, Office of Wetlands, Oceans and Watersheds. Washington, DC. 149 pp.



## **II. Laboratory Standard Operating Procedures for Benthic Macrofauna Samples**

Samples are preserved in the field with formalin and delivered or shipped to a contracted laboratory. The following section describes the laboratory procedure for sorting and taxonomic identification of macrobenthic organisms collected from MEP soft-bottom infauna surveys using a Van Veen grab or hard bottom/riprap destructive sampling (epifauna) using a suction sampler. These methods are consistent with the laboratory procedures outlined in the National Coastal Condition Assessment (NCCA) 2020 Laboratory Operations Manual (US EPA 2021). For additional program details refer to the MEP Benthic Monitoring QAPP (MassDEP 2025a).

### **1.0 Health and Safety**

In addition to the laboratory's requirements, persons using this SOP must abide by the following health and safety procedures:

1. Wear proper personal protection clothing and equipment (e.g., lab coat, gloves, and protective eyewear/goggles).
2. When working with potentially hazardous chemicals (e.g., formalin, reagent alcohol, Rose Bengal) or biological agents (benthic organisms and sediments), laboratory personnel must follow all manufacturer's Safety Data Sheet recommendations, and avoid inhalation, skin contact, eye contact, or ingestion. If skin contact occurs, remove clothing immediately and rinse thoroughly. Wash the affected skin areas thoroughly with large amounts of soap and water. When working with formalin, laboratory personnel must follow the OSHA Formaldehyde Standard (29 CFR 1910.1048).

### **2.0 Laboratory Equipment**

#### **2.1 Sample Preparation – Sorting**

The following equipment and materials are required for sample preparation, subsampling, sorting, and taxonomic identifications:

- U.S. 35 sieve (500  $\mu\text{m}$  or 0.5 mm) for soft-bottom infaunal samples
- U.S. 18 sieve (1000  $\mu\text{m}$  or 1.0 mm) for hard-bottom/riprap destructive samples
- Round buckets
- Standardized, or gridded screen - 40 Mesh (380- $\mu\text{m}$  openings, T304 stainless steel wire, 34GA (0.010"))
- 6-cm scoop
- White or clear plastic or enamel pan (6" x 9") for sorting
- Teaspoon
- Permanent ink pen (e.g., Pigma Micron® pen, Sharpie)

- Pencil or alcohol resistant ink pen
- Dropper
- Fine-tipped forceps (watchmaker type, straight and curved)
- Vials with caps or stoppers
- Sample labels for vials
- Reagent alcohol (5% methanol, 5% isopropanol, 85% ethanol)
- Stereo zoom microscope (6-10X magnification or greater)

## **2.2 Sample Preparation - Taxonomy Identification**

The following equipment is required for benthic macroinvertebrate taxonomic identification:

- Stereo dissecting microscope with fiber optics light source (50-60X magnification)
- Compound microscope (10, 40, and 100X objectives, with phase-contrast capability)
- Digital camera with high resolution capability mounted on a microscope (optional)
- Petri dishes
- Permanent ink pen (e.g., Pigma Micron® pen, Sharpie)
- Pencil or alcohol resistant ink pen
- Dropper
- Fine-tipped forceps (watchmaker type, straight and curved)
- Vials with caps or stoppers
- Sample labels for vials
- Reagent alcohol in a plastic wash bottle
- Taxonomic Bench Sheet
- Hand tally counter
- Taxonomic keys (For example, Smith 1964, Gosner 1971, Bousfield 1973, Abbott 1974, Fauchald 1977, and Pollock 1998).

## **3.0 Sample Receipt**

The laboratory procedure for benthic samples begins with the receipt of the samples at the subcontracted laboratory.

1. Record receipt of samples and sign the Chain of Custody (COC) form (Figure 1).
2. Inspect each jar THE SAME DAY THEY ARE RECEIVED:
  - a. Add 10% formalin to the jar, if necessary (i.e., to cover the contents completely).
  - b. Verify that the date collected, site identification, and sample number on the label also appear on the COC form in the shipment.

- c. Notify the Project Manager if any jars were broken and/or there are discrepancies between the custody form and jars.
3. Store the sample containers at room temperature until sorting begins. Replace the 10% buffered formalin with reagent alcohol within 7 days of collection for better preservation of the organisms.
4. To facilitate the sorting process, all samples will be stained with Rose Bengal. Add Rose Bengal to the reagent alcohol to the point of saturation. Samples should be stained at least overnight but no longer than 48 hours before sorting the infaunal samples to avoid over-staining.
5. Maintain the COC form with the samples; it will be needed if the samples are transported to any other location (e.g., for taxonomic identification, external quality control (QC) evaluation).

#### **4.0 Sample Preparation – Sorting**

This section describes the steps for the sorter in preparing the sample and picking organisms.

1. Remove the lid from the sample container and remove the internal sample label. Record the sample collection information on a Sample Card or datasheet.
2. Carefully decant the reagent alcohol from the sample container by pouring the fluid through a 0.5 mm or 1.0 mm sieve (selected based on the sample type, benthic infaunal or hard-bottom/riprap destructive) into a separate container. Gently rinse the sample with tap water using the spray nozzle, being careful to use a low-volume spray so the organisms will not be damaged. Rinse sample until residual water coming through the sieve is clean. Using the spray, carefully direct the sample contents into a clean beaker. Ensure that all organisms have been removed from the sieve.
3. Remove sieved organisms from the beaker and place into a sorting tray. Ensure all organisms have been removed from the beaker.
4. Sort all samples under a minimum of 6x dissecting microscope. Remove the macroinvertebrates from the detritus with forceps. In general, do not remove:
  - Empty snail or bivalve shells
  - Organisms of water surface-dwelling or strict water column arthropod taxa, and meiofauna.
  - Incidentally-collected terrestrial taxa.
  - Fragments such as legs, antennae, gills, wings, or tails.
  - For Oligochaeta, attempt to remove only whole organisms or fragments that include the head. Do not remove fragments without the head.
  - In case of uncertainties, place the organism in a vial with reagent alcohol for the taxonomist to make the final determination.

5. Place picked organisms of the same type into a single set of jars and vials containing reagent alcohol.
6. Remove the remaining material left on the sorting pan (i.e., material such as sticks, organic debris) and place it in a separate container with preservative (reagent alcohol). Label the container “Picked,” on both internal and external labels.
7. Label the vials and jars of sorted organisms and material with an external label using a permanent ink pen. Internal sample labels should be made of cotton rag paper or an acceptable substitute and written with pencil or alcohol resistant ink pen.
8. Retain the vials and materials for the time period specified in Section 10.0.
9. Thoroughly clean all sample preparation and sorting equipment and make sure all equipment is free of organisms prior to sorting the next sample.

## **5.0 Sample Preparation - Subsampling**

During the sorting process, if a sample contains organisms that are not separable from the sediment, then an additional step of subsampling may be warranted. For example, in the Pilot Study: Pleasant Bay (Sweeny and Rutecki 2019), an extremely large number of very small juvenile bivalves were essentially the same size as the sieve (0.5 mm) and therefore could not be practicably counted. The approved solution was to subsample the material that remained on the 0.5 mm mesh.

Note: No subsampling will occur without prior discussion and approval of the project manager, MassDEP, and/or the Town/client.

For samples that have been approved for subsampling use the following steps:

1. Remove the lid from the sample container and remove the internal sample label. Record the sample collection information on a Sample Card or datasheet.
2. Carefully decant the reagent alcohol from the sample container by pouring the fluid through a 0.5 mm or 1.0 mm sieve (selected based on the sample type) into a separate container.
3. Following removal of the preservative, gently wash the sample and circulate (elutriate) sample with water and allow any light material and organisms that might be in the gravel/sand to float to the top of the water. Pour the water through the sieve and set material aside for sorting. Sort as above.
4. Repeat Step 3 until the water runs clear.
5. To separate the heavy material into homogeneous sizes to facilitate sorting, sieve the remaining material through a stack of different sized sieves finishing with a 0.5 mm or 1.0 mm sieve at the bottom of the stack. Material on the different sized sieves that does not require subsampling will be set aside for sorting and sorted as above.
6. Place the material that is to be subsampled into a pan (for example 30.5 cm by 30.5 cm [12 in by 12 in] inside dimensions with marks at the edges for grids 6 cm by 6 cm) marked with a grid. Spread the sample material over the bottom of the pan as evenly

- as possible. Move the sample into the corners of the pan using forceps, spoon, or by hand. Vibrate or shake the pan gently to help spread the sample.
7. Use a random number generator to select at least 10% (or the approved percentage) of the squares to ensure that the subsample material is representative of the overall sample. For example, if the tray is subdivided into 30 squares, then 3 squares would be selected for sorting.
  8. Remove all the material from the selected squares. This can be done by placing a metal dividing frame over the sample at the approximate location of the square selected for processing. Use a pair of rulers or other straight edges to facilitate lining up the frame at the intersection, if necessary. Remove the material within the frame using a scoop, teaspoon, forceps, or dropper depending on the consistency of the sample.
  9. Inspect the tray for any remaining organisms. Use the following rules when dealing with organisms that lie on the line between two squares:
    - a. An organism belongs to the square containing its head.
    - b. If it is not possible to determine the location of the head (i.e., for polychaetes), the organism is considered in the square containing most of its body.
    - c. If the head of an organism lies on the line between two squares, all organisms on the top of a square and those on the right side of a square belong in that square, and are picked with that square.
  10. Place the subsampled material into a sorting tray and proceed with sorting as above.
  11. Record the number of organisms found in subsampled material on the Sample Card or datasheet. Record the squares selected and the total number of squares samples on the Sample Card or datasheet. If laboratory protocol is to record total for subsample material on cards or datasheets, multiple raw counts by appropriate multiplier and enter total number of organisms
  12. Remove the remaining material left on the sorting pan from the selected squares (i.e., material such as sticks, organic debris) and place it in a separate container with preservative (reagent alcohol). Label the container “Picked,” on both internal and external labels.
  13. Return all material not subsampled (remaining on the tray) to the original container with the preservative that was set aside. This container will include the original sample labels. Prepare two additional labels “Unsorted Sample Remains” and place one inside the container and attach the other to the outside of the container. Replace the lid and tighten securely. Archive the container until all appropriate QC checks are completed (subsampling and taxonomy), and in accordance with survey and laboratory requirements.

In the Pilot Study: Pleasant Bay (Sweeny and Rutecki 2019) example from above the following procedure was used. The samples that had considerable quantities of sand containing large numbers of the very small bivalves (*Gemma gemma*) were subsampled to facilitate the counting effort and estimate the number of *G. gemma*. The project manager and benthic taxonomic experts determined that 25% of the material retained on the 0.5 mm sieve

the would be selected for sorting. This was a conservative approach to ensure a valid estimate of the small bivalves. MassDEP was notified of the issue and approved the subsampling solution. Following removal of the preservative, samples were gently washed, and the light material was elutriated from the matrix and set aside for sorting. To separate the heavy material into homogeneous sizes to facilitate sorting, the remaining material was sieved through a stack of different sized sieves finishing with a 0.5 mm sieve at the bottom of the stack. The sand with the juvenile bivalves retained on a 0.5 mm mesh was spread out evenly in a pan marked off with 36 squares. To sort  $\frac{1}{4}$  (25%) of the sand, a random numbers table was used to select 9 squares of material out of the total of 36 squares. Material from the 9 squares was removed from the pan and all *G. gemma*, as well as any incidental remaining molluscs were counted. Raw counts were multiplied by 4 to achieve the estimate for the entire sample and entered on the datasheet.

## 6.0 Taxonomic Identification

The taxonomist performs the following steps in identifying the benthic macroinvertebrates:

1. Upon receipt of a set of sample vials from the sorter:
  - a. Compare all site identification codes and sample numbers on the form with those entered on the labels of samples, and resolve any discrepancies with the sorter.
  - b. Determine if any vials are broken. For any broken vial, attempt to recover as much of the sample as possible. Describe the damage on the Taxonomic Bench Sheet.
  - c. Maintain the COC form with the sample vials; it will be needed to return/store them.
2. Empty one sample vial at a time into a small Petri dish. Add reagent alcohol to keep the organisms covered. Remove the internal sample label and complete the top portion of a Taxonomic Bench Sheet, using the information from the label.
3. View the sample to ensure that all necessary diagnostic characters have been observed, according to the taxonomic key or other literature.
4. Identify organisms to the lowest practical taxonomic level (species is the target for all organisms with the exception of meiofauna, which are smaller than 0.5 mm). Additional exceptions include Oligochaeta (Class) and Chironomidae (Family) in samples from marine, polyhaline and mesohaline regions. If a laboratory or individual taxonomist is having trouble reaching the species level for a taxonomic group but not for an individual organism which might be damaged or otherwise difficult to identify, the lab must contact the project lead for guidance. Add any necessary data qualifiers.
5. Record the identifications. For example, using the Taxonomic Bench Sheet, record the identification in the column labeled "taxon." Enter the number of larvae, pupae,

and adults, or total count (e.g., mollusks), if appropriate life history column does not apply, of each taxon under the appropriate columns.

- a. Refer to the World Register of Marine Species (WORMS) website to check the scientific name to ensure that there have not been any name changes:  
<http://www.marinespecies.org/aphia.php?p=search>
- b. It should be noted if the target taxonomic level cannot be achieved due to immature or damaged organisms.
- c. If damaged organisms can be identified, they are counted ONLY if the:
  - 1) Fragment includes the head, and, in the case of arthropods, the thorax;
  - 2) Oligochaetes have a sufficient number of segments in the head;
  - 3) Mollusk shell (bivalve or gastropod) is occupied by an organism;
  - 4) Organism is the sole representative of a taxon in the sample.
- d. If a unique taxon is determined for which the appropriate taxonomic level is not available in the literature and there are other taxa in that taxonomic level:
  - 1) Provide good quality digital photographs of the organism to outside experts for identification; and
  - 2) Include the tentative identification in the database with a data qualifier so that these organisms can be distinguished from other organisms in the data analysis.
  - 3) When the outside expert identifies the organism, update the database with the correct identification.
6. Compare taxa names from the taxa list provided by the project manager to the names used for the identifications. Check the non-matches and correct them.
7. Complete the identification by entering the totals for each developmental stage and the total number of each taxon in the cells at the bottom of the sheet. Cross-check to be sure the totals were summed correctly.
8. Save one specimen from each taxa in a labeled vial with 70% reagent alcohol for the reference collection. The label should include the lowest possible taxonomic level of the organism, embayment collected from, station collected from, and date of collection. Return the identified organisms to the original sample vial, fill with reagent alcohol, and cap tightly.
9. Return or store the samples according to laboratory protocols and requirements.
10. Verify that all required data has been recorded by the taxonomist or QC personnel. If the results were recorded on paper, provide the Taxonomic Bench Sheet to data entry staff.

## 7.0 Data Entry

All data generated by taxonomic identification will be manually read from the instrument display (optical field of a microscope) and entered directly into an electronic format (e.g., Excel spreadsheet), or entered into laboratory forms or datasheets, and then manually entered into an electronic format. All manually entered data will receive 100% verification or will be entered and checked using double data entry. Standardized codes and qualifiers help to ensure consistency over time in a benthic monitoring program. Tables 1 and 2 identify the required data codes that the contracted laboratory must provide to the Project Manager for benthic macrofauna samples.

Data reduction is the process of converting raw numbers (e.g., numbers of organisms per replicate) into data that can be displayed graphically, summarized in tables, or compared statistically for differences between mean values for sampling stations or times. Macrofauna data analysis requires that some data be derived from the raw numbers for the Synthesis Report. All data reduction will be performed electronically, either by the instrument software or in a spreadsheet, and will be validated according to procedures described in the MEP Benthic Monitoring QAPP Section D (MassDEP 2025a).

Prior to the release of any data from the contracted laboratory, the data will be reviewed and approved by laboratory personnel. The review will consist of a tiered approach that will include reviews by the person performing the work, a qualified peer, and supervisory and/or QA personnel.

**Table 1. Benthic macrofaunal and destructive sample data codes. Data codes are revised from NCCA 2020 (US EPA 2021).**

Field	Format	Description
EVENT_ID	Character	Identifier of sampling event (survey)
LAB_NAME	Character	Name of lab
DATE_RECEIVED	MM/DD/YY HH:MM	Date sample was received by lab
SITE_ID	Character	Site identification code as used on sample label
SAMPLE_ID	Character	Sample ID as used on field sheet (on sample label)
SAMPLE_TYPE	Character	INFAUNAL or DESTRUCTIVE
DATE_COLLECTED	MM/DD/YY HH:MM	Date sample was taken



**Table 1. Continued.**

Field	Format	Description
CONDITION_CODE	Character	Condition codes describing the condition of the sample upon arrival at the laboratory.
		Flag      Definition
		OK      Sample is in good condition
		C      Sample container is cracked
		ML      Sample label is missing
		NP      Not enough preservative used
		Q      Other quality concerns, not identified above (explain in COND_COMMENTS)
COND_COMMENTS	Character	Explanation for Q FLAG (if needed)

**Table 2. Benthic macrofaunal taxonomic identification data codes. Data codes are revised from NCCA 2020 (US EPA 2021).**

Field	Format	Description
EVENT_ID	Character	Identifier of sampling event (survey)
LAB_NAME	Character	Name of lab
DATE_RECEIVED	MM/DD/YY HH:MM	Date sample was received by lab
SITE_ID	Character	Site identification code as used on sample label
SAMPLE_ID	Character	Sample ID as used on field sheet (on sample label)
DATE_COLLECTED	MM/DD/YY HH:MM	Date sample was taken
DATE_TAXON	MM/DD/YY	Date that the taxonomist started identifying organisms in the sample
CONDITION_CODE	Character	Condition codes describing the condition of the sample upon arrival at the laboratory.
FAMILY	Character	Taxonomic family
GENUS	Character	Taxonomic genus
SPECIES	Character	Taxonomic species
APHIA_ID	Numeric	World Register of Marine Resources (WoRMS) Database ID. If taxon is not in this list, provide citation for reference used to identify organism in CITATION field
TAXA_NAME	Character	Complete taxon name
ABUNDANCE_TOTAL	Numeric	Total number of individuals
DISTINCT	Character	Distinct taxa in sample (y/n)

**Table 2. Continued.**

Field	Format	Description
CITATION	Character	Citation for reference used to identify organism, if taxon not present in WoRMS.
QA_FLAG (if appropriate)	Character	QA/QC flag (lab may use its own flags, if defined in QA_COMMENTS field)
		FlagDefinition
		DDDamaged Organism, poor condition or fragments
		IMImmature
		NPNot enough preservative used
		UNUnknown. Identification is tentative. Organism has been sent to expert taxonomist for definitive identification.
		NTNot able to meet target level for identification (may be used with other codes, or explain in QA_COMMENTS field)
		SSample shipping problem (explain in QA_COMMENTS field)
		QOther quality concerns, not identified above
COND_COMMENTS	Character	Explanation for Q FLAG (if needed)
LAB_COMMENTS	Character	General laboratory analysis comments

## 8.0 Sample and Record Retention

The laboratory shall retain:

1. Macrofauna samples (both archived and processed samples) and sample materials, including vials, slides, and sorting residuals, will be held until acceptance of the Synthesis Report by the Town(s) and MassDEP. These samples can then be disposed of after approval from the Program Manager. Processed samples will be maintained at the laboratory contracted for sorting and identification. Macrofauna sample residues will be held until the data report is accepted by MassDEP, and then may be discarded. Reference collection specimens will be retained by the contracted laboratory until the next survey (3 to 5 years) and then provided to the next designated laboratory. Reference collection specimens will be clearly identified, labeled with the project name and unique identification number. Materials shall be stored in a cool location away from sunlight. The laboratory shall periodically check the reference collection and sample materials for degradation and refill jars and vials with reagent alcohol if necessary.

2. All the project records, including laboratory notebooks and the reference library, will be maintained at least 5 years.

After the stated time periods, the laboratory shall follow its internal protocols for disposal.

## 9.0 Sample QC

Benthic samples will be checked for QA/QC following the procedure detailed in the MEP Benthic Monitoring QAPP and presented below.

The data quality goals for analysis of benthic macrofauna are: (1) all samples be processed, (2) all animals be removed for identification and enumeration, (3) all infaunal animals be counted accurately, (4) the taxonomic identifications be accurate (correct), and (5) the identifications correspond to those used throughout the monitoring program. At least 95 percent of all animals must be removed from a sample to pass the quality control (QC) evaluation.

### 9.1 Sorting

Sorting technicians will remove all organisms from the samples and separate them into major taxonomic groups. All residual material will be labeled and stored for QC analysis. For the QC analysis, samples will be divided into batches of approximately 10 samples. Approximately 10% of the samples from each batch will then be randomly chosen for an independent QC check. Only senior technicians will perform the QC evaluations (a senior technician is defined as having three or more years of sorting experience). Under no circumstances will the same individual who sorted the sample perform the QC evaluation. In most cases, a batch of samples is defined as ten consecutively sorted samples. By definition, at least 95% of all animals must be removed from a sample to pass the QC evaluation (i.e., the percent sorting error must be  $\leq 5\%$ ). The following formula will be used to calculate the percent sorting error for each QC sample:

$$\frac{\text{Number of animals found in QC inspection}}{\text{Total number of animals present in sample}} \times 100 = \text{percent sorting error}$$

If more than 5% of the total organisms in the QC sample have been missed, the sample fails QC evaluation, and all remaining samples from that batch will be re-sorted. Technicians will be informed of any necessary corrective measures. This procedure will be repeated until the batch of samples passes the QC evaluation. An exception will be made for low abundance samples (a sample with fewer than 60 organisms) that are chosen for the QC evaluation. Any low abundance sample in which three or fewer organisms were missed is considered to pass the sorting QC evaluation even if the percent sorting error is  $>5\%$ . Samples in which no organisms are present will be excluded from the sorting QC selection process. A record of all sorting QC evaluations will be maintained for each batch.

## 9.2 Identification and Enumeration

The same basic QC principles described in Section 9.1 (Sorting) will generally apply to species identifications. At least 10% of the samples will be checked to detect any unacceptable identification and enumeration errors. Only senior taxonomists will perform the QC check. QC samples will be selected in the same manner as described in Section 9.1. Additionally, the same percent accuracy level will be used to determine if a sample passes the QC evaluation, and the same corrective measures will be implemented if a sample fails the QC evaluation. The following formula will be used to calculate the percent taxonomy error for each QC sample:

$$\frac{\text{Total number of taxonomy errors}}{\text{Total number of animals present in sample}} \times 100 = \text{percent taxonomy error}$$

In certain cases it may not be necessary to reprocess the entire batch of samples if only minor corrections are needed (e.g., name changes). When any misidentification is discovered, all previously identified samples containing that taxon will be rechecked. A record of all identification QC evaluations will be maintained.

## 10.0 Storage

1. Upon completion, the sorted material and the vials of identified animals are boxed for off-site storage.
2. A Storage Label (Figure 2) will be completed and attached to one end of the storage box. The following information is to be provided:
  - a. Project Name, Box Number, and Project Date
  - b. Brief description of the package contents
  - c. Storage Date
  - d. Preservative
  - e. Manager's Name
3. On the Sample Storage Sheet (Figure 3) an accurate listing of the project name and number, collection date, station/replicate, and description for each sample will be completed. While only one task should be entered on a Sample Storage Sheet, multiple boxes may be included on a Sample Storage Sheet.
4. The original Sample Storage Sheet is placed in the Laboratory Storage Book and a copy placed in the box.
5. Samples are stored in the laboratory's storage facility until the Synthesis Report is approved by the Town(s) and MassDEP. With permission from the Program Manager, following report approval, samples are removed from storage and prepared for sample disposal as described below in Section 11.

## 11.0 Disposal

1. Upon authorization from the Project Manager, samples will be removed from the storage facility and prepared for sample disposal.
2. Sample disposal, the separation of liquids and solids from processed samples, is conducted at the laboratory's ventilated hood by trained individuals.
3. Liquids and solids (including sample residue, glass vials, animals and electrical tape) from sample residue are separated, containerized and labeled following appropriate hazardous waste requirements.
4. The laboratory will adhere to local and state Hazardous Waste Small Generators requirements and hold wastes on site until the subcontracted hazardous waste vendor arrives and removes the wastes. Appropriate documentation, for example copies of the Hazardous Waste Manifest and the Land Ban Form, are filed with the laboratory's manager.

## 12.0 References

- 29 CFR 1910.1048. Occupational Safety and Health Administration, Department of Labor. Occupational Safety and Health Standards, Toxic and Hazardous Substances. Formaldehyde. Title 29 Code of Federal Regulations. Part 1910.1048.
- Abbott, R.T. 1974. American Seashells. The Marine Mollusca of the Atlantic and Pacific Coasts of North America. Van Nostrand Reinhold Company, New York.
- Bousfield, E.L. 1973. Shallow-water Gammaridean Amphipoda of New England. Comstock Publishing Associates, Ithica, NY.
- Fauchald, K. 1977. The Polychaete Worms. Definitions and Keys to the Orders, Families and Genera. Natural History Museum of Los Angeles County. Los Angeles.
- Gosner, K.L. 1971. Guide to Identification of Marine and Estuarine Invertebrates. Wiley Interscience, New York.
- Pollock, L. 1998. A Practical Guide to the Marine Animals of Northeastern North America. Rutgers University Press. New Brunswick, New Jersey.
- Rutecki, D. and M. Sweeny. 2022. Massachusetts Estuaries Project, Benthic Monitoring Quality Assurance Project Plan (QAPP). Prepared by Normandeau Associates, Inc., Falmouth, MA. 2022. 110 pp + Appendices.
- Smith, R.I. 1964. Keys to Marine Invertebrates of the Woods Hole Region. Marine Biological Laboratory, Woods Hole, MA.
- Sweeny, M. and D. Rutecki. 2019. Embayment-Specific Study Plan: Pleasant Bay Pilot Field Study for MassDEP Massachusetts Estuaries Project. Prepared by Normandeau Associates, Inc., Falmouth, MA. 45 pp.

US EPA (U.S. Environmental Protection Agency). 2021. National Coastal Condition Assessment 2020 Laboratory Operations Manual. Version 1.2. EPA- 841-F-19-004. U.S. Environmental Protection Agency, Office of Water. Washington, DC. 169 pp.

## Chain of Custody Form

Project Name: _____ Project Number: _____ Originating Contact: _____ Originator Location: _____ Final Destination: _____ Sampler(s): _____						Presv.		Parameters				Page    of	
												Method of Shipment:	
												Comments Below:	
Sample		Collection		Containers		Grab.	Comp.						
No.	Identification	Date	Time	No.	Type								
Total													

Relinquished by: (signature)	Received by: (signature)	Relinquished by: (signature)	Received by: (signature)	Relinquished by: (signature)	Received by: (signature)
Printed Name:	Printed Name:	Printed Name:	Printed Name:	Printed Name:	Printed Name:
Date:	Date:	Date:	Date:	Date:	Date:

Figure 1. Example of a Chain of Custody Form.

<b>PROJECT NAME:</b>			<b>BOX NUMBER:</b>	
<b>PROJECT CODE:</b>			<b>MANAGER:</b>	
<b>PROJECT DATE:</b>			<b>STORAGE DATE:</b>	
<b>SAMPLE DESCRIPTION:</b>				
<b>SAMPLE INFO:</b>			<b>PRESERVATIVE:</b>	
<input type="checkbox"/> RESIDUE	<input type="checkbox"/> CONT.	<input type="checkbox"/> VIALS	<input type="checkbox"/> 6% FORM.	<input type="checkbox"/> 70% ETOH

BoxLabel.AI\_2015

**Figure 2. Example of a Storage Label.**



## Storage Sheet

Project Name: \_\_\_\_\_

Project Year: \_\_\_\_\_

Page \_\_\_\_\_

Project Code: \_\_\_\_\_

**Project Manager:** \_\_\_\_\_

**Project Task:** ICH(IP) \_\_\_\_\_, ICH(Ent) \_\_\_\_\_, Benthos \_\_\_\_\_, Other \_\_\_\_\_

[illegible]

**Figure 3. Example of a Sample Storage Sheet.**

### **III. Laboratory Standard Operating Procedures for Sediment Analysis**

At each sampling site, the Field SOP instructs the crews to collect sediment samples for grain size analysis and total organic carbon (TOC). The field crew then ships the samples on wet ice to a subcontracted laboratory. Once the samples arrive, the laboratory will store the TOC samples in a freezer at -20°C and refrigerate the grain size samples at 4 °C. The holding time for grain size analysis and TOC is 28 days. For additional program details refer to the MEP Benthic Monitoring QAPP (MassDEP 2025a).

#### **1.0 Health and Safety**

The laboratory must require its staff to abide by appropriate health and safety precautions which includes wearing proper personal protection clothing and equipment (e.g., lab coat, protective eyewear, gloves). When working with potentially hazardous chemicals (e.g., weak acid), laboratory personnel must follow all manufacturer's Safety Data Sheet recommendations and avoid inhalation, skin contact, eye contact, or ingestion. Laboratory personnel must avoid contacting skin with acid. If skin contact occurs, remove clothing immediately. Wash the affected skin areas thoroughly with large amounts of water.

#### **2.0 Laboratory Equipment**

The analytical methods selected for grain size and TOC analysis specify the required equipment.

#### **3.0 Sample Receipt**

Upon arrival of the samples, the laboratory must inspect the samples promptly on receipt. As samples arrive, the laboratory must:

1. Record receipt of samples and sign the Chain of Custody (COC) form (Figure 1).
2. Inspect each jar THE SAME DAY THEY ARE RECEIVED:
  - a. Verify that the site identification and sample number on the label also appear on the COC form in the shipment.
  - b. Notify the Project Manager if any jars were broken and/or there are discrepancies between the COC form and jars.
3. Maintain the COC form with the samples; it will be needed if the samples are transported to any other location.
4. Check that each shipping container has arrived undamaged. Check the temperature of one of the samples in the cooler using a thermometer that reads from 21 °C (i.e., room temperature) down to -20 °C or lower (i.e., the expected temperature of frozen samples), or an infra-red (IR) temperature "gun" and record the reading. Field crew ships sediment samples on wet ice; the batch laboratory freezes the sample and ships with dry ice. Record the condition and temperature of the sample in the database.

5. Verify that all that all required data have been recorded by laboratory personnel (Table 3).
6. Transfer the TOC samples to the freezer for storage. Except during processing and analysis stages, the samples must be stored frozen to less than or equal -20 °C and transfer the samples for grain size analysis to the laboratory refrigerator.
7. Notify the Project Manager immediately concerning any problems involving sample integrity, conformity, or inconsistencies as soon as possible following sample receipt and inspection.

**Table 3. Sediment analysis sample data codes. Data codes are revised from NCCA 2020 (US EPA 2021).**

Field	Format	Description
EVENT_ID	Character	Identifier of sampling event (survey)
STAT_ID	Character	Station identification code as used on sample label
SAMPLE_ID	Character	Sample ID as used on chain of custody form (on sample label)
DATE_COLLECTED	MM/DD/YY HH:MM	Date sample that the field crew collected the sample
LAB_NAME	Character	Name of lab
DATE_RECEIVED	MM/DD/YY	Date sample was received by lab
ANALYSIS_TYPE	Numeric	GRAIN SIZE, TOC, or Contaminant
ARRIVAL_TEMP	Numeric	Temperature of sample upon arrival at the laboratory.
CONDITION_CODE	Character	Condition codes describing the condition of the sample upon arrival at the laboratory.
		Flag
		Definition
		OK
		Sample is in good condition
		C
		Sample container is cracked
		L
		Sample or container is leaking
		ML
		Sample label is missing
		Q
		Other quality concerns, not identified above (explain in COND_COMMENTS)
COND_COMMENTS	Character	Explanation for Q FLAG (if needed)

#### 4.0 Analytical Procedures

The laboratory shall perform analysis of sediment samples to determine grain size and concentrations of TOC. The laboratory will follow all QC/QA procedures for the analytical method being followed. No field-collected QC samples, including field duplicates, or

equipment and field blanks for sediment chemistry are required. Adequate sediment is collected for the analytical laboratories to perform the required matrix spike/matrix spike duplicate (MS/MSD) analyses.

#### **4.1 TOC**

TOC samples will be sent to an independent laboratory that uses the US EPA Method 9060. Results will be reported in units of mg/kg or % with a method detection limit (MDL) of 0.01% and a target accuracy of 10% (US EPA 2021).

#### **4.2 Grain Size Analysis**

Grain size can be done by any method that reports the determination as percent silt and meets QA/QC requirements. An example of one method is provided below.

##### ***4.2.1 Laboratory Equipment***

The following equipment is required for grain size analysis:

- Nest of 6 sieves (2 mm, 1 mm, 500  $\mu$ , 250  $\mu$ , 125  $\mu$ , and 63  $\mu$ )
- Two 5gallon receptacle bucket, on which nested sieves will snugly fit
- Sink with a spray nozzle
- Approximately 4 feet of rubber tubing
- Disposable tin foil and paper cupcake tins/baking cups or small similarly sized metal pans (any metal that can be heated to 135 °F)
- Drying oven (135 °F)
- Electronic digital scale (0.01 g accuracy)
- 500 ml squirt bottle filled with tap water
- Spoon or spatula

##### ***4.2.2 Procedure***

The procedure for grain size analysis is as follows:

1. Pre-weigh 7 pre-labeled cupcake tins (one for each of the sieve's contents plus the final wash water/silty-clay rinse product) and record the weight. For example, weight for tin labeled #1 corresponds to 2 mm sieve, tin #2 corresponds to 1 mm sieve, etc.).
2. Place the nest of 6 sieves in decreasing size, largest, 2 mm sieve on top, and 63  $\mu$  sieve on the bottom, over the 5-gallon bucket. Make sure the fit on the bucket is snug such that 100% of the water is retained by the bucket.
3. Place entire contents of the sediment sample into the top of the 6 nested sieves washing all residue from the container using a squirt bottle. If placing the entire sample is causing the sieves to clog, a smaller portion (for example  $\frac{1}{4}$  of the sample) can be placed into the top sieve and rinsed until the water has passed through all sieves, then another  $\frac{1}{4}$  of the sample placed in and rinsed through. The entire sample will be washed through the sieves, but in smaller increments instead of all at once.

4. Using the spray nozzle on the sink, gently spray the sediment contents in the top sieve until water coming through the sieve is clear. This can be determined by lifting the sieve up at an angle while gently spraying the contents.
5. Transfer contents to the corresponding tin using spoon or spatula and squirt bottle.
6. Repeat steps 2 through 5 for each of the sieves.
7. Residue left in the 5- gallon bucket is the  $< 63 \mu$  sized silt and will need to settle out of suspension by sitting undisturbed for 24 hours.
8. Place the cupcake tins into the drying oven set to 135 °F and let sit undisturbed until there is no sign of internal moisture within the residue (approximately 24 hours). Most samples are dry within 24 hours.
9. After the residue in the 5-gallon bucket has settled out for 24 hours, siphon off the clear water using the rubber tubing, stopping before any sediment is sucked up into the tubing. Place the residue into one (or more if needed) pre-labeled and pre-weighed cupcake tins using a squirt bottle. Place into the drying oven until dry.
10. Once all samples are dried, weigh the contents while still in the cupcake tin (0.01 g).
11. Discard contents.
12. Calculate the weight for each grain size by subtracting the pan weight from the total weight, and record on datasheet under each of the size categories.

Grain size will be classified following the Coastal and Marine Ecological Classification Standard (CMECS) sediment grain size descriptors (FGDC 2012) and reported as a percentage by weight in five categories as follows:

- Very coarse sand = sum of 2 mm and 1 mm sieve material
- Coarse sand = 500  $\mu$  to  $< 1$  mm (0.5 to  $< 1$  mm)
- Medium sand = 250  $\mu$  to  $< 500 \mu$  (0.25 to  $< 0.5$  mm)
- Fine sand = 125  $\mu$  to  $< 250 \mu$  (0.125 to  $< 0.25$  mm)
- Very fine sand = 63  $\mu$  to  $< 125 \mu$  (0.0625 to  $< 0.125$  mm)
- Silt =  $< 63 \mu$  ( $< 0.0625$  mm)

## 5.0 Data Entry

All data generated by the laboratory will be either electronically transferred from the instrument or manually read from the instrument display (e.g., digital scale display) and entered directly into an electronic format, or into laboratory forms and then manually entered into an electronic format. All manually entered data will receive 100% verification or will be entered and checked using double data entry. Standardized codes and qualifiers help to ensure consistency over time in a benthic monitoring program. Tables 3, 4 and 5 identify the required data codes that the laboratory must provide to the Project Manager for sediment samples.

Prior to the release of any data from the contracted laboratory, the data will be reviewed and approved by laboratory personnel. The review will consist of a tiered approach that will include reviews by the person performing the work, by a qualified peer, and by supervisory and/or QA personnel.

**Table 4. Analysis data codes for TOC and other parameters including contaminants with single result values. Data codes are revised from NCCA 2020 (US EPA 2021).**

Field	Format	Description
YEAR	Numeric	Survey year
EVENT_ID	Character	Identifier of sampling event (survey)
STAT_ID	Character	Station identification code as used on chain of custody form (on sample label)
SAMPLE_ID	Character	Sample ID as used on chain of custody form (on sample label)
SAMPLE_NUMBER	Character	Sample number as used on chain of custody form (on sample label)
DATE_COLLECTED	MM/DD/YY HH:MM	Date sample that the field crew collected the sample
LAB_NAME	Character	Name of lab
DATE_RECEIVED	MM/DD/YY	Date sample was received by lab
ANALYSIS_TYPE	Character	TOC or Contaminant
ARRIVAL_TEMP	Numeric	Temperature of sample upon arrival at the laboratory.
CONDITION_CODE	Character	Condition codes describing the condition of the sample upon arrival at the laboratory.
		Flag
		Definition
		OK
		Sample is in good condition
		C
		Sample container is cracked
		L
		Sample or container is leaking
		ML
		Sample label is missing
		NP
		Not enough preservative used
		VT
		Volume not sufficient for testing
		VR
		Volume not sufficient for retest, if required
		Q
		Other quality concerns, not identified above (explain in COND_COMMENTS)
COND_COMMENTS	Character	Explanation for Q FLAG (if needed)
PARAMETER	Character	Analyte name
METHOD	Character	Laboratory method used

**Table 4. Continued.**

Field	Format	Description
DATE_ANALYZED	MM/DD/YY	Date that the analysis started
HOLDING_TIME	Y/N	Analysis performed within holding time
MDL	Numeric	Lab method detection limit
RL	Numeric	Actual Reporting limit (based on the unique matrix of sediment for each batch of samples)
MOISTURE	Numeric	Moisture in the sample (value used by lab to convert wet units to dry)
MOIST_UNIT	Character	Unit used to report moisture (% or mg/kg)
DILUTION	Numeric	Dilution of sample (blank if no dilution)
RESULT	Numeric	Concentration value
RESULT_UNIT	Character	Unit of measurement for RESULT, MDL, and RL
QC_CODE	Character	Apply laboratory defined QC codes and describe in the comments field. Provide set of laboratory's code as part of the case narrative
COMMENT	Character	Explain situation that created QC code, or any unusual aspects

**Table 5. Sediment grain size analysis data codes. Data codes are revised from NCCA 2020 (US EPA 2021).**

Field	Format	Description
YEAR	Numeric	Survey year
EVENT_ID	Character	Identifier of sampling event (survey)
STAT_ID	Character	Station identification code
SAMPLE_ID	Character	Sample ID as used on chain of custody form (on sample label)
SAMPLE_NUMBER	Character	Sample number as used on chain of custody form (on sample label)
DATE_COLLECTED	MM/DD/YY HH:MM	Date sample that the field crew collected the sample
ANALYSIS_TYPE	Numeric	GRAIN SIZE
CONDITION_CODE	Character	Condition codes describing the condition of the sample upon arrival at the laboratory.

**Table 5. Continued.**

Field	Format	Description	
		Flag	Definition
		OK	Sample is in good condition
		C	Sample container is cracked
		L	Sample or container is leaking
		ML	Sample label is missing
		NP	Not enough preservative used
		VT	Volume not sufficient for testing
		VR	Volume not sufficient for retest, if required
		Q	Other quality concerns, not identified above (explain in COND_COMMENTS)
COND_COMMENTS	Character	Explanation for Q FLAG (if needed)	
PARAMETER	Character	Analyte name	
METHOD	Character	Laboratory method used	
DATE_PROCESSED	MM/DD/YY	Date that the analysis started	
HOLDING_TIME	Y/N	Analysis performed within holding time	
MDL	Numeric	Lab method detection limit	
RL	Numeric	Actual Reporting limit (based on the unique matrix of sediment for each batch of samples)	
MOISTURE	Numeric	Moisture in the sample (value used by lab to convert wet units to dry)	
MOIST_UNIT	Character	Unit used to report moisture (% or mg/kg)	
DILUTION	Numeric	Dilution of sample (blank if no dilution)	
PCT_Gravel	Numeric	Percentage of gravel	
PCT_VC_Sand	Numeric	Percentage of very coarse sand	
PCT_C_Sand	Numeric	Percentage of coarse sand	
PCT_M_Sand	Numeric	Percentage of medium sand	
PCT_F_Sand	Numeric	Percentage of fine sand	
PCT_VF_Sand	Numeric	Percentage of very fine sand	
PCT_Silt	Numeric	Percentage of silt	
PCT_Clay	Numeric	Percentage of clay	
UNIT	Character	Unit of measurement for RESULT, MDL, and RL	
QC_CODE	Character	Apply laboratory defined QC codes and describe in the comments field. Provide set of laboratory's code as part of the case narrative	
COMMENT	Character	Explain situation that created QC code, or any unusual aspects of the analysis	



## **6.0 Sample QC**

The laboratory will follow all QC/QA procedures for the analytical method being followed. The laboratory will also follow all laboratory in-house QA/QC procedures. QC activities include checking condition of samples upon arrival, storing sample appropriately, analyzing samples within the holding time, instrument calibration, and verifying all required data is recorded.

## **7.0 Sample Record Retention**

The laboratory shall retain original records, including laboratory notebooks and the reference library, for a minimum of 5 years. After the stated time period, the laboratory shall follow its internal protocols for disposal.

## **8.0 References**

- FGDC (Federal Geographic Data Committee). 2012. Coastal and Marine Ecological Classification Standard. June 2012. Marine and Coastal Spatial Data Subcommittee, Federal Geographic Data Committee. June 2012. FGDC-STD-018-2012. 343 pp.
- Rutecki, D. and M. Sweeny. 2022. Massachusetts Estuaries Project, Benthic Monitoring Quality Assurance Project Plan (QAPP). Prepared by Normandeau Associates, Inc., Falmouth, MA. 2022. 110 pp + Appendices.
- US EPA (U.S. Environmental Protection Agency). 2021. National Coastal Condition Assessment 2020 Laboratory Operations Manual. Version 1.2 March 2021. EPA- 841-F-19-004. U.S. Environmental Protection Agency, Office of Water. Washington, DC. 169 pp.
- .

## **IV. Laboratory Standard Operating Procedures for Underwater Still Images and/or Video**

Digital still images and/or video collected as part of the soft-bottom infaunal grab samples or hard-bottom/riprap destructive samples will be used as a visual record of the bottom habitat at the sampling location. These images will only be analyzed as described below if specifically stated in the Embayment Specific Study Plan. Still images and video footage collected from stand-alone surveys will be analyzed as part of the survey following the procedures described below. Analysis of digital still images and video will require a trained analyst for habitat characterization and benthic macrofauna identification. For additional program details refer to the MEP Benthic Monitoring QAPP (MassDEP 2025a).

### **1.0 Digital Still Images**

The following procedure will be used to analysis still images from macrofaunal sampling and stand-alone still image surveys.

#### **1.1 Laboratory Equipment**

- Still photograph captures (DVD or electronic file)
- A computer equipped with a photograph editing software

#### **1.2 Procedure**

Digital still image analysis begins with receipt of DVD or electronic copies of all images. The Chain of Custody (COC) form should be checked and filled out upon data acquisition. Digital sill analysis is typically accomplished using a square meter quadrat. However, in environments with poor visibility, a 0.5 x 0.5 meter quadrat is recommended to take the still photographs. Since visibility in shallow estuaries is typically poor, the 0.5 square meter quadrat and modified method may be required.

Digital still images collected for a still image survey will be analyzed using the following procedure. A total area of 1.0 x 1.0 meters will be analyzed in these images. If visibility was reduced and a 0.5 x 0.5 meter quadrat was used for the survey, combine the four photographs taken at each sample location into a single composite image covering the required 1.0 square meter area using a photograph editing software. Analyze each image for substrate type, habitat relief, sediment drape, and the relative abundance of macroalgae and macrofauna. Substrate types will be characterized for particle size following the Coastal and Marine Ecological Classification Standard (CMECS) sediment grain size descriptors (Table 6). Additional substrates that could be observed in digital images are presented in Table 7. Habitat relief, the difference in elevation between two surfaces, will be characterized as none, low, moderate, and high as described in Table 8. Drape, the visible layer of detrital material on the top of rock surface, will be characterized as absent, low, moderate, or heavy as described in Table 9. Relative abundance of macroalgae and macrofauna in each image will be determined by identifying organisms to the lowest practical taxon and using percent present per image. Percent present per image will be determined by using the photo editing

software to place a grid template consisting of 100 squares over each image and counting the number of squares a species occurred in for all species observed in the image. Each grid square represents 1% of the image. For digital still image surveys conducted along a transect, percent present for each species for the complete transect will be determined by averaging the percent present per image of all locations photographed along the transect. Relative abundance estimates of species in digital still images will be made based on the descriptions in Table 10. Evidence of fishing activities (e.g., trawl scars and lobster pots) and physical disturbances will be noted. The data from the video will initially be entered either on datasheets or directly into an Excel spreadsheet. Data entered on a datasheet will then be entered into an Excel spreadsheet. The spreadsheet will be delivered to the Project Manager.

**Table 6. Sediment grain size descriptors (FGDC 2012).**

<b>Descriptor</b>	<b>Grain Size (millimeters)</b>	<b>Class Sizes (phi)</b>
Clay	< 0.004	> 8
Silt	0.004 to < 0.0625	> 4 to 8
Mud	< 0.0625	> 4
Sand	0.0625 to < 2	4 to < -1
Very Fine Sand	0.0625 to < 0.125	4 to < 3
Fine Sand	0.125 to < 0.25	3 to < 2
Medium Sand	0.25 to < 0.5	2 to < 1
Coarse Sand	0.5 to < 1	1 to < 0
Very Coarse Sand	1 to < 2	0 to < -1
Gravel	2 to < 4,096	-1 to < -12
Granule	2 to < 4	-1 to < -2
Pebble	4 to < 64	-1 to < -6
Cobble	64 to < 256	-6 to < -8
Boulder	256 to < 4,096	-8 to < -12

**Table 7. Additional substrates that could be observed in digital images.**

Substrate	Description
Shell Hash	Surface substrate layers are dominated by loose shell accumulations with a median particle size of 2 mm to < 64 mm (granules and pebbles). Shells may be broken or whole (FGDC 2012).
Shell Reef Substrate	Substrate that is dominated by living or non-living cemented, conglomerated, or otherwise self-adhered shell reefs, with a median particle size of 4,096 millimeters or greater in any dimension. Live reef building fauna may or may not be present (FGDC 2012).
<i>Crepidula</i> Reef Substrate	Shell Reef that is primarily composed of conglomerated <i>Crepidula</i> shells (FGDC 2012).
Mussel Reef Substrate	Shell Reef that is primarily composed of self-adhered or conglomerated mussel shells (FGDC 2012).
Oyster Reef Substrate	Shell Reef that is primarily composed of cemented or conglomerated oyster shells (FGDC 2012).
Subcrop	Pieces of bedrock that have broken off but have not moved from its original location, or an occurrence of bedrock beneath a fairly flat-laying and widespread sediment deposit.
Talus	An accumulation of angular rock debris at the base of an outcrop that has occurred through periodic rockfall from the adjacent outcrop.

**Table 8. Habitat relief descriptions.**

Habitat Relief	Height (meters)
None	0
Low	0.1 to < 0.5
Moderate	0.5 to 2
High	> 2

**Table 9. Drape categories and descriptions.**

<b>Drape</b>	<b>Description</b>
Absent	Hard surface, encrusting, or fouling organisms are clearly visible
Low	A film of sediments covers less than 50% of the hard substrate or fouling organisms
Moderate	More than half of the hard substrate or organisms are covered or obliterated
High	Most of the hard substrate or encrusting/fouling organisms are covered and indistinguishable

**Table 10. Relative abundance descriptions for digital still images.**

<b>Relative abundance</b>	<b>Percentage</b>
Absent	The species was not observed in the still image
Rare	The species was observed in less than 1% of the still image or the transect average
Present	The species was observed in 1 to 25% of the still image or the transect average
Common	The species was observed in 26 to 50% of the still image or the transect average
Abundant	The species occurred in 51 to 100% of the still image or the transect average

## **2.0 Digital Video**

The following procedure will be used to analysis video footage from macrofaunal sampling and stand-alone video surveys.

### **2.1 Laboratory Equipment**

- High-Definition digital video footage (DVD or electronic file)
- Still photograph captures (DVD or electronic file)
- Computer equipped with a monitor and video viewing software (for example VLC media player) and photograph editing software (for example Adobe Photoshop™)

### **2.2 Procedure**

Video analysis begins with receipt of DVD or electronic copies of all video material. The Chain of Custody form should be checked and filled out upon data acquisition. The HD digital video footage will be reviewed for habitat characteristics and heterogeneity (i.e. substrate types, habitat relief, and sediment drape) and for biotic components. Substrate types will be characterized for particle size following the CMECS for sediment grain size (Table 6). Additional substrates that could be observed in the digital images are described

in Table 7. Habitat relief, defined as the difference in elevation between two surfaces, for the macroscale (1 to 10 meters) features observed in the digital images will be characterized as none, low, moderate, and high (Table 8). Sediment drape is the visible layer of detrital material on the top of rock surfaces composed of fine-grain sediment, phytodetritus, zooplankton fecal pellets, tubes, and mucus. Drape will be characterized as absent, low, moderate, or heavy (Table 9). Biotic components will include the presence and general characterization of epibenthic invertebrates, finfish, and habitat. Organisms will be identified to the lowest practical taxonomic level using standard taxonomic keys for the geographic area. Relative abundance estimates of organisms in digital video footage will be made based on the descriptions in Table 11. Evidence of fishing activities (e.g., trawl scars and lobster pots) and physical disturbances will be noted. Representative screen shots from the start, middle, and end of each video transect will be collected using the screenshot feature in a media player software (e.g., VLC media player). Additional still images may be extracted from the video if unique features or epibenthic organisms are observed. If still images are taken simultaneously with the digital video footage, the still images will be concurrently reviewed<sup>1</sup> for each transect and used to confirm benthic organism identification and estimates of relative abundance. The data from the video will initially be entered on datasheets and then into an Excel spreadsheet. The spreadsheet will be delivered to the Project Manager.

**Table 11. Relative abundance descriptions for digital video footage.**

Relative abundance	Description
Absent	The species was not observed in the video footage
Rare	The species was observed in less than 1% of the screens, i.e. length of the video monitor from top to bottom (representing, on average, 3 linear feet of substrate)
Present	The species was observed in 1 to 25% of the screens
Common	The species was observed in 25 to 50% of the screens
Abundant	The species was observed on more than 50% of the screens

### 3.0 Data Entry

All data generated by image analysts will be manually read from the instrument display (computer monitor) and entered directly into an electronic format (e.g., Excel spreadsheet), or entered into laboratory forms or datasheets, and then manually entered into an electronic format. All manually entered data will receive 100% verification or will be entered and checked using double data entry

---

<sup>1</sup> These still images are for verification purposes only and are not required to be analyzed following the procedures described in Section 1.0 above unless specifically requested in the Embayment Specific Study Plan.

Standardized codes and qualifiers help to ensure consistency over time in a benthic monitoring program. The underwater digital image codes are presented in Tables 12 and 13.

**Table 12. Underwater digital image survey codes.**

Field	Format	Description
EVENT_ID	Character	Identifier of sampling event (survey)
SURVEY_NAME	Character	Name of sampling survey
VESSEL_NAME	Character	Name of the vessel used for the survey
CHIEF_SCIENTIST	Character	Name of the scientist in charge of the survey
STAT_ID	Character	Station identification code
STAT_ARRIV_LOCAL	MM/DD/YY HH:MM	Station arrival date and time (local time)
BEG_LATITUDE	Numeric	Beginning latitude measured at each station (decimal degrees)
BEG_LONGITUDE	Numeric	Beginning longitude measured at each station (decimal degrees)
END_LATITUDE	Numeric	Ending latitude measured at each station (decimal degrees)
END_LONGITUDE	Numeric	Ending longitude measured at each station (decimal degrees)
NAVIGATION_CODE	Character	How station location was determined (e.g., LORAN-C, line of sight, survey map, etc.).
NAV_QUAL	Numeric	Estimated accuracy of navigation in meters.
DEPTH_TO_BOTTOM	Numeric	Depth to bottom in meters
COMMENTS	Character	Comments on survey detailing any exceptions from standard procedures

**Table 13. Underwater digital image analysis data codes.**

Field	Format	Description
EVENT_ID	Character	Identifier of sampling event (survey)
LAB_NAME	Character	Name of lab
STAT_ID	Character	Station identification code
DATE_COLLECTED	MM/DD/YY	Date image was taken
STAT_ARRIV_LOCAL	MM/DD/YY HH:MM	Station arrival date and time (local time)
IMAGE_DATE_TIME_BEG_LOCAL	MM/DD/YY HH:MM	Video only: Time of the beginning of this video (local time)
IMAGE_DATE_TIME_END_LOCAL	MM/DD/YY HH:MM	Video only: Time of the end of this video (local time)
USABLE_MINUTES	Numeric	Video only: Number of usable minutes between the image_date_time_beg and image_date_time_end
DEPTH_BEG	Numeric	Video only: Depth of water at image_time_beg (meters)
DEPTH_END	Numeric	Video only: Depth of water in at image_time_end (meters)
DEPTH	Numeric	Still only: Depth of water in which the image was collected
DATE_ANALYSIS	MMDDYY	Date of analysis
SUBS_CODE	Character	Codes describing the substrate observed in the digital image
		Code      Definition
		b      Boulders
		c      Cobbles
		cpgp      Cobbles pavement, gravel pavement
		cp+ob      Cobble pavement and occasional boulders
		g      Gravel
		gp      Gravel pavement
		mm      Man-made rocks
		mx      Mix
		null      No primary substrate code given
		rr      Riprap
		s      Sand
RELIEF_CODE	Character	Codes describing the habitat relief observed in the digital image
		Code      Definition (See Table 8)
		n      None
		l      Low
		m      Moderate
		h      High



**Table 13. Continued.**

Field	Format	Description
SED_DRAPE_CODE	Character	Codes describing the sediment drape observed in the digital image
		Code      Definition (See Table 9)
		a      Absent
		l      Low
		m      Moderate
		h      High
SUSP_MATTER_CODE	Character	Codes describing the suspended matter observed in the digital image
		Code      Definition
		h      High
		mh      Moderate to high
		vh      Very high
FAMILY	Character	Taxonomic family
GENUS	Character	Taxonomic genus
SPECIES	Character	Taxonomic species
TAXA_NAME	Character	Complete taxon name
REL_ABUND	Character	Codes describing the suspended matter observed in the digital image
		Code      Definition (See Tables 10 and 11)
		a      Absent
		r      Rare
		p      Present
		c      Common
		ab      Abundant
ANAL_COMMENTS	Character	General laboratory analysis comments

#### 4.0 Image Analysis QC

All appropriate high-definition video footage and still images will be analyzed. Video footage and still images will be examined for a range of substrate characteristics, sediment drape, and habitat relief; the occurrence of large identifiable taxa at each station; and evidence of fishing activities. Encrusting, cryptic, or very abundant taxa will not be counted from the video due to visual resolution and time constraints.

## **5.0 Sample Record Retention**

The laboratory or contractor analyzing the images shall retain original records, images, video including laboratory notebooks and Excel spreadsheet files, for a minimum of 5 years. After the stated time period, the laboratory or contractor shall follow its internal protocols for file disposal.

## **6.0 References**

- FGDC (Federal Geographic Data Committee). 2012. Coastal and Marine Ecological Classification Standard. June 2012. Marine and Coastal Spatial Data Subcommittee, Federal Geographic Data Committee. June 2012. FGDC-STD-018-2012. 343 pp.
- Rutecki, D. and M. Sweeny. 2022. Massachusetts Estuaries Project, Benthic Monitoring Quality Assurance Project Plan (QAPP). Prepared by Normandeau Associates, Inc., Falmouth, MA. 2022. 110 pp + Appendices.

## **V. Laboratory Standard Operating Procedures for Sediment Profile Imaging (SPI; Optional)**

### **1.0 Laboratory Equipment**

A computer equipped with a monitor and video reviewing software (for example VLC media player), photograph editing software (e.g., Adobe Photoshop™), and National Institutes of Health (NIH) ImageJ (open platform image analysis software) is required to analyze the SPI footage. Analysis of SPI data will require a trained analyst. For additional program details refer to the MEP Benthic Monitoring QAPP (MassDEP 2025a).

### **2.0 Procedure**

The sediment profile images will be reviewed within seven business days of survey completion to provide a “quick look” analysis. Parameters that will be evaluated in the “quick look” analysis are:

- Sediment grain size- categorized following the CMECS sediment grain size descriptors (Table 6)
  - Sediment layering, thickness, and type
  - Surface and subsurface fauna and structures
  - Approximate prism penetration
  - Approximate surface relief
- Approximate apparent redox potential discontinuity (aRPD) depth- categorized following the CMECS depth modifiers (Table 14)
  - Other major, readily discernable patterns

Within one week of completion of the “quick look” review, the results will be communicated to the Project Manager via an email summary of the survey.

Each image file will be labeled with station and replicate data. The first analytical step is accomplished by visually examining the images and recording all observed features into a preformatted, standardized spreadsheet file. The parameters to be measured are summarized in Table 15 and discussed in more detail in Appendix D of MassDEP (2025). Further details about these analyses can also be found in Rhoads and Germano (1986), Nilsson and Rosenberg (1997), Rosenberg et al. (2001), and Shumchenia and King (2010).

The videotapes also are analyzed visually, with all observed features also recorded into a preformatted, standardized spreadsheet. Photo editing software and NIH ImageJ are used to preprocess and analyze the three still images collected at each station. Computer analysis of each image is standardized by executing a series of macro commands. After visual and computer image analyses are completed, a standard set of parameters taken from both

analyses is combined and tabulated into an Excel spreadsheet. The SPI results, in the form of an Excel spreadsheet, will be delivered to the Project Manager.

### 3.0 Data Entry

All data generated by SPI analysts will be either electronically transferred from the instrument or manually read from the instrument display (video monitor) and entered directly into an electronic format (e.g., Excel spreadsheet). Standardized codes and qualifiers help to ensure consistency over time in a benthic monitoring program. Tables 16 and 17 show the parameters codes for the SPI survey and analysis. Prior to the release of any data from SPI analysis, the data will be reviewed and approved by a senior analyst.

**Table 14. aRPD Depth Modifier (FGDC 2012).**

<b>aRPD Depth Values</b>	<b>aRPD Depth (centimeters)</b>
Zero	0.0
Diffusional	> 0.0 to 1.0
Shallow	> 1.0 to 2.0
Moderate	> 2.0 to 3.5
Deep	> 3.5 to 5.0
Very Deep	> 5

**Table 15. Parameters Measured from Sediment Profile Images**

Parameter	Units	Method <sup>1</sup>	Description
Sediment Grain Size	phi (Φ)	V	An estimate of sediment types present. Determine by comparison of image to images of known grain size.
Prism Penetration	cm	CA	A geotechnical estimate of sediment compaction. Average of maximum and minimum distance from sediment surface to bottom of prism window
Sediment Surface Relief	cm	CA	An estimate of small-scale bed roughness. Maximum depth of penetration minus minimum.
Apparent Reduction-oxidation Potential Discontinuity Depth (from color change in sediment)	cm	CA	Estimate of depth to which sediments are oxidized. Area of aerobic sediment divided by width of digitized image.
Surface Features			
Pelletal Layer	—	V	Note if present
Bacterial Mats	—	V	If present, note color
Epifauna	—	V	If present, note and identify
Submerged aquatic vegetation	—	V	Note if present
Tubes			
• Type	—	V	Identify as amphipod or polychaete
• Density	Number	V	Estimate number (none, few, some, many)
Subsurface Features			
Methane/Nitrogen Gas Voids	Number	V	Count
Infauna			
• Visible Infauna	Number	V	Count, identify
• Burrow Structures Feeding	—	V	Count
(Oxic) Voids	Number	V	Count
• Successional Stage	—	V	Identify
Organism-Sediment Index (OSI)	—	CA	Derived from aRPD, Successional Stage, and Voids (Rhoads and Germano 1982, 1986)

<sup>1</sup> V: Visual measurement or estimate

CA: Computer analysis

**Table 16. Sediment profile imaging survey data codes.**

Field	Format	Description
EVENT_ID	Character	Identifier of sampling event (survey)
SURVEY_NAME	Character	Name of sampling survey
VESSEL_NAME	Character	Name of the vessel used for the survey
CHIEF_SCIENTIST	Character	Name of the scientist in charge of the survey
STAT_ID	Character	Station
STAT_ARRIV_LOCAL	MM/DD/YY HH:MM	Station arrival date and time (local time)
BEG_LATITUDE	Numeric	Beginning latitude measured at each station (decimal degrees)
BEG_LONGITUDE	Numeric	Beginning longitude measured at each station (decimal degrees)
END_LATITUDE	Numeric	Ending latitude measured at each station (decimal degrees)
END_LONGITUDE	Numeric	Ending longitude measured at each station (decimal degrees)
NAVIGATION_CODE	Character	How station location was determined (e.g., LORAN-C, line of sight, survey map, etc.).
NAV_QUAL	Numeric	Estimated accuracy of navigation in meters.
DEPTH_TO_BOTTOM	Numeric	Depth to bottom in meters
COMMENTS	Character	Comments on survey detailing any exceptions from standard procedures

**Table 17. Sediment profile imaging analysis parameter codes.**

Field	Format	Unit	Description
EVENT_ID	Character		Identifier of sampling event (survey)
LAB_NAME	Character		Name of lab
STAT_ID	Character		Station identification code
DATE_COLLECTED	MM/DD/YY HH:MM		Date image was taken
DATE_ANALYSIS	MM/DD/YY		Date image was analyzed
ANOXIC_VOID_NUM	Numeric		Number of water-filled spaces in sediment that appear to be abandoned feeding voids
AVG_PEN	Numeric	cm	Average penetration
AVG_RPD	Numeric	cm	Average depth of the apparent color redox potential discontinuity layer
BURR_NO	Numeric		Number of burrows
GAS_VOID_NUM	Numeric		Number of gas-filled spaces in sediment resulting from methanogenesis
GRN_SZ	Numeric		Sediment grain size
OSI	Numeric		Organism-Sediment Index
OXIC_VOID_NUM	Numeric		Number of active, water-filled spaces in sediment resulting from sub-surface feeding activity of infauna
PEN_MAX	Numeric	cm	Maximum penetration depth of camera
PEN_MIN	Numeric	cm	Minimum penetration depth of camera
RPD_MAX	Numeric	cm	Maximum depth of the apparent color redox potential discontinuity layer
SR	Numeric	cm	Surface relief across the 15 cm width of the face plate. Calculated as (PEN_MAX – PEN_MIN)
SUB_FAUNA_WORMS	Numeric		Infaunal worms counted
SUCC_STG	Numeric		Estimated infaunal successional stage
SUR_FEATURES	Numeric		Features on the sediment surface
TUBE_AMPH	Numeric		Amphipod tube
TUBE_POLY	Numeric		Polychaete tube

#### 4.0 Analysis QC

The QC objectives for SPI analysis are that (1) at least three images from each station will be analyzed, (2) all parameters defined in this SOP and in the Benthic Monitoring QAPP (MassDEP 2025a) will be analyzed for all images, and (3) that analytical systems used will enable repeatable measurements and determinations to be made.

The comparability of the SPI analyses will be ensured by using the same analyst throughout the project whenever possible. Slight variation in the manner in which the analyst examines the slide may occur. This may result in a slight variation of image areas analyzed within and between slides. To control for analyst error, 10% of all slides will be reanalyzed and the results compared to previous results. If any discrepancies with the original analysis are found then all images will be checked and reanalyzed.

## **5.0 Sample Record Retention**

The SPI contractor shall retain original records, images, video including laboratory notebooks and Excel spreadsheet files, for a minimum of 5 years. After the stated time period, the laboratory shall follow its internal protocols for disposal.

## **6.0 References**

- FGDC (Federal Geographic Data Committee). 2012. Coastal and Marine Ecological Classification Standard. June 2012. Marine and Coastal Spatial Data Subcommittee, Federal Geographic Data Committee. June 2012. FGDC-STD-018-2012. 343 pp.
- Nilsson, H.C., and R. Rosenberg. 1997. Benthic habitat quality assessment of an oxygen stressed fjord by surface and sediment profile images. *Journal of Marine Systems* 11: 249–264.
- Rhoads, D.C. and J.D. Germano. 1986. Interpreting long-term changes in benthic community structure: a new protocol. *Hydrobiologia* 142: 291–308.
- Rosenberg, R., H.C. Nilsson, and R.J. Diaz. 2001. Response of benthic fauna and changing sediment redox profiles over a hypoxic gradient. *Estuarine Coastal and Shelf Science* 53: 343–350.
- MassDEP. 2025a. Massachusetts Estuaries Project Marine Benthic Monitoring Quality Assurance Project Plan. CN 510.5. Massachusetts Department of Environmental Protection, Bureau of Water Resources, Division of Watershed Management, Watershed Planning Program. Worcester, MA. In cooperation with Normandeau Associates, Inc.
- Shumchenia, E.J., and J.W. King. 2010. Evaluation of sediment profile imagery as a tool for assessing water quality in Greenwich Bay, Rhode Island, USA. *Ecological Indicators* 10: 818–825.