Lower Duwamish Waterway Group

Port of Seattle / City of Seattle / King County / The Boeing Company

YEAR 3 MONITORING REPORT

Enhanced Natural Recovery/Activated Carbon Pilot Study

Lower Duwamish Waterway

FINAL

Prepared for:

The U.S. Environmental Protection Agency
Region 10
Seattle, Washington

The Washington State Department of Ecology
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TABLE OF CONTENTS

Page

TABLES

FIGURES

APPENDICES

ACRONYMS AND ABBREVIATIONS

AC	activated carbon
AOC	Administrative Order on Consent
AOC2	Second Amendment to the AOC
aRPD	apparent redox-potential discontinuity
ASTM	American Society for Testing and Materials
BC	black carbon
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
C_{free}	freely dissolved concentrations
cm	centimeter(s)
cm^2	square centimeter(s)
CSL	Cleanup Screening Level
DQO	data quality objective
dw	dry weight
Ecology	Washington State Department of Ecology
ENR	enhanced natural recovery
ENR+AC	enhanced natural recovery with activated carbon
EPA	U.S. Environmental Protection Agency
GAC	granular activated carbon
IDW	inverse distance weighted
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
m^2	square meter(s)
mg/kg	milligram(s) per kilogram
MLLW	mean lower low water
MTC	Materials Testing & Consulting, Inc.
ng/L	nanogram(s) per liter
NOC	natural organic carbon
PAC	powdered activated carbon
PCB	polychlorinated biphenyl
ppt	part(s) per thousand
PDMS	polydimethylsiloxane
PRC	performance recovery compound
PSEP	Puget Sound Estuary Program
QAPP	quality assurance project plan
RAL	remediation action level
ROD	record of decision
RTK	real-time kinematic
SPI/PV	Sediment profile imaging/plan view

SPME	solid-phase micro extraction
SQS	Sediment Quality Standard
TOC	total organic carbon
TVS	total volatile solid(s)
µg/kg	microgram(s) per kilogram
µm	micrometer(s)
UMBC	University of Maryland Baltimore County
ww	wet weight

EXECUTIVE SUMMARY

Introduction

In 2014, EPA and Ecology directed the Lower Duwamish Waterway Group (LDWG) to evaluate the potential effectiveness of using Activated Carbon (AC) with Enhanced Natural Recovery (ENR) treatment technology to remediate Polychlorinated Biphenyls (PCBs) in aquatic sediment in the Lower Duwamish Waterway (LDW). ENR sediment remediation technology, which is approved for full-scale implementation in the LDW, functions by adding a layer of clean material on top of contaminated sediment, accelerating natural recovery processes. The U.S. Environmental Protection Agency (EPA) and Washington State Department of Ecology (Ecology) were interested in whether the performance of ENR could be further improved by adding AC to the materials typically used for ENR, referred to herein as "ENR+AC". AC can bind PCBs that normally partition between sediment and porewater, reducing the PCB bioavailability and thus reducing the potential for exposure to PCBs in sediments and accumulation in the food chain. At the direction of EPA and Ecology, LDWG conducted a multi-year pilot study in the LDW to compare the performance of ENR+AC to ENR without AC.

This pilot study was specified under the Second Amendment (U.S. EPA, 2014) to the Administrative Order on Consent (AOC) for the Remedial Investigation/Feasibility Study for the Lower Duwamish Waterway (AOC2). The intent of the study, as articulated in AOC2, was as follows:

> *"The study is intended to help inform the remedial design for the LDW related to the implementation and effectiveness of remedial technologies. Study results will be used to re-assess and appropriately refine the technology assignment assumptions for ENR, ENR/AC, and (if approved by EPA and Ecology) ENR/AC/scour mitigation applications."*

The goals of the pilot study were as follows (AOC2):

- Verify that ENR amended with AC can be placed successfully in the LDW
- Assess the stability of ENR and ENR+AC over time in areas of high disturbance (e.g., scoured areas and vessel berthing areas)
- Evaluate the performance of ENR+AC compared to ENR alone in reducing PCB bioavailability in locations with a range of PCB concentrations
- Assess potential impacts of AC to the benthic invertebrate community that colonizes the ENR+AC materials after construction

Approach

The pilot study established three one-acre areas within the LDW representing different site conditions where ENR+AC and ENR would be compared. The study plots were an intertidal area subject to wind waves/ wakes and groundwater discharge, a scour area representative of areas throughout the site that may experience scour from propwash during vessel berthing, and a subtidal area.

The study plots were selected in accordance with the study goals in AOC2, including the goal to:

> *"Evaluate performance of ENR/AC compared to ENR alone in locations with a range of polychlorinated biphenyl (PCB) concentrations;"*

The target range of total PCB concentrations in AOC2 was expressed as follows:

> *"The study plots will be selected to include a range of PCB concentrations from the RAL (SQS) up to the CSL."*

The Sediment Quality Standard (SQS) is the same value as the Remedial Action Level (RAL; 12 milligrams per kilogram [mg/kg] organic carbon) for surface sediments in EPA's Record of Decision (ROD). As the Cleanup Screening Level (CSL; 65 mg/kg organic carbon) exceeds the ROD upper limit for ENR (36 mg/kg organic carbon), the study design per AOC2 was intended to test ENR and ENR+AC performance in locations that included levels above 36 mg/kg organic carbon at some locations so as to "re-assess and appropriately refine the technology assignment assumptions for ENR, ENR/AC, and (if approved by EPA and Ecology) ENR/AC/scour mitigation applications."

Based on data collected prior to the study (as reviewed in Amec Foster Wheeler (2015a; Appendix A), PCB concentrations in surface sediments collected from point locations indicated that concentrations ranged as follows for each plot:

- Intertidal plot: 9 mg/kg organic carbon to 150 mg/kg organic carbon
- Scour plot: 3 mg/kg organic carbon to 183 mg/kg organic carbon
- Subtidal plot: 4 mg/kg organic carbon to 180 mg/kg organic carbon

These data include PCB concentrations below the ROD RAL and above the upper limit for ENR.

Each of the study areas was divided into two one-half-acre subplots – one subplot for ENR only and one subplot for ENR+AC. From December 2016 to January 2017, each of the ENR subplots received a 6- to 9-inch layer of ENR material (a mixture of sand and gravel in the intertidal and scour plots and sand in subtidal plot). At each of the ENR+AC subplots, granular activated carbon

(GAC) was incorporated into the ENR material at a planned 4% AC content by weight based on the proportions of the sand, gravel, and AC feedstocks that were combined. As measured in samples collected from the barge immediately prior to placement, AC in the ENR+AC material was 4% in the subtidal ENR material and 2.7% in the scour and intertidal ENR materials. The differences between the 4% AC content added to the ENR by weight and the measured AC concentrations in the barges before placement in the scour and intertidal plots were attributed to losses during sample processing; sample preparation for the scour and intertidal plots required pre-sieving to remove gravel material (Amec Foster Wheeler et al., 2018a) and measured data from both plots were mass-corrected to account for the gravel fraction that was removed.

After construction completion in 2017, the plots were monitored for three annual post-construction monitoring events (2018, 2019, and 2020) using multiple lines of evidence, including measurements of PCB bioavailability using passive samplers; measurements of AC, total organic carbon, and PCBs; and underwater sediment-profile and plan-view photography to evaluate ENR and ENR+AC layer presence and thickness and benthic invertebrate colonization stages. In addition, during the third year of monitoring in 2020, a laboratory bioaccumulation study and a survey of benthic invertebrate community inhabiting the ENR and ENR+AC layers were conducted.

Results

A summary of the post-construction monitoring findings is presented below.

Table ES-1. Summary of Findings for Pilot Study Goals.

Study Question	Plot		
	Intertidal	**Scour**	**Subtidal**
Were the treatments placed successfully?	Yes	Yes	Yes
Were the treatments stable?	Yes	Yes	Yes
Were the treatments successful in reducing PCB bioavailability?	Yes Availability in both treatments reduced by more than 95%	Yes Availability in the ENR+AC treatment reduced by 50-90%; Availability in the ENR subplot was already low before treatment[1]	Yes Availability in both treatments reduced by more than 90%
Did adding AC improve the ability of ENR treatment to reduce PCB bioavailability?	Yes, very slightly	Unclear	No
Did adding AC impact benthic community?	No	No	No

Note(s):

1. Low baseline bulk-sediment and porewater PCB concentrations in the scour ENR subplot made it impossible to assess success in reducing PCB bioavailability in this subplot.

The following conclusions can be made from the pilot study:

1. **Placement was Successful and Material Remained In-Place**: The ENR and ENR+AC layers were placed successfully and remained in-place over the 3-year post-construction monitoring period. AC was incorporated into the ENR material at a planned 4% AC content by weight. As measured in the barge immediately prior to placement, AC in the ENR+AC material was 2.7% at the scour and intertidal plots and 4% at the subtidal plot. These lower AC levels measured in the scour and intertidal ENR+AC material are attributed to losses during sample processing. Further details are described in Section 3.2.3. Post-construction (Year 0) measurements showed that there was some AC loss during placement, but such losses were anticipated with this application method. AC content decreased over Years 1 to 3; however, these decreases in AC concentrations were attributed primarily to dilution from naturally deposited silt material and bioturbation (Tables 3.2-2 and 3.2-3). In the subtidal plot, barge bridle chain dragging also contributed to AC losses measured in the top 10 cm through mixing and dilution with underlying material and possibly through suspension and transport. Despite these processes, the content of AC in the layers through Year 3 remained at levels that have been shown in previous studies to be effective in enabling large reductions in PCB availability such that the pilot study was able to answer the study goals by comparing ENR and ENR+AC results (Section 3.2.3).

   There are several lines of evidence supporting the understanding that changes in AC concentrations over time were due primarily to dilution:

   - Increases of TOC concentrations and percent fines and corresponding decreases in AC concentrations together suggest that surface sediment was mixing with natural sediment deposits in the pilot surfaces (see Sections 3.2.1 and 3.2.3).

   - The selective removal of AC from buried intact ENR+AC areas is unlikely. Sediment cores were collected from the subtidal plot in Year 3 for the Year-3 laboratory biological study. Analysis of the Year-3 sediment cores collected from the subtidal plot showed that the ENR and ENR+AC materials remained intact, except in the southern-most portion of the subplots where bridle chain dragging had the greatest impacts. In the area affected by bridle chain dragging, the ENR and ENR+AC layers were not detected in the surface samples or SPI photos, presumably because they were absent, blended into the underlying sediment, or buried by silt to a depth of 18 inches or more.

- Sediment cores were collected by the Upper Reach Remedial Design team at five intertidal plot locations in July 2021. These intertidal plot cores penetrated the entire thickness of the ENR/AC layers, making it possible to measure the ENR and ENR+AC material thicknesses. The thicknesses of the ENR and ENR+AC layers in these cores indicates that there has been no loss since the material was placed, demonstrating stability of the ENR and ENR+AC layers in the intertidal plot for the study duration (see Section 3.2.4). These results are consistent with the Year-3 subtidal plot cores, discussed above, that demonstrated ENR and ENR+AC stability in the subtidal plot, except for the portion impacted by bridle chain disturbances. No layer-penetrating cores were collected at the scour plot.

- In all three plot areas, the ENR subplots showed no sign of AC migration from the ENR+AC subplots. Given the proximity of the subplots in each site and the tidal currents present, if AC were eroding from the ENR+AC subplots, we might expect to have found it in the adjacent untreated subplots. However, no measurable AC was found. Not finding AC in ENR only subplots could suggest that the AC remained in place, or that it was moved beyond the adjacent ENR subplots.

2. **Both ENR and ENR with AC Treatments Reduced PCB Bioavailability**: Both treatments performed well at plots where the performance could be most accurately assessed (subtidal and intertidal plots). At these plots, PCB bioavailability (the amount of PCBs in porewater available for uptake by biota) was reduced by ENR and ENR+AC by approximately 90% or more from pre-construction baseline. Conditions at the scour plot were not ideal for a comparison of ENR and ENR+AC, because of low baseline bioavailable PCB concentrations in the ENR subplot. In the scour ENR+AC subplot, PCB bioavailability was reduced by approximately 50-90% from baseline. However, the very low baseline PCB porewater concentrations in the scour ENR subplot were comparable to concentrations measured in the overlying LDW surface water (Windward, 2019), which made it difficult to detect a further reduction in bioavailability after placement of the ENR material. If baseline concentrations in the scour ENR subplot were similar to the other subplots, the scour ENR subplot is likely to have performed comparably to the other ENR subplots. Results of the bioaccumulation study also showed that the passive samplers could be used to predict PCB bioavailability and uptake by benthic organisms.

3. **AC did not Substantially Improve ENR Performance**: Year 1 to 3 passive sampling results in the intertidal and subtidal plots indicate that ENR reduced baseline PCB

bioavailability so much that any additional improvements by AC were difficult to detect. In both plots, Year 3 results at ENR and ENR+AC subplots were not meaningfully different. These conclusions were supported by an additional Year 3 bioaccumulation study using clams and polychaetes exposed to subtidal ENR and ENR+AC samples. ENR versus ENR+AC comparisons at the scour plot were inconclusive due to low baseline PCB porewater concentrations, especially in the ENR plot.

The observation that AC did not substantively improve ENR performance was unexpected. When designing the study, the overriding hypotheses were that ENR alone could achieve remedial goals and that the addition of AC would further enhance ENR performance. While the first was demonstrated, the second was not generally observed. We hypothesize the following:

- In general, ENR performed better than anticipated. The ENR subplots achieved 90% reductions in PCB bioavailability compared to baseline, rivaling results often reported for remedies using only AC at sediment sites. For example, at the Bremerton, WA site, AC reduced PCB bioavailability in the upper 10 centimeters (cm) of the sediment bed by an average 81±11% in the first 10 months after treatment, and by 90±6% after 33 months, reflecting a slight increase in performance and showing the stability of the amendment (Kirtay et al., 2018). Because ENR-only plots achieved 90% reductions in PCB bioavailability in the LDW pilot study, the opportunity to see improvements due to AC addition would have required concentration reductions greater than 90%.

- Mixing and dilution observed during the study was dominated by natural silt deposition and biological mixing. Sediment cores collected from the subtidal plot for the Year 3 biological study showed that the subtidal ENR and ENR+AC layers were substantially intact, except for the upstream most corner of the subtidal plot. In addition, five cores recently collected from the intertidal plot during upper reach remedial design showed intact ENR and ENR+AC layers. Because of this behavior, results were governed by surface sedimentation, dilution from surface sediment silt deposits, and overlying surface water dissolved PCB concentrations.

- Baseline whole sediment and porewater total PCB concentrations were relatively low compared to baseline levels in other AC studies, making the measurement of differences between subplot conditions difficult. A 90% reduction in bioavailable total PCB concentrations resulted in porewater concentrations that were relatively close to concentrations measured in the overlying LDW surface water. Further reductions contributed by AC were difficult to measure.

4. **AC did not Adversely Impact Benthic Communities:** Underwater photography evaluations conducted in Years 1 through 3 did not indicate an adverse effect of AC on the benthic community and provided evidence for benthic community recolonization with time. A benthic community survey conducted in Year 3 in all three plots also confirmed a lack of an AC impact. The few minor differences that were noted were attributed to the effects of physical disturbances and differences in silt accumulations, not AC, affecting habitat conditions in the subtidal and scour plots. These conclusions were also supported by the Year 3 bioaccumulation study, which observed no adverse effects on mortality or growth in clams and polychaetes exposed to the ENR or ENR+AC layers.

Conclusions

Overall, results indicate that both ENR and ENR+AC were successful in reducing PCB bioavailability under a wide variety of conditions in the LDW. ENR reduced PCB bioavailability so much that the improvements gained by adding AC were inconsequential. With few exceptions, multiple lines of evidence demonstrated that both the ENR and ENR+AC materials were generally stable over the 3-year monitoring period. No evidence was found for indicating an adverse effect of AC on benthic invertebrate communities.

YEAR 3 MONITORING REPORT
Enhanced Natural Recovery/Activated Carbon Pilot Study
Lower Duwamish Waterway

1.0 INTRODUCTION

The Lower Duwamish Waterway Group (LDWG) conducted a pilot study to evaluate the potential effectiveness of an innovative sediment technology in the Lower Duwamish Waterway (LDW). The study was designed to determine whether Enhanced Natural Recovery (ENR) material amended with activated carbon (AC) can be applied successfully to reduce the bioavailability of polychlorinated biphenyls (PCBs) in contaminated sediments in the LDW. The study compared the effectiveness of ENR amended with AC (ENR+AC) to ENR without added AC in three study areas (called *plots*) in the LDW. The three plots were referred to as the intertidal plot, the scour plot, and the subtidal plot. Each plot comprised two subplots, one with ENR alone, and the other with ENR+AC. Design and construction details were reported in the Construction Report (Amec Foster Wheeler, 2018a) and were summarized in the Year 1 Monitoring Report.

This pilot study was specified under the Second Amendment (U.S. EPA, 2014) to the Administrative Order on Consent (AOC) for the Remedial Investigation/Feasibility Study for the Lower Duwamish Waterway, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Docket No. 10-2001-0055, issued by the U.S. Environmental Protection Agency (EPA) and Washington State Department of Ecology (Ecology) on December 20, 2000. The Second Amendment to the AOC, which is referred to as AOC2, included a statement of work for the pilot study, including general provisions of the work to be performed, a list of study steps/tasks, and a schedule for deliverables. In accordance with AOC2, Amec Foster Wheeler et al., (2016a)[1] prepared a quality assurance project plan (QAPP) and supporting addenda that detailed the monitoring of the pilot study plots. The work described herein was performed in accordance with the EPA- and Ecology-approved QAPP and Errata (Amec Foster Wheeler et al., 2016a, 2016c) and QAPP addenda (Amec Foster Wheeler et al., 2016b, 2017, 2018a, and Wood et al., 2020).

1.1 PROJECT GOALS

The Record of Decision (ROD; U.S. EPA, 2014a) and AOC2 identified the goals for the ENR/AC pilot study to help inform the data quality objectives (DQOs) and engineering design of the pilot study plots. The ROD identifies the application of ENR in areas that meet the Remedial Action

[1] Amec Foster Wheeler is now "Wood Environment & Infrastructure Solutions, Inc."

Level (RAL) criteria specified for ENR. ENR also may include in situ treatment using activated carbon (or other amendments) pending the results of a pilot study to evaluate the effectiveness and potential impacts of amendment use (U.S. EPA, 2014a). Pilot study results will be used during design to assess and appropriately refine the technology assignment assumptions of ENR with respect to addition of AC.

The intent of the study, as articulated in AOC2, was as follows:

> *"The study is intended to help inform the remedial design for the LDW related to the implementation and effectiveness of remedial technologies. Study results will be used to re-assess and appropriately refine the technology assignment assumptions for ENR, ENR/AC, and (if approved by EPA and Ecology) ENR/AC/scour mitigation applications."*

The goals of the pilot study, as stated in AOC2, are:

- Verify that ENR amended with AC can be applied successfully in the LDW by monitoring physical placement (uniformity of coverage and percent of carbon in a placed layer)
- Evaluate performance of ENR+AC compared to ENR alone in locations with a range of PCB concentrations
- Assess potential impacts to the benthic community in ENR+AC compared to ENR alone
- Assess changes in bioavailability in ENR+AC compared to ENR alone
- Assess the stability of ENR and ENR+AC in scour areas (such as berthing areas)

The QAPP identified the following DQOs for the ENR/AC Pilot Study:

- DQO-1: Verify the Placement of the ENR and ENR+AC Materials – Determine whether the ENR and ENR+AC material can be placed in the subtidal, intertidal, and scour plots within the targeted specifications
- DQO-2: Evaluate the Stability of ENR and ENR+AC Materials – Evaluate the stability of the ENR materials and the stability of the AC material in the ENR matrix in the scour plot
- DQO-3: Assess Changes in Bioavailability in ENR+AC Compared to ENR Alone – For the purposes of the pilot study, changes in bioavailability are based on measurements of the bioavailable fraction of PCBs as represented by the porewater PCB concentrations. This was amended in QAPP Addendum 2 (Amec Foster Wheeler et al.,

2017) to include a laboratory bioaccumulation study in Year 3 of the pilot study, which was designed to "provide an additional line of evidence and evaluate the potential changes in PCB bioavailability in ENR+AC compared to ENR alone."

- DQO-4: Assess the Potential Impacts of AC on Benthic Communities – To determine whether the use of AC could adversely affect the benthic communities in the LDW, a benthic survey will be conducted in Year 3

This Year 3 Monitoring Report satisfies Task 5 of AOC2 which requires the Year 3 Monitoring Report to include the Year 2 and Year 3 monitoring results. The report also includes discussion of data collected from baseline, Year 0, and Year 1.

1.2 OVERALL APPROACH

The overall approach involved the construction of paired ENR and ENR+AC study subplots in three distinct areas in the LDW, representing intertidal and subtidal conditions and an area expected to be prone to sediment scour associated with berthing actions. Details of the engineering design, including ENR material grain size and AC specifications are provided in the Narrative Design Report (Amec Foster Wheeler et al., 2015a), and the plans and specifications for the construction of pilot plots (Amec Foster Wheeler et al., 2015b). The plot selection memorandum (LDWG, 2015) provided sediment results for LDW contaminants of concern, a physical description of the plots, and the basis for selecting each of the plot areas. Construction details were reported in the Construction Report (Amec Foster Wheeler et al., 2018a) and were summarized in the Year 1 Monitoring Report (Wood et al., 2019). An overview of the pilot study configuration is provided here.

The ENR and ENR+AC material was placed on sediments in three 1-acre plots that represent different physical conditions as follows:

- **Intertidal Plot (River Mile 3.9)**

  The intertidal plot represents intertidal conditions in the LDW, defined as sediments above -4 feet mean lower low water (MLLW)

- **Scour Plot (River Mile 0.1)**

  The scour plot represents subtidal areas of the LDW that may experience scour (e.g., berthing areas)

- **Subtidal Plot (River Mile 1.2)**

  The subtidal plot represents subtidal conditions in the LDW

Figure 1.1-1 shows the plot locations in the LDW and the locations of the ENR and ENR+AC subplots in each study area. Each plot is approximately 1 acre in size and each of the three plots is divided into two subplots, each approximately ½ acre in size.

The study plots were selected in accordance with the study goals in AOC2, including the goal to:

> *"Evaluate performance of ENR/AC compared to ENR alone in locations with a range of polychlorinated biphenyl (PCB) concentrations"*

The target range of PCB concentrations in AOC2 was expressed as follows:

> *"The study plots will be selected to include a range of PCB concentrations from the RAL (SQS) up to the CSL."*

The SQS is the same value as the RAL (12 milligrams per kilogram [mg/kg] organic carbon) for surface sediments in EPA's ROD. As the Cleanup Screening Level (CSL; 65 mg/kg organic carbon) exceeds the ROD upper limit for ENR (36 mg/kg organic carbon), the study design per the AOC amendment was intended to test ENR and ENR+AC performance in locations that included levels above 36 mg/kg organic carbon at some locations so as to "re-assess and appropriately refine the technology assignment assumptions for ENR, ENR/AC, and (if approved by EPA and Ecology) ENR/AC/scour mitigation applications."

Based on data collected prior to the study (as reviewed in Amec Foster Wheeler, 2015a, Appendix A), PCB concentrations in surface sediments collected from point locations indicated that concentrations ranged as follows for each plot:

- Intertidal plot: 9 mg/kg organic carbon to 150 mg/kg organic carbon
- Scour plot: 3 mg/kg organic carbon to 183 mg/kg organic carbon
- Subtidal plot: 4 mg/kg organic carbon to 180 mg/kg organic carbon

These data include PCB concentrations below the ROD RAL and above the upper limit for ENR.

1.3 STUDY PLOT DESIGN AND CONSTRUCTION

Because the goal of the pilot study was to evaluate the performance of ENR augmented with AC as compared with that of ENR alone, the pilot study evaluated side-by-side subplots. At each of the three plot locations, the design was to place a nominal 6- to 9-inch-thick layer of sand or gravelly sand ENR material. For each respective study plot, both subplots received the same base ENR material, at the same target thicknesses. The subtidal plot had only sand and the intertidal and scour plots had gravelly sand. For each respective plot area, ENR, and ENR+AC subplots were composed of the same materials and thicknesses, except that AC was added to the ENR+AC subplots. The planned AC dosage rate was 4% (by weight) AC in the ENR+AC material. This dosage rate is consistent with reports by others to reduce PCB bioavailability (Patmont et al., 2015). As measured in the barge immediately prior to placement, the measured AC in the ENR+AC material was 4% at the subtidal plot and 2.7% at the scour and intertidal plots. The differences between the 4% AC content added to the ENR by weight and the measured AC concentrations in the scour and intertidal plots were attributed to losses during sample processing. Sample preparation for the scour and intertidal plots required pre-sieving to remove gravel material (Amec Foster Wheeler et al., 2018a); measured data from both plots were mass-corrected to account for the gravel fraction that was sieved before analyses were performed. Regardless, and as discussed in Section 3.2.3, AC at 2.7% is well within the range of an effective AC dosage for the reduction of PCB availability.

The AC used in the ENR+AC material was "OLC 18X70 Coconut Fine Mesh Activated Carbon" (Calgon Corporation) and was well graded across the size range of 200 to 1,000 micrometers (µm; Amec Foster Wheeler et al., 2018a). Given that granular activated carbon (GAC) is defined as "having a minimum of 90% of the sample weight retained on a 180-µm standard sieve" (Rakowska et al., 2012), the AC used in the study is considered GAC, not powdered activated carbon (PAC). The GAC size range was selected for the following reasons:

- During design, there was concern that the use of PAC as compared to GAC could have resulted in an unacceptably high loss of AC during placement, resulting in failure to attain target AC concentrations in the ENR+AC subplots.
- Alternative AC delivery methods also were evaluated, including the use of an aggregate-coated delivery system such as AquaGate. This approach would have complicated the study, necessitating the addition of an uncoated aggregate to the ENR layer for comparison. Furthermore, the amount of aggregate needed to support the target PAC concentration would have overwhelmed the ENR layers with aggregate.
- Other delivery methods (e.g., Sedimite) did not allow homogenous AC mixing with the ENR material.
- Over the 3-year time frame of this pilot study, GAC will reach the same sorption equilibration as PAC (Kupryianchyk et al., 2013; Kupryianchyk et al., 2015; Thompson et al., 2016).

For the reasons noted above, EPA, Ecology and the project team selected GAC over PAC for an ENR application. The AC particle size distribution was specified to include a blend of relatively fine-grained AC (200 µm diameter) to more coarse-grained particles (1,000 µm diameter).

Prior to placement, all ENR and ENR+AC materials were wetted to saturate the AC material before placement. In order to minimize placement variability effects in data interpretation, the ENR and ENR+AC materials were placed at the study plots using an excavator capable of reaching 46 feet below the waterline and equipped with a 5-yard hydraulically operated environmental bucket modified to distribute the material evenly over the bucket footprint. The excavator was equipped with real-time kinematic (RTK) GPS to facilitate precision placement of the material. Construction was conducted over 39 working days between December 1, 2016, and January 26, 2017.[2]

The design specifications required 80% plot coverage with 6 to 9 inches ENR or ENR+AC material, respectively, and 100% of the plots with at least 4 inches of ENR/ENR+AC material. The thicknesses of the placed material for each of the subplots are summarized in Table 1.2-1; all plot areas achieved the minimum thicknesses of 6 inches, though in some cases more than 9 inches of material was placed. Average thickness of the placed material across the six subplots ranged from 9.5 to 13.7 inches (Amec Foster Wheeler et al., 2018a). The post-construction assessment of the plot areas determined that the ENR and ENR+AC materials were placed with enough precision to allow for comparison between ENR and ENR+AC subplots (Amec Foster Wheeler et al., 2018a).

2.0 SAMPLING AND ANALYSIS AND DATA QUALITY

This section describes the methods used for data collection and data analysis. Additional detail, analytical methods, and data quality assurance and control requirements are provided in the project QAPP documents (Amec Foster Wheeler et al., 2016a and b, 2017, 2018a, and Wood et al., 2020). A timeline of sampling activities is provided in Table 2.1-1.

To meet the project goals, the following five monitoring events were developed:

- Baseline monitoring was conducted between July and November 2016, prior to placement of the ENR and ENR+AC material. Baseline samples were collected to

[2] As stated in the Construction Report (Amec Foster Wheeler et al., 2018a) – "the means and methods used for this pilot project were appropriate for placement on a pilot scale but would not be practicable for full-scale implementation. In order to make full-scale placement practicable, higher production rates would need to be achieved. Results of this pilot suggest this is feasible while attaining AC target levels. Site conditions and other objectives will determine which methods are best suited for specific locations."

determine the concentrations of PCBs in sediment and porewater within each plot prior to placement of the ENR and ENR+AC material.

Prior to construction, the ENR and AC materials were analyzed for PCB congeners using EPA Method 1668C. In the ENR gravel and sand samples, the total PCB concentrations were less than 0.04 micrograms per kilogram dry weight[3] (µg/kg). In the AC material, the total PCB concentration was 0.035 µg/kg.

All ENR and AC materials had PCB concentrations below 2 µg/kg, the lowest LDW cleanup goal for PCBs. The ENR material also was tested for metals and organic compounds for comparison to benthic cleanup levels in the ROD; all chemicals were below their respective cleanup levels (Amec Foster Wheeler et al., 2018a).

- Placement confirmation (Year 0) monitoring was conducted in January and February 2017. Year 0 monitoring was used to document the thicknesses and evenness of the ENR and ENR+AC materials and the distribution and content of the AC in the ENR+AC subplots immediately after construction.
- Three Post-Placement Monitoring events at Year 1 (conducted from March to June 2018), Year 2 (conducted from March to June 2019), and Year 3 (conducted from July to October 2020)[4] were used to gather data on the stability and performance[5] of the ENR+AC layer over time, relative to the ENR layer at adjacent subplots. Additional studies conducted in Year 3 assessed the potential effects of AC on the benthic communities.

The remainder of Section 2 presents an overview of the methods used in the pilot study:

- Section 2.1 details the compositing approaches used in many of the key study measurement approaches
- Section 2.2 provides information on the Sediment Profile Imagery methods
- Section 2.3 details the measurement of sediment porewater salinity

[3] All sediment PCB concentrations are presented in dry weight concentrations.
[4] Sampling activities in Year 3 were delayed approximately 3 months from the original plan due to the COVID pandemic.
[5] Both in situ and ex situ porewater studies, and additional laboratory bioaccumulation tests using clams and polychaetas were used to analyze performance.

- Section 2.4 contains the methods of collection and analysis of bulk sediment samples, and preparation, deployment, retrieval, and analysis of passive samplers to measure PCB availability in sediment

- Section 2.5 contains the approaches for the Year 3 laboratory bioaccumulation study, using cores collected from the subtidal plot, and the benthic macroinvertebrate survey

- Section 2.6 provides information on the laboratory procedures used to analyze the sediment, porewater, and tissue samplers

- Section 2.7 notes deviations from the QAPP and results of data validation.

2.1 COMPOSITE SAMPLING DESIGN OVERVIEW

The sampling design, which is fully described in the Enhanced Natural Recovery/Activated Carbon Pilot Study QAPP (Amec Foster Wheeler et al., 2016b) and associated QAPP addenda, is summarized below.

Each subplot was divided into six grid cells from which individual samples were collected for composite sampling (Figure 2.1-1). Sample composites were comprised of individual samples collected from each of the six grid cells. Each grid cell was further divided into 24 location cells, numbered 1 through 24, to facilitate randomized sample location selections for each sampling event. Resampling individual composite cells was avoided.

At the outer edge of each study subplot (either ENR or ENR+AC), a 5-foot buffer was established to avoid sampling in areas potentially influenced by untreated sediments and to influence from the adjacent subplot (Figure 2.1-1). No samples were collected within the buffer zone.

For each monitoring year, three composite samples were generated for each subplot using six discrete subplot samples, respectively. The discrete samples were collected from six grid cells per subplot. The planned compositing scheme was as follows: within each grid cell, five discrete sediment and porewater samples were collected at six location cells determined by a random number generator. These samples were identified as “A”, “B”, “C”, “D”, or “E” composites. The porewater samples were collected with passive samplers, that is, solid-phase micro extractions (SPMEs). In Year 2 and 3, duplicate SPME collection was performed at “E” locations and designated as “F”. Composite samples of six discrete grab samples were created within each subplot from the five discrete sample groups (representing A, B, C, D, E, or F), which were composited together to form the A, B, C, D, E, and F composite samples. The schematic shown in Figure 2.1-2 illustrates the manner in which the composites for A, B, and C, are collected and composited. Figures 2.1-3 through 2.1-5 show the actual sample locations for each subplot over the monitoring years.

During the baseline, Year 1, and Year 2 sampling events, sediment and porewater composites formed with the D and E sample groups were archived pending analyses of the A, B, and C sediment and porewater results. These archived D and E composites were not analyzed because sufficient statistical power was achieved with A, B, and C composites and because analysis of the D and E composites would not likely change the findings (U.S. EPA, 2018). In Year 0, only A, B, and C composites were collected.

In Year 3, some individual SPMEs intended for A, B, or C composites were not recovered, so SPMEs intended for D, E/F composites were substituted to maintain five to six SPME locations per composite as described in QAPP Addendum 4 (Wood et al., 2020) and Appendix A. As in previous years, unused SPMEs were archived. The unused SPMEs were not analyzed based on results of the statistical power analysis. All SPME locations submitted for analysis are shown on Figures 2.1-3 through 2.1-5. Archived sample locations are shown in Appendix B and are not discussed further in this report.

Composite sampling approaches were used for the laboratory bioaccumulation study performed in Year 3 using cores collected from the subtidal plot. For the bioaccumulation study, six composite samples were generated—three per subplot—using six cores per composite, for a total of 36 cores; those cores were randomly located in each respective subplot area. Bioaccumulation Study composite sample locations are shown in Figure 2.1-6.

2.2 SEDIMENT PROFILE AND PLAN VIEW IMAGERY

Sediment profile imaging (SPI) has been used extensively to evaluate cap placement and stability at sediment capping sites. SPI combined with plan view (PV) images (SPI/PV), analysis processes, and interpretative frameworks are described in the project QAPP and the *Baseline SPI/PV Data Report* (Appendix F in Wood et al., 2019). Figure 2.2-1 includes a schematic of the SPI/PV. The camera system takes a high-resolution image of the seafloor (or river or lake bottom) as it approaches the seafloor, creating a plan view image. It then settles onto the bottom and the sediment-profile prism descends into the sediment bed surface. The SPI camera takes a picture of the upper 21 centimeters (cm; maximum penetration) of the sediment column in profile. The key SPI/PV parameters measured for the study and their interpretive value include:

> **Sediment texture, layering, and mixing:** Sediment grain size, strata (e.g., sand overlying silt) and the mixing between heterogeneous strata can be measured in the imagery. This allowed the texturally distinct ENR/ENR+AC materials to be identified and

mapped. Silt deposits that accumulated on top of the ENR/ENR+AC material over the course of the study were identified and measured when present.

SPI prism penetration depth: The distance the SPI prism passively descended into the bottom, measured as the SPI penetration depth, is a function of sediment consolidation. Because the same weight was used for all surveys, penetration depths for different sampling events could be compared. The measured penetration depths over time (from baseline through Year 3) provide a line of evidence on the presence of ENR/ENR+AC material, sediment bed consolidation, and the thickness of the silt deposits overlying the ENR/ENR+AC material.

Apparent Redox-Potential Discontinuity (aRPD) Depth and benthic ecological features: Following a disturbance, marine and estuarine benthic infaunal communities follow a predictable successional pattern described by Pearson and Rosenberg (1978) and Rhoads and Germano (1982, 1986). The illustration in Figure 2.2-1 shows this generalized progression from an initial community of tiny, densely populated, tubiculous, surface-dwelling polychaete assemblages (Stage 1) to a mature community of deep-dwelling, head-down deposit feeders (Stage 3). In Stage 3, distinctive feeding voids and aerated burrows are visible in the SPI images. The depth of the oxic surface sediments layer, the aRPD depth measured in the SPI images, is a function of biogenic mixing depth and intensity and is shallow immediately following a disturbance and deepens as benthic community recolonization progresses over time. The measured aRPD depths, designated successional stages, and number and depths of feeding voids (indicative higher-order or Stage 3 infauna) in the SPI images provide information on the relative status of benthic community recolonization at the test plots over time.

As part of the pilot study, SPI/PV imagery was collected at all plots during baseline and for Years 0, 1, 2, and 3. For the baseline effort, the sample design was to collect and analyze three replicate SPI/PV images from 12 stations in each plot (six stations per subplot); the subplots were divided into six grid cells and one station was identified for each grid cell. During Years 0 through 3, the sample design was to collect and analyze three replicate SPI/PV images from 24 stations within each plot (12 stations per subplot); two SPI/PV stations were sampled for each of the six grid cells in each subplot. The SPI/PV locations for each year corresponded to the grid cells used for bulk sediment sampling and SPME deployments.

For each event, SPI/PV images were collected approximately 1 to 3 months before sediment and porewater sampling to avoid potential short-term disturbances of the bottom by the SPI camera prior to other sampling activities. In addition, the SPI/PV image collection prior to sediment and porewater collection would allow potential changes to the sediment/porewater collection if plot conditions based on the SPI/PV imaging suggested that modifications to the methods were needed. The Year 0 SPI/PV results are available in the Construction Report (Amec Foster Wheeler et al., 2018a). The baseline and Year 1 SPI/PV data reports are provided as an appendix to the Year 1 Monitoring Report (Wood et al., 2019). The Year 2 and Year 3 SPI/PV data reports are provided in Appendix C to this report.

The timing of each SPI/PV survey is listed below:

- Baseline: July 2016
- Year 0: January/February 2017
- Year 1: March 2018
- Year 2: March 2019
- Year 3: June 2020

2.3 Porewater Salinity Sampling

Salinity was collected as an additional line of evidence used to evaluate the potential for groundwater upwelling and discharge through the sediment bed. Low salinity levels could indicate groundwater discharge (i.e., freshening). Of interest is whether groundwater discharge could explain variable porewater PCB results.

Porewater was collected by SCUBA divers using a syringe attached to a piezometer, which was inserted approximately 10 cm into the sediment (baseline) or ENR or ENR+AC material (Years 1, 2, and 3) (Amec Foster Wheeler et al., 2016b). Once the piezometer was inserted into the substrate, the syringe plunger pulled back creating a vacuum that pulled porewater from the substrate. After transport of the filled syringe to the surface, the porewater in the syringe was then injected into the conductivity meter (Myron L Ultrameter II 6P) and the temperature and conductivity were recorded. Salinity was calculated from temperature and conductivity measurements using the mathematical approaches used in EPA SW-846 Test Method 9050A (U.S. EPA, 1996). Porewater salinity samples were collocated with sediment core and SPME sample locations.

The following porewater salinity measurements were made in the baseline, Year 1, Year 2, and Year 3 events:

- Baseline event: porewater salinity was determined at 51 locations in the intertidal plot, 56 locations in the scour plot, and nine locations in the subtidal plot. The numbers of samples from the intertidal and scour plots differed because they were based on the number of successfully recovered SPMEs. Also, QAPP Addendum 1 reduced the number of salinity samples at the subtidal plot (Amec Foster Wheeler et al., 2016b).

- Year 1: porewater salinity was determined at 28 locations in the intertidal plot, 11 locations in the scour plot, and eight locations in the subtidal plot. The uniformity of salinity measurements during baseline in the scour plot allowed for the reduced number of salinity measurements during Year 1, in accordance with the QAPP (Amec Foster Wheeler et al., 2016a) and EPA and Ecology approval.
- Year 2: porewater salinity was determined at 53 locations in the intertidal plot, six locations at the scour plot, and six locations at the subtidal plot. As with Year 1, and in accordance with the QAPP (Amec Foster Wheeler et al., 2016a), EPA and Ecology approved an additional reduction in the number of salinity samples collected at the scour plot for Year 2.
- Year 3: porewater salinity was determined at 33 locations at the intertidal plot, 12 locations at the scour plot, and 12 locations at the subtidal plot.

2.4 Porewater and Sediment Sampling

Sediment porewater and bulk sediment were sampled in the 0- to 10-cm surface sediment interval for the baseline, Year 1, Year 2, and Year 3 monitoring events. Sediment samples were used to measure bulk sediment PCB concentrations and various physical properties including particle size distribution, total organic carbon (TOC), and the AC fraction of organic carbon. The method of measurement for the AC fraction changed between the baseline sampling event and the Year 1 sampling event, as described in Section 2.5.1 and in Addendum 3 (Amec Foster Wheeler et al., 2018b).

Porewater was sampled to measure the concentrations of freely dissolved PCBs (total C_{free} PCBs) using either in situ or ex situ SPME passive samplers. Silt deposition and silt movement occurred in some locations after material placement. The depth and transient nature of silt deposition in the scour plot made the deployment and retention of the SPME passive samplers less predictable. While silt deposition also was seen in the subtidal plot, the same problems were not encountered, because porewater was measured ex situ. Due to the depth and the transient nature of silt recorded in the scour plot in Years 1 and 2, the porewater and sediment sampling design was modified for the scour plot in Year 3 to factor in the influence of transient nature of the silt deposition. This modification is discussed later in this section.

In situ SPME exposures were used for the intertidal and scour plots, and ex situ SPME exposures were used for the subtidal plot. For the subtidal plot, ex situ SPME sampling was approved in QAPP Addendum 1 (Amec Foster Wheeler et al., 2016b) due to the high loss rates (e.g., >90%) of in situ SPME samplers during the baseline event. The high loss rate was attributed to vessels transiting through the subtidal plot area, with barge bridle chains dragging on the waterway bottom. While there also may be other causes for the disturbance, several observations strongly suggest that bridle chains are the most probable cause. During the baseline SPME deployment and retrieval events, divers reported that the waterway bottom was disturbed with furrows one to 1.5 foot wide parallel to the river flow (Amec Foster Wheeler et al., 2016b). These furrows appeared to have been created mechanically, compared to natural sand waves that typically are oriented perpendicular to the river flow (Amec Foster Wheeler et al., 2016b). During the study, field personnel reported repeatedly witnessing barges traveling along the river with their bridle chains dragging, and the paths of the barges coincided with the furrows observed by the divers.

Divers deployed and retrieved SPMEs in the scour plot, and in the intertidal plot during the baseline event. For Years 1-3, SPMEs in the intertidal plot were deployed and retrieved by hand at low tide. For the subtidal plot, sediment samples for bulk sediment analyses and for the ex situ SPME deployments were collected using a power grab sampler. Sediment samples were collected during SPME retrievals at the intertidal and scour plots. Collection of sediment samples at the subtidal plot was conducted at the same time that the sediments were collected for the ex situ exposures. Because sediment and SPME samples were collocated to represent the same locations, sediment samples were not collected from those locations where SPMEs could not be recovered or analyzed.

Typically, in situ SPMEs were retrieved after 4-6 weeks of exposure, and ex situ SPMEs were incubated for 7-9 weeks. Dates for all sediment and porewater sampling activities can be found in Table 2.1-1. Yearly sampling locations can be found in Figures 2.1-3 through 2.1-5. The sample collection date, plot, subplot, treatment type, sample ID, grid cell, location cell, composite (A, B, C, D, E, and F), and coordinates for the discrete samples are summarized in Appendix B Table B2. The compositing scheme follows the procedures described in Section 2.1. The laboratory results from the pre-sieved intertidal and scour plot samples were subsequently adjusted to account for the average weight of the gravel removed prior to analysis by the laboratories. Deviations are discussed further in Section 2.7 below.

Event-specific details associated with the porewater and sediment sampling are provided in Sections 2.4.1 to 2.4.5 below.

2.4.1 Baseline Porewater and Sediment Sampling

Sediment and SPME samples were composited for baseline analyses, as described in Section 2.1. At the intertidal and scour plots, in situ sediment-exposed SPMEs were deployed in the top 10 cm of the sediment surface. The in situ sediment-exposed SPME sampler (at intertidal and scour plots) exposure durations averaged 39 days (ranging from 32 to 45 days). During SPME retrieval, sediment samples were collected by divers using hand cores.

As shown in Appendix B Table B2-C, SPMEs at one out of 36 scour plot locations and two out of 36 intertidal locations were either not usable[6] or not recovered. These numbers pertain to primary SPMEs (A, B, C) and do not include backup SPMEs (D, E) as backup SPMEs were not analyzed. Sediment samples were not collected where SPMEs were not recovered so that sediment and SPME composites would represent matched locations in each subplot.

At the subtidal plot, sediment porewater was measured in the laboratory using ex situ exposure methods described in QAPP Addendum 1 (Amec Foster Wheeler et al., 2016b). At each study location, sediment for the ex situ SPME exposures were collected by inserting small diameter plastic core tubes into a grab sample obtained using a 0.2-square meter (m^2) pneumatically powered stainless-steel grab sampler. After transport of the cores to the laboratory, SPMEs were deployed in the top 10 cm in each individual core sample and were exposed ex situ for 51 days. Sediment samples for additional analyses were obtained from the same power grab samples used for the ex situ SPME exposure cores.

The C_{free} results from SPMEs exposed for longer time periods (i.e., subtidal SPMEs) would not necessarily be higher or lower than C_{free} results from SPMEs exposed to shorter time periods. The C_{free} results are based on equilibrium concentrations in the SPME, estimated using the loss rates of the Performance Reference Compounds (PRCs) that are added to the SPME prior to deployment. Thus, longer exposure durations do not bias C_{free} results, although longer durations generally improve C_{free} precision, accuracy, and detection limits.

2.4.2 Year 0 Sediment Sampling

In Year 0, after construction of the study plots was completed in January 2017, sediment was collected from each of the study plots to characterize grain size, total organic carbon (TOC), and total volatile solids (TVS) in the top 10 cm of the post-placement material.

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[6] Unusable SPMEs were those that, at the time of recovery, were mostly exposed to overlying water or were lying on the surface of the sediment.

An analytical method issue was discovered with the black carbon (BC) method planned for use in measuring the natural sourced GAC within the ENR material. Therefore, TVS was used during Year 0 sampling as an alternative to BC for measuring AC content in the plots. The BC method issue is described in QAPP Addendum 3 (Amec Foster Wheeler et al., 2018b).

Sediment samples were collected within the ENR+AC and ENR subplots at the intertidal, scour, and subtidal plots. Hand cores were collected at low tide on foot in the intertidal plot and by divers in the scour plot. Samples in the subtidal plot were collected using the same method as during baseline (power grab sampler).

Sediment samples collected from intertidal and scour plots were air dried so that samples could be sieved to remove the coarser gravel fractions in the ENR material. The weight of the coarse fractions (No. 4 sieve and larger) and the weight of the finer fractions (less than the No. 4 sieve) were recorded. The size fraction passing the No. 4 sieve (sand, silt, and clay fractions) were analyzed for TOC and TVS. Sediment samples from the subtidal plot were not air dried or pre-sieved prior to compositing and analysis because no gravel sized material was included in the ENR material at this plot. In addition, only in Year 0, the discrete samples from the ENR+AC subplots were also analyzed for both TOC and TVS to investigate variability within the subplots.

2.4.3 Year 1 Porewater and Sediment Sampling

In Year 1, SPME samplers were exposed in situ and ex situ following the same procedures used in baseline sampling. The in situ sediment-exposed SPME sampler (at intertidal and scour plots) had exposure durations averaged 42 days (ranging from 41 to 44 days). Samplers that were exposed ex situ in sediment cores (from the subtidal plot) had sampler exposure durations of 58 days. As noted for SPME baseline C_{free} results, the differences in exposure durations do not bias results.

Year 1 sediment samples were collected in the same manner as for Year 0. After samples were air dried and composited, samples from the intertidal and scour plots were sieved with a 3/8-inch sieve and a No. 4 sieve using the same procedure that was used during Year 0. As shown in Appendix B Table B2-C, SPMEs at 7 out of 36 scour plot locations and 3 out of 36 intertidal locations were either not usable[7] or not recovered. These numbers pertain to primary SPMEs (A, B, C) and do not include backup SPMEs (D, E) as backup SPMEs were not analyzed. Sediment samples were not collected where SPMEs were not recovered so that sediment and SPME composites would represent matched locations in each subplot.

[7] Unusable SPMEs were those that, at the time of recovery, were mostly exposed to overlying water or were lying on the surface of the sediment.

2.4.4 Year 2 Porewater and Sediment Sampling

SPME samplers in Year 2 were exposed in situ and ex situ following the same procedures used in Year 1. In addition to the 0- to 10-cm SPME deployments, 0- to 1-cm SPMEs were deployed in the scour and intertidal plots to measure PCB concentrations at the sediment-water interface.[8] Methods and results of the 0- to 1-cm SPME analyses are reported in Appendix D. The in situ sediment-exposed SPME sampler (at intertidal and scour plots) exposure durations averaged 39 days (ranging from 38 to 41 days). Samplers that were exposed ex situ in sediment cores (from the subtidal plot) had exposure durations of 57 days. As noted for SPME baseline C_{free} results, the differences in exposure durations do not bias results.

During the Year 2 event, sediment samples were collected in the same manner as for Year 1. After intertidal and scour samples were air dried and composited, samples were sieved with a 3/8-inch sieve and a No. 4 sieve using the same procedure that was used during Year 1. In each subplot at the scour plot, depositional material, mostly silt, was collected at 6 randomly determined locations with 2 cm or more of silt thickness to create a composite sample for bulk sediment chemical testing. The depositional material was taken from the hand cores collected by the divers.

SPME recoveries are shown in Appendix B Table B2-D. For the 0- to 10-cm SPMEs, 8 out of 36 scour plot locations and 2 out of 36 intertidal locations were either not usable or not recovered. For the 0- to 1-cm SPMEs, 10 out of 18 scour plot locations were either not usable or not recovered. These numbers pertain to primary SPMEs (A, B, C) and do not include backup SPMEs (D, E) as backup SPMEs were not analyzed.

2.4.5 Year 3 Porewater and Sediment Sampling

Year 3 SPME samplers were exposed in situ and ex situ following the same procedures used in Year 1 and as modified in QAPP Addendum 4 (Wood et al., 2020). The in situ sediment-exposed SPME sampler (at intertidal and scour plots) exposure durations averaged 46 days (ranging from 44 to 50 days). Samplers that were exposed ex situ in sediment cores (from the subtidal plot) had exposure durations of 63 days. As noted for SPME baseline C_{free} results, the differences in exposure durations do not bias results. During the Year 3 event, two different approaches, Type 1 and Type 2, were used for the deployment and collection of SPME and sediment samples at scour plot as described in QAPP Addendum 4 (Wood et al., 2020); the approach and corresponding results are summarized in Appendix D. In addition, at the scour plot, depositional material, mostly silt, from each subplot was collected at each SPME deployment location with ≥ 3-cm silt deposition to create a composite sample for bulk sediment chemical testing as described in QAPP Addendum 4 (Wood et al., 2020). Silt was collected from the sediment bed surface by manually

[8] The 0- to 1-cm SPMEs were deployed only during the Year 2 event.

moving silt material into a submerged sample jar. Sediment plumes generated during sampling suggest that some losses occurred during sampling, and those losses likely biased toward the loss of fines.

SPME recoveries are shown in Appendix B Table B2-E. For the Type 1 SPMEs, 9 out of 60 scour plot locations were either not usable or not recovered. For Type 2 SPMEs, 6 out of 60 scour plot locations were either not usable or not recovered. Twenty out of 60 SPMEs at intertidal locations were either not usable or not recovered. For the ex situ SPMEs, one out of the 60 subtidal plot locations was not recovered. The ex situ SPME that was not recovered may have been misplaced during removal from the jar or may have fallen out of the stainless-steel mesh envelope used to hold the SPMEs in transit to the analytical laboratory. These counts included both primary composite locations (A, B, C) as well as backup locations (D, E) as backup locations were used to substitute for missing primary location SPMEs. All ex situ SPMEs for scour plot depositional material sampling were recovered.

2.5 YEAR 3 LABORATORY BIOACCUMULATION STUDY AND BENTHIC MACROINVERTEBRATE SURVEY

Two biological studies were conducted in Year 3 – a laboratory bioaccumulation study (described in QAPP Addendum 2, Amec Foster Wheeler et al., 2017) and a benthic macroinvertebrate survey (Amec Foster Wheeler et al., 2016a). The approaches for these efforts are described in Sections 2.5.1 and 2.5.2.

2.5.1 Laboratory Bioaccumulation Study

The laboratory bioaccumulation study was designed as an additional line of evidence to address DQO-3: *Assess Changes in Bioavailability in ENR+AC Compared to ENR Alone*.

The laboratory bioaccumulation study exposed live organisms and SPMEs to subtidal plot ENR and ENR+AC material collected in Year 3. Results were used to compare PCB concentrations accumulated by the live organisms and in porewater SPME samples (reported as total C_{free} PCBs) after exposure to ENR and ENR+AC (Amec Foster Wheeler et al., 2016b). Although it was not a formal study objective, the study also allowed for comparison between bioaccumulation and C_{free} results to assess ability of C_{free} measurements to predict bioavailability at the site. The laboratory bioaccumulation study methods are described in Appendix E and summarized below.

The bioaccumulation study was performed using intact cores collected from 36 locations in the subtidal plot (18 locations in the ENR subplot and 18 locations in the ENR+AC subplot), as shown on Figure 2.1-6. Divers collected the sediment cores on August 10 to 12, 2020, using a hand-held coring device fitted with a slide hammer and a pre-cleaned 6-inch-diameter, 24-inch-long polycarbonate core liner. The target depth interval for the sediment cores was the uppermost 18 inches (45 cm) of sediment.

The bioaccumulation study was conducted at EcoAnalysts' laboratory (Port Gamble, Washington). The 28-day bioaccumulation study was conducted according to EPA/600/R-93/183 (U.S. EPA, 1993), ASTM Method E 1022-94 (ASTM International, 2013), and the project-specific QAPP Addendum 2 (Amec Foster Wheeler et al., 2017). The study used two test species – the polychaete worm (*Nephtys caecoides*) and the bivalve clam (*Mya arenaria*).

The bioaccumulation test was performed within the intact sediment core tubes; each core representing an individual replicate collected within one of three different subplot locations (A, B, or C). Each core included both test species and SPME fibers. A control sediment also was evaluated concurrently. Approximately 1.9 liters of overlying water was added to each core aerated with an air line, and each core was supplied with a continuous flow of seawater through an adjustable drip valve.

Upon test initiation, SPME fibers were inserted into the top 10 cm of the sediment within each core. Once SPMEs were deployed, organisms were added to each test chamber. A total of 20 *N. caecoides* and five *M. arenaria* were introduced into each test chamber. Due to the size of the clams and concern over maintaining healthy water quality for the duration of the test, one clam was removed from each of the ENR and ENR+AC chambers on Day 1, leaving a total of four *M. arenaria* in each test chamber (clams from control sediments were not removed). During test initiation, samples of *N. caecoides* and *M. arenaria* were sacrificed and preserved for chemical analysis as baseline tissue samples so that concentrations of PCBs in the organisms prior to exposure to the sediment could be quantified. SPMEs were also inserted into a seawater-only control core with no organisms or sediment, to measure total C_{free} PCBs within the flow-through seawater used for the test.

During the 28-day exposure, test chambers were maintained under flow-through conditions and water quality measurements were taken in all chambers daily. Notations were also made throughout the duration of the test on the vertical positioning of organisms within the core tubes, and these observations, as well as recovery of the organisms at the end of the study indicated that organisms primarily remained within the top 10 cm of the cores.

On Day 28, the study was terminated. First, SPME fibers were removed and packaged for cold storage. After SPME removal, the top 10 cm of sediment was removed from the core tube. A 4-ounce jar was filled with sediment collected from the top 10 cm of sediment for chemical analysis, then the remaining sediment was sieved to recover the clams and worms (Appendix E). The number of surviving clams and worms was recorded for each core.

Surviving *M. arenaria* (with more than 50% of the body above the sediment-water interface) were included in survival counts but excluded from tissue weights (for growth analysis) and from analytical samples due to concern that they were not as exposed as those buried. The number of unburied clams in each of the 36 core tubes ranged from 0 to 2 (Table 3-3 in Appendix E). Full details of survival and exposure to surface counts are shown in the 28-Day Survival Summary (Appendix E). All surviving *N. caecoides* that were found to be buried were included in their respective measurements of growth, mortality, and tissue analytical samples.

Before analyses, *N. caecoides* and *M. arenaria* recovered from the core tubes were depurated for 24 hours in clean conditions to allow the organisms to purge their digestive tracts of ingested sediment. After depuration, *M. arenaria* were shucked, and the soft tissue was placed in certified pre-cleaned glass jars, weighed, and frozen. *N. caecoides* were placed in certified pre-cleaned glass containers, weighed, and frozen. All test control tissues were processed as above and placed in certified pre-cleaned glass jars, weighed, frozen and archived at EcoAnalysts. Tissues from all pre-test and sediment exposures (except for the laboratory control) were shipped overnight on dry ice to the analytical laboratory where the samples were homogenized and composited.

Tissue, SPME, and sediment composites were created by combining samples from six cores into one composite sample. Three composites were created for each subplot each consisting of *N. caecoides*, *M. arenaria*, SPMEs and sediment. Biological samples were analyzed for PCB congeners and lipids; SPMEs were analyzed for PCB congeners; and sediments were analyzed for PCB congeners, particle size distribution, TOC, and AC.

2.5.2 Benthic Macroinvertebrate Survey Surface Sediment Collection and Field Processing

In Year 3, a benthic macroinvertebrate survey was conducted to compare the benthic communities that were established in each of the ENR+AC subplots to the benthic communities in the corresponding ENR subplots. A full description of the benthic macroinvertebrate survey is described in Appendix F.

Five replicate surface-sediment samples were collected from each subplot, 20-cm-diameter hand-operated “cookie cutters” at the locations shown in Figures 2.5-1, 2.5-2, and 2.5-3. The cookie cutter is a 20-cm-diameter, 12-cm-deep bottomless stainless-steel cylinder used to extract uniform samples from the sediment surface.

Sediment sampling for the survey varied slightly by plot:

- At the **intertidal plot**, samples were collected by hand using the 20-cm-diameter hand-operated cookie cutters by personnel that waded onto the plot at low tide. Samples were collected from locations with approximately 0.5 foot of water depth to increase the likelihood that epifauna would be present at the time of collection.
- At the **scour plot**, samples were collected by SCUBA divers using the 20-cm-diameter hand-operated cookie cutters.
- At the **subtidal plot**, samples were initially collected using a 0.2-square-meter power grab operated from the sampling vessel. Once on board the sampling vessel, the benthic sample was then collected from the power grab sample using the same 20-cm-diameter cookie cutter used for the other plots.

The sediment sample obtained from each location was processed in the field, on board the sampling vessel. Samples were first sieved through a 1.0-millimeter screen using filtered water drawn from the LDW. Organisms and debris collected on the screen were placed into sample containers with alcohol for transport to EcoAnalysts in Port Gamble, WA where they were preserved for storage until they could be sorted into taxonomic categories and enumerated at EcoAnalysts' taxonomic laboratory in Moscow, ID.

2.6 LABORATORY ANALYSES

The analyses conducted on sediment and porewater samples during each of the monitoring events are summarized below and shown in Appendix B. The laboratory records, reports, electronic deliverables, and chain-of-custody forms are provided in Appendix G. The laboratory analyses and QA/QC procedures were performed in accordance with the QAPP and QAPP addenda.

2.6.1 Sediment Samples

Composited sediment samples collected during the baseline sampling event were analyzed for the following parameters:

- PCB congeners by EPA Method 1668C, by Frontier Analytical Laboratory (Frontier)
- Grain Size by ASTM Method D422, by Alpha Analytical Laboratory (Alpha)
- TOC by EPA Method 9060 at Alpha
- Black Carbon (BC) by Gustafsson et al., (1997) at Alpha

Composited sediment samples collected during the Year 0 sampling event were analyzed for the following parameters:

- Grain Size by ASTM Method D422, by Alpha Analytical Laboratory (Alpha)
- TOC by EPA Method 9060 at ALS
- Total volatile solids (TVS) by Standard Methods SM 2540E at Alpha

Composited sediment samples collected during the Year 1, Year 2, and Year 3 sampling events were analyzed for the following parameters:

- PCB congeners by EPA Method 1668C, by Frontier
- Grain size by Puget Sound Estuary Program (PSEP), by Materials Testing & Consulting, Inc. (MTC)
- TOC by EPA Method 9060 at ALS
- AC/BC by Grossman and Ghosh (2009) at the University of Maryland Baltimore County (UMBC)

Total PCB concentrations in sediment were calculated as the sum of detected congeners for each composite.

As discussed in QAPP Addendum 3 (Amec Foster Wheeler et al., 2018b), during Year 0 it was determined that the original BC analysis method yielded results that were biased low. The Gustafsson (1997) method used to measure BC underestimated the amount of the AC present, as the AC selected in this study was a natural-sourced AC that was lost during the combustion steps used in sample processing. To address this issue, TVS was analyzed in Year 0 as a surrogate measurement for black carbon. This measurement was used to confirm the AC content of the ENR+AC materials during construction.[9] For Year 0, TVS represents the percent AC in the placed material.[10] The ENR material was tested prior to the addition of AC and organic carbon content was found to be negligible (i.e., 0.169% TOC in gravelly sand and 0.032% TOC in sand). This is because the materials were composed of mineral material (sand and gravel), and were not expected to contain substantial amounts of organic matter. This allowed the use of TVS to represent a measure of the AC added to the material in Year 0.

[9] The samples were collected from ENR+AC material coming down the conveyer belts prior to barge loading.
[10] Additional discussion on black carbon, TVS, and TOC measurements can be found in Section 2.1.3 of the Construction Report (Amec Foster Wheeler et al., 2018b).

A new approach was needed for monitoring AC in Years 1 to 3. Because conventional TOC and TVS methods cannot differentiate between BC (including AC), natural organic carbon, and inorganic carbonates, conventional TOC and TVS methods were not suitable for measuring AC in sediments after placement (i.e., Years 1 to 3). The Gustafsson method used to measure BC could not distinguish AC from natural carbon sources or combustion sources in the sediments depositing on the plots over time. The Gustafsson method involves two ignition temperatures, a low temperature to remove natural organic carbon (NOC) and a high temperature to remove BC (and presumably AC); weight differences after these two ignition points are used to measure NOC and BC, respectively. Year 0 results showed that the low-temperature ignition point inadvertently ignited coconut-fiber AC, which meant that AC could not be distinguished from NOC. The solution was to employ a more AC-specific method, the “Grossman and Ghosh AC/BC method” developed at UMBC. This method can differentiate between natural organic material found in native sediment and the AC that was placed with the ENR material without the loss of AC associated with the Gustafsson method. This is accomplished by using a chemical digestion method that removes natural organic carbon without affecting the AC (and BC); AC and BC are measured thermally, by ignition, after the natural organic carbon is removed. The Grossman and Ghosh (2009) method did not distinguish AC from black carbon sources depositing on the plots over time. The success of the Grossman and Ghosh method resulted in the use of the Grossman and Ghosh (2009) method to measure AC/BC in Years 1-3 of monitoring as outlined in QAPP Addendum 3.

As outlined in QAPP Addendum 3, grain size distributions were measured at different laboratories using different methods for different events. During the baseline and Year 0 events, Alpha measured grain size using ASTM Method D422. For Years 1 to 3, MTC measured grain size using PSEP. While there are some minor differences in the methods, mainly the use of some different sieve sizes, results are comparable when the samples are reclassified as gravel, sand, and fines using corresponding sieve sizes used by both methods. Further explanation is provided in Appendix C of the Year 1 Monitoring Report (Wood et al., 2019).

Measured data from intertidal and scour plots were mass-corrected to account for the gravel fraction that was sieved from analytical portion of the sample. The subtidal plot was constructed with sandy material rather than sandy-gravel, and therefore, sample data were not mass corrected for subtidal plot.

2.6.2 Porewater Samples

Porewater PCB concentrations were determined based on PCBs measured in SPME fibers. Following sediment exposures, SPMEs were maintained cold (4 degrees Celsius) until they could be processed. Processing consisted of compositing SPMEs from each composite group into a vial, followed by addition of solvent (hexane) to extract the PCBs from the SPME. Composited SPME extracts for baseline and Year 1, 2, and 3 monitoring events, and the Year 3 Bioaccumulation Study were analyzed for PCB Congeners by EPA Method 1668C. The passive sampling, compositing, and C_{free} quantification methods were performed in accordance with the QAPP, and the reports detailing the PCB C_{free} calculations for Years 2 and 3 are provided in Appendix A. Freely dissolved total PCB concentrations (total C_{free} PCBs) in sediment porewater were calculated as the sum of detected congeners for each composite, as calculated from the SPME fiber extract analyses per the methods in the QAPP. This congener summation approach was consistent for all total PCB concentrations presented in this report.

2.6.3 Tissue Samples

After weighing tissue samples and measuring growth, tissue samples from the Year 3 Bioaccumulation Study were homogenized and composited at Frontier Analytical Laboratory prior to analysis for PCB Congeners by EPA Method 1668C and for lipid analyses by gravitational methods.

2.7 PROJECT QUALITY ASSURANCE / QUALITY CONTROL

Data QA/QC includes a discussion of QAPP deviations during the pilot study, data validation and data qualifiers, review of C_{free} calculations, and data usability.

2.7.1 QAPP Deviations

The following are deviations from the QAPP documents:

- Porewater salinity was calculated from temperature and conductivity measurements that were made on board the sampling vessel or on shore using a conductivity meter rather than using an underwater conductivity meter as proposed in the QAPP (see Section 2.3).
- All benthic infauna samples were collected using a hand-operated 20-cm-diameter cookie cutter rather than a 0.1-m^2 van Veen grab sampler.
- Four clams, instead of five, were used for each tissue sample composite from laboratory bioaccumulation study.
- In all sampling events, recovery of SPMEs at the intertidal and scour plots was less than 100%. For some SPME composites, only four or five locations were composited rather than six, due to lost or unusable SPMEs. In Years 2 and 3, the composition of the composites was modified from the QAPP in the subplots with lower recoveries to increase the number of SPMEs to six (where possible) for analysis. See Appendix A for the details.

These QAPP deviations did not affect the data quality or data usability.

2.7.2 Data Validation and Data Qualifiers

Year 2 and Year 3 analytical data received from Frontier, ALS, MTC, and UMBC were validated by Sayler Data Solutions, Inc. PCB congener data were subjected to Stage 4 validation. TOC, activated carbon, and grain size data were subjected to Stage 2A validation. The data validation reports are provided in Appendix H.

The data were reviewed using guidance and quality control criteria documented in the analytical methods and the following project and guidance documents:

- Quality Assurance Project Plan – Enhanced Natural Recovery/Activated Carbon Pilot Study, Lower Duwamish Waterway (Amec Foster Wheeler et al., 2016a)
- National Functional Guidelines for Inorganic Superfund Data Review (U.S. EPA, 2014b)
- National Functional Guidelines for High Resolution Superfund Methods Data Review (U.S. EPA, 2016)
- National Functional Guidelines for Superfund Organic Methods Data Review (U.S. EPA, 2014c)

Data qualifiers were assigned during data validation if applicable control limits were not met, in accordance with EPA's data validation guidelines and the quality control requirements included in the referenced methods. The laboratory and data validation qualifiers and definitions are summarized in Appendix H.

In addition to the review and assessment of the documentation identified above, data packages subjected to the Stage 4 validation included verification of reported concentrations for the field and quality control samples, verification of intermediate transcriptions, and review of instrument data such as mass spectra to verify analyte identification procedures.

In all events, 32,569 data points were reported. Of these, 1,939 results (6%) were estimated (i.e., J/UJ qualified) and 11 results (0.03%) were rejected. Completeness was 99.97%.

Results were estimated (i.e., J/UJ-qualified) for the following reasons:

- Precision (replicates) greater than acceptance limits
- Isotope dilution standard recovery outside of acceptance limits

- Hold time exceeded
- The background concentration of PCBs that were detected in trip blanks exceeded the detected concentration and no PCB free concentration was reported. These results are considered not detected at the lowest available detection limit, the MDL
- Extent of PCB equilibration between porewater and SPME sampler is less than 20%. The reported C_{free} value has higher uncertainty due to the larger value used to estimate a steady state concentration in the passive sampler

Of the 15 mono- and di-chlorinated PCB congeners (PCB-01 to PCB-15), 11 non-detect results in sample LDW-Y2-IN-ENR+AC-CA-S010 were rejected. These results were rejected because the sample completely evaporated during laboratory preparations causing erratic internal standard injections and extracted internal standard responses.

2.7.3 C_{free} Calculation Review

In the Year 2 and 3 events, C_{free} concentrations and estimated detection limits (EDLs) or minimum level of quantitation (MLs) of each detected PCB were re-calculated by the validator following the procedure outlined in the C_{free} calculation reports included in Appendix A and compared to reported values, as outlined in the QAPP. Concentrations agreed within a reasonable variation for rounding differences. Calculated relative percent differences (RPDs) were between 0 and 5, indicating that the data was usable.

The data validator performed a calculation verification check on the conversion of SPME extract concentrations to C_{free} concentrations using PRCs.

In Year 2, the data from one of the trip blank samplers (LDW-Y2-IN-S010-TB) was rejected due to the following reasons:

1. Concentrations of PCB PRCs in LDW-Y2-IN-S010-TB were 20% or more lower than the other two trip blanks, indicating a potential analytical anomaly.
2. Approximately 70% of the concentrations of PRCs in the samplers exposed to the sediment were higher than concentrations of PRCs in LDW-Y2-IN-S010-TB.
3. If LDW-Y2-IN-S010-TB was used in the calculation process, many of the sample results would be incalculable due to the concentrations of PRCs in the exposed samplers being higher than average concentrations of PRCs in the trip blanks.

Therefore, after consultation with EPA and Ecology, the data from the other two trip blanks (LDW-Y2-SC-S010-TB and LDW-Y2-SU-S010-TB) were used to calculate the average concentration of the PRC in the polydimethylsiloxane (PDMS) at the beginning of the deployment.[11]

In Year 3, the data from one of the trip blank samplers (LDW-Y3-SC-S010-TB) was rejected due to the following reasons:

1. Concentrations of PCB performance recovery compounds (PRCs) in LDW-Y3-SC-S010-TB were 20% or more lower than the average of concentrations of PRCs in the other 3 TBs, indicating a potential anomaly.
2. Approximately 60-70% of the concentrations of PRCs in the samplers exposed to the sediment were higher than concentrations of PRCs in LDW-Y3-SC-S010-TB.
3. If LDW-Y3-SC-S010-TB is used in the calculation process, many of the sample results sample results would be incalculable due to the concentrations of PRCs in the exposed samplers being higher than average concentrations of PRCs in the trip blanks.

Therefore, after consultation with EPA and Ecology, the results from the anomalous LDW-Y3-SC-S010-TB sample were excluded from the calculation process such that data from the other three trip blanks (LDW-Y3-SU-S010-TB, LDW-Y3-IN-S010-TB and LDW-Y3-EXTRA-S010-TB) were used to calculate the average concentration of the PRC in the PDMS at the beginning of the deployment (as described in Appendix A). The anomalous result was expected to have been caused by variability in analytical processing and/or analysis. Sampler production is not expected to be a contributor to these anomalies as sampler preparation follows a detailed procedure with thorough QA/AC practices.

One sample (LDW-Y3-SC-ENR+AC-CB-S010-LONG) indicated concentrations for eight of the ten PRCs in the SPME that were slightly higher than the average concentration of PRCs in the three trip blank samples. This was observed for the eight most hydrophobic PRCs and may indicate limited equilibration of the sampler. Deploying samplers in conditions where mass transfer of compounds between the sediment porewater and passive sampler is limited results in limited equilibration. One common example of this is the sampler coming in direct contact with an impermeable surface such as solid rock, thus reducing contact with sediment porewater. The PRC results from just two PRCs were used to calculate C_{free} in this sampler. Because the calculation process relies on regression modeling[12], the use of only two PRCs does not allow an estimation of

[11] See Appendix A for additional details.
[12] See Appendix A Attachment A.

uncertainty around the C_{free} estimates for this sample. As a result, uncertainty values were not calculated for this sample.[13]

2.7.4 Data Usability

The bulk sediment, porewater and tissue data collected during Year 2 and 3 sampling events met the criteria set forth in the referenced quality assurance documents. Data validation resulted in 6% of results qualified as estimated. All results are acceptable for their intended use. The complete validated data sets are provided as EDDs in Wood et al., 2019 and 2021.

3.0 RESULTS AND DISCUSSION

Results are reported for the following:

- SPI/PV results (Section 3.1)
- Grain size distribution, silt deposition, carbon, and salinity results (Section 3.2)
- Bulk-sediment PCB results (Section 3.3)
- Porewater (SPME) PCB results (Section 3.4)
- Biological results, including bioaccumulation test results and benthic community findings (Section 3.5)

3.1 SPI/PV Results and Trends

This section describes the temporal trends in the primary SPI/PV observations and measurements made in the baseline survey in July 2016, the post-construction survey in January/February 2017 (Year 0), and during monitoring Years 1 through 3 (2018-2020). This is a high-level summary of the major SPI/PV survey findings. Appendix C-1 provides a detailed summary of the SPI/PV survey results for each of the five surveys (baseline and Year 0 through Year 3). The SPI/PV observations and measurements of the ENR and ENR+AC layers in Years 0, 1, 2, and 3 were useful in addressing DQO-1: *Verify the Placement of the ENR and ENR+AC Materials* and DQO-2: *Evaluate the Stability of ENR and ENR+AC Materials*. Additionally, the SPI/PV observations and measurements of benthic successional stages were useful in addressing DQO-4: *Assess the Potential Impacts of AC on Benthic Communities*. Observations of silt and other physical conditions were useful in providing supporting lines of evidence in interpreting passive sampling data used to address DQO-3: *Assess Changes in Bioavailability in ENR+AC Compared to ENR Alone*.

[13] See Appendix A Table A6 of Attachment A.

3.1.1 ENR/ENR+AC Material Stability and Visual AC Detection

Table 3.1-1 summarizes the observations of ENR/ENR+AC material presence and silt deposits at all plots over the course of the project. From Year 0 through 3, the ENR or ENR+AC material was present and intact in the SPI and PV images collected in all cells at the intertidal and scour plots. The material thickness was typically greater than the SPI camera penetration depth which averaged 11 cm or less at each plot following the placement of the coarse-grained material in Year 0 (Table 3.1-2), i.e., the SPI prism did not penetrate through the ENR/ENR+AC material so the thickness of the material could not be measured using this method with very few exceptions. At the subtidal plot, ENR/ENR+AC material was intact and present in cells 1 through 4 of both subplots, but was physically disturbed or not visually present in cells 5 and/or 6 of both subplots in Years 1 through 3. Subtidal plot cells 5 and 6 are subject to anthropogenic disturbance by barge bridle chain dragging (Amec Foster Wheeler et al., 2016b). Visual detection of AC amendments in the SPI/PV was limited across all surveys. A few images from Years 0 and 1 show very black sand and/or silt-sized particles in images from the ENR+AC plots. In Year 2, a single image from the subtidal ENR+AC subplot (cell 6) show a fine-grained, black surface layer that may be AC, possibly representing reducing conditions or a concentrated seam of AC. No definitive AC particles were observed in the Year 3 images from the ENR+AC subplots. This apparent decrease in visual detection over time may reflect the mixing of the AC particles into the sediment matrix and/or the coating of AC particles that change/conceal their appearance.

3.1.2 Silt Deposits

Table 3.1-1 also summarizes the silt deposits observed in the SPI/PV images throughout the study. Immediately following construction, a thin veneer of silt was observed overlying the ENR/ENR+AC material in all plots. Figures 3.1-1, 3.1-2, and 3.1-3 show the silt deposit and bottom disturbance patterns and representative images from each plot in Year 3. These figures illustrate the general patterns observed over Years 1 through 3. Over Years 1 through 3, consistent patterns of silt deposition and silt admixing into ENR/ENR+AC material were observed at the intertidal plot and over the downstream portion of the scour plot; and consistent patterns of bottom disturbance, silt admixing, and silt deposition were observed at the subtidal plot (Table 3.1-1).

At the intertidal plot, silt inputs are observed across both subplots and the silt is generally admixed into the ENR/ENR+AC matrix rather than being evident as a silt deposit overlying the material (Figure 3.1-1). A few intertidal locations exhibited thin (1 to 2 cm), compact silt layers over the material.

In Years 1 through 3, the scour plot consistently showed a distinct silt deposit over the entire ENR subplot and the adjacent half of the ENR+AC subplot, while the downstream half the ENR+AC subplot lack any silt, which is attributed to tug traffic/prop wash in that area that precludes the accumulation of silt. Evidence for prop wash included visual observation of tugboat maneuvering by field personnel, and the absence of silt deposition in the portion of the scour plot nearest the location of where tugboats would transit to their berths. The measured thickness of the scour plot silt deposit varied from year-to-year. The Years 1 and 3 silt layers averaged 9 and 4 cm over the ENR and ENR+AC subplots, respectively, while the Year 2 silt deposits were about half as thick, averaging 5 and 2 cm, respectively (Table 3.1-1).

The subtidal plot showed varying levels of silt deposition in Years 1 through 3 in the ENR and ENR+AC subplots (Table 3.1-1). In Year 1, silt was mixed into the ENR and ENR+AC material, but no distinct silt deposit layers were observed. In Year 2, relatively thin layers of silt were observed in cells 1 through 4 of both subplots (maximum thickness of 4 and 6 cm over the ENR and ENR+AC subplots, respectively). Distinct silt layers were not generally discernable in the chain-disturbed areas of cells 5 and 6. In Year 3, more silt was evident over cells 1 to 4 of the ENR+AC subplot compared with the ENR subplot (maximum thickness of 5 and 15 cm over the ENR and ENR+AC subplots, respectively).

3.1.3 ENR and ENR+AC Material Consolidation

Table 3.1-2 lists the average SPI prism penetration depth obtained at each plot/subplot over the course of the study. Figures 3.1-4, 3.1-5, and 3.1-6 present box and whisker plots of this penetration data for the intertidal, scour, and subtidal plots, respectively. Because the SPI camera was fully weighted for all surveys after construction, the penetration depths obtained are a good measure of the relative surface sediment bearing strength over time. It is clear from these data that the sediment bed became progressively firmer from the ENR/ENR+AC placement in early 2017 through the Year 2 survey in March 2019 (2+ years). This appears to be due to ENR/ENR+AC material settling/compaction over time, combined with the mixing of fines into the ENR/ENR+AC material interstices creating a substrate that grew more resistant to SPI prism penetration. The trend stopped in Year 3 when penetration depth either leveled off (intertidal plot) or increased some (scour and subtidal plots) reflecting the thickness of Year 3 silt deposits.

3.1.4 Benthic Community Recolonization

Figure 2.2-1 illustrates, and Section 2.2 describes the infaunal successional paradigm that guides the assignment of successional stages in SPI images. The measured aRPD depths, the designated successional stages, and number and depths of feeding voids in the SPI images from each survey are discussed here as lines of evidence on the degree of benthic community recolonization at the plots over time. It is important to note, however, that the often-minimal SPI prism penetration in areas with coarse-grained ENR/ENR+AC material at the sediment surface limited some of the measurements that could be made from the SPI images. As a result, either or both the aRPD depth and the presence of feeding voids at depth were often unmeasurable or indeterminate, resulting in indeterminate successional stage designations. An indeterminate successional stage classification means that the presence of Stage 3 infauna, the most advanced infaunal recolonization state, could not be ruled in or out. It does not mean that Stage 1 or 2 organisms were not present. Surface and near-surface macroinvertebrates were observed at all locations sampled with the SPI camera throughout this study. In addition, epifauna were observed in many of the collocated PV images.

Table 3.1-2 includes the average aRPD depths from each plot/subplot over the course of the study. Figures 3.1-7, 3.1-8, and 3.1-9 present box and whisker plots of the aRPD measurements for the intertidal, scour, and subtidal plots, respectively. Table 3.1-2 also includes the percent of all stations sampled from each subplot that exhibited Stage 3 infauna in at least one replicate.[14] Finally, Table 3.1-3 lists the number of feeding voids counted per subplot in Years 1 through 3; given the variable penetration obtained between surveys (Table 3.1-2), the number of voids per unit area was calculated and is included in Table 3.1-3. The number of feeding voids per square centimeter (cm^2) of the sediment column imaged from each survey is plotted in Figure 3.1-10.

Varying levels of benthic community recolonization are evident at each treatment plot, apparent differences, or lack thereof, between subplots are noted here.

- During the baseline survey, the predominately silty intertidal plot exhibited Stage 3 infauna in 67% of the 12 stations sampled (Table 3.1-2). In the Year 3 survey, the intertidal plot shows similar recolonization metrics between the two subplots, with both intertidal subplots showing evidence of Stage 3 at 25% of the stations. Of note, aRPD depths, Stage 3 percentage, and number of feeding voids/cm^2 was highest in Year 1 and have decreased since then (Table 3.1-2 and Figure 3.1-10). This appears to reflect the impact of reduced prism penetration over time (Figure 3.1-4) which biases aRPD measurements low and increases the percentage of indeterminate successional stages. Overall, the SPI benthic community indicators are very similar between the ENR and ENR+AC subplot, i.e., suggesting the AC amendment did not differentially affect the benthic community.

- The scour plot exhibited Stage 3 infauna at all locations sampled during the baseline survey (Table 3.1-2). It shows widespread evidence of Stage 3 infauna in Years 1

[14] Table 3.1-2 also lists the percentage of stations with indeterminate successional status (all replicates). As noted, the presence of Stage 3 infauna cannot be ruled in or out at these stations, it also does not mean that Stage 1 or 2 organisms are not present.

through 3. Stage 3 infauna have been observed at all ENR subplot stations since Year 1 (Table 3.1-3) and the density of feeding voids (#/cm²) in the scour ENR subplot is more than double the densities measured in the ENR+AC subplot (Figure 3.1-10). This difference between the subplots appears to reflect the difference in physical substrate characteristics between the subplots. The consistent absence of silt over the downstream half of the ENR+AC subplot led to low penetration depths which prelude successional stage designations. At this portion of the ENR+AC subplot, the differences in the benthic assemblage from the silt-covered ENR plot are expected, as the coarse-grained ENR+AC substrate is kept free of silt, presumably due to the presence of prop wash from vessel traffic. The silt-covered upstream portion of the ENR+AC subplot shows levels of Stage 3 infauna similar to that of the ENR subplot. For example, in Year 3, Stage 3 were present at all stations from cells 2, 4, and 6, adjacent to the ENR subplot (see Figure 2.1-4), but only observed at two of the six stations sampled in cells 1, 3, and 5 (see Year 3 SPI/PV Data Report in Appendix C). Overall, these data indicate that the physical substrate, i.e., silt versus sand and gravel, is the primary factor determining the apparent benthic infaunal community differences between the two subplots.

- During the baseline survey, the subtidal plot exhibited Stage 3 infauna at 50% of stations (Table 3.1-2), with Stage 1 or 2 noted elsewhere. In Years 1 and 2, the subtidal plot showed similar levels of recolonization over time between the ENR and ENR+AC subplots. The subtidal plot exhibited chronically low penetration depths, so aRPD depths are likely biased low and successional stages were indeterminate at many locations. In Year 3, the thicker silt deposit over the ENR+AC subplot versus the ENR subplot results in deeper aRPD depths and notably higher percentage of Stage 3 infauna in the ENR+AC subplot (Table 3.1-2). As at the scour plot, this difference in benthic assemblages between subplots appears to be a function of physical substrate differences between the subplots (i.e., the reduced penetration in and texture of coarser sediments limits the detection of Stage 3 organisms even if they are likely present) rather than the presence or absence of AC in the ENR material.

3.1.5 Benthic Physical Habitat Change – Baseline to Year 3

Figures 3.1-11 through 3.1-13 show SPI images from the intertidal, scour, and subtidal plots, respectively. Four images from each subplot, one each from the 2016 baseline (pre-construction) survey, the Year 0 survey (immediate post-construction in 2017), and the Year 1 (2018) and Year 3 (2020) surveys, are shown that provide examples of the gross changes in the upper sediment column composition in each subplot over time. Figures 3.1-1 through 3.1-3 show additional images from each plot and summarize the silt deposition and bottom disturbance patterns observed in Year 3.

Figure 3.1-11 shows that the intertidal plot (both subplots) was predominately silt prior to material placement. Macroalgae was also observed at a subset of locations. The sand and gravel ENR and ENR+AC material placed at the site in 2017 changed the surface sediment texture. A higher concentration of dark/black particles can be seen in the Year 0 ENR+AC image compared with the ENR only image, possibly representing reducing conditions or a concentrated seam of AC. Individual AC particles were not generally detected visually after Year 0, perhaps reflecting mixing with natural organic matter and dilution or developing a biofilm coating. In Year 1, ambient silts mixed into the ENR material matrix were evident at some locations while other areas remained mostly coarse-grained, this pattern was similar on both subplots. By Year 3, a mix of silt and ENR/ENR+AC material was present at most locations sampled (Figure 3.1-1), macroalgae and evidence of biogenic mixing were also widespread.

Figure 3.1-12 shows time-series images from the scour plot. The baseline substrate was predominately silt, but a thin shell and sand lag deposit observed on the sediment surface in cell 1 of the ENR+AC plot suggested that that area was subject to periodic high energy events. The Year 0 images from both subplots show the gravel and sands placed throughout, and dark AC particles are evident in the ENR+AC image. At Year 1, the upstream ENR images show a thick layer (averaging 9 cm across the subplot) of silt overlying the ENR material. The ENR+AC image from downstream cell 3 exhibits only ENR+AC material in Year 1. The Year 3 ENR+AC image from cell 2 adjacent to ENR subplot shows a silt deposit overlying the ENR+AC material (Figure 3.1-12). A thicker deposit of silt is seen at the ENR cell 2 image at the upstream end of the plot. Overall, due to the accumulation of silt across ¾ of the scour plot blanketing the ENR/ENR+AC material, the benthic habitat/sediment texture of the upper sediment column (top 10 cm approximately) resembles the silt-dominated baseline condition 3 years following construction.

Figure 3.1-13 shows time-series images from the subtidal plot. The baseline substrate was predominately silt, but a chaotic fabric (i.e., dark and light sediment patches in the sediment column and stratigraphic banding at depth) in some images suggested periodic physical disturbance. The Year 0 images from both subplots show the sand placed at the plot. The presence of dark AC particles in the ENR+AC images versus the ENR image is more visually subtle than in gravel/sand mixtures place at the other plots. The Year 1 image from the ENR subplot shows the compact silt mixed with ENR sands that was typical of cells 1 through 4 in both subplots. The ENR+AC Year 1 image from cell 5 shows a substrate where the ENR+AC material has been disturbed by the barge bridle chain dragging (Amec Foster Wheeler et al., 2018a). The Year 3 ENR+AC image shows a recolonized silt deposit (feeding void in middle, right of image) overlying the ENR+AC material. The Year 3 ENR image is from an area where the ENR material was disturbed. The benthic habitat in the downstream 2/3 of the subtidal plot approaches the baseline habitat condition as silts accumulate over the sands placed there. The upstream area of the plot remains an area subject to anthropogenic physical disturbance (Figure 3.1-3).

3.2 Grain Size Distribution, Silt Deposition, Carbon Analyses, ENR/ENR+AC Layer Thickness, and Porewater Salinity

This section reports the results for grain size distribution and carbon content of bulk sediment for the baseline, Year 0, Year 1, Year 2, and Year 3 sampling events; the measurements of salinity in porewater; thicknesses of silt deposition upon the ENR and ENR+AC materials for Years 1, 2, and 3; and an evaluation of ENR/ENR+AC layer thickness at the subtidal plot for Year 3. Evaluation of grain size and AC content helped understand the placement stability of the ENR and ENR+AC materials (DQO-1: *Verify the Placement of the ENR and ENR+AC Materials* and DQO-2: *Evaluate the Stability of ENR and ENR+AC Materials*), PCB bulk chemistry results, and C_{free} results. Several ancillary lines of evidence were used to address DQO-3: *Assess Changes in Bioavailability in ENR+AC Compared to ENR Alone*. Porewater salinity helps understand the potential for groundwater upwelling. The evaluation of silt thickness informs how silt deposition influences bulk sediment results, including TOC, AC, and grain size, all of which affect bulk sediment and porewater C_{free} PCB concentrations. ENR and ENR+AC layer thickness at the subtidal plot confirms the vertical thickness and stability of the ENR and ENR+AC materials.

3.2.1 Grain Size (Percent Fines)

Percent fines under baseline conditions ranged from 50 to 80% in all three plots and decreased after placement of the coarser-grained ENR and ENR+AC materials **(**Table 3.2-1, Figures 3.2-1 and 3.2-2). At Year 0, shortly after placement of the ENR and ENR+AC materials, the percent fines decreased to a range of 0.2 to 2% fines (Figure 3.2-2). After the drop in percent fines between baseline and Year 0, the median percent fines increased or remained relatively constant every year in most subplots (Table 3.2-1; Figures 3.2-3 through 3.2-6).

The increase in mean total percent fines over time was most pronounced in the subtidal plot. The intertidal plot saw little increases in percent fines after the Year 1, where the average percent fines remained less than 5% (baseline percent fines in the intertidal plot were 52% in ENR, and 53% ENR+AC). There was no overall significant difference in mean percent fines between ENR and ENR+AC subplots (p = 0.131) using an ANOVA with data from all plots for Year 1, Year 2, and Year 3, with mean total percent fines as the dependent variable and subplot and plot as independent variables. Baseline and Year 0 were excluded from the analysis because they took place prior to or immediately after material placement. However, when a Wilcoxon rank sum test was run for each independent plot, using data from Years 1-3, there was a significant difference between ENR and ENR+AC found in the subtidal plot ($p = 0.0018$) only. This is likely due to evidence of barge bridle chain dragging affecting one subplot more than the other. The intertidal and scour plots were not found to have significant differences in percent fines between ENR and ENR+AC.

In Year 3, two sampling approaches took place in the scour plot, identified as Type 1 and Type 2. Type 1 samples involved undisturbed locations, in which overlying silt was left in place. Type 2 samples involved the clearing of silt when silt deposits were 3 cm or more in thickness (see Section 2.4.5 and Appendix D). The silt material resting on top of the scour plot ENR and ENR+AC layers also was collected[15] and measured; silt on the ENR plot had average of 68% fines and silt on the ENR+AC plot had average of 48% fines. In this case, the difference in percent fines was related to silt deposition and was not construction related.

The increases in percent fines in all three plots over time are attributed to natural sedimentation of fine-grained sediment onto the ENR and ENR+AC layers and the integration of those fines into the interstitial pores of the ENR and ENR+AC materials. Natural sedimentation is supported by SPI/PV observations and the measured silt thicknesses in all three plots over the 3-year monitoring period. The higher percent fines measured in all three plots under baseline conditions, ranging from approximately 50 to 80%, also supports this observation—the percent fines under baseline conditions may be viewed as a surrogate for natural sediment deposits in the vicinity of all three plots. This depositional material, with much higher percent fines, are mixed with the ENR and ENR+AC materials that had minimal percent fines immediately upon placement.

In addition, sieving data (percent mass retained on the 3/8-inch sieve, percent mass retained on the #4 sieve, and the percent mass passing the #4 sieve) from individual core samples within the scoured area of the scour ENR+AC subplot (Figure 3.1-2) was reviewed to evaluate the stability of the ENR materials in this area. On Figure 3.2-7, 12 individual cores collected within the scoured area are shown along with data collected immediately after placement (Year 0) from the ENR+AC subplot. These data showed that immediately after placement (Year 0), the percent mass retained on the 3/8-inch sieve was on the order of 35%, and the mass retained on the #4 sieve was around 8%. Thus, over 40% was very large material consisting of the coarse sand and gravel mix used for the ENR+AC layer. Looking at the samples collected during Year 3, a majority of the results

[15] Silt was collected from the sediment bed surface by manually moving silt material into a submerged sample jar. Sediment plumes observed during sampling suggest that some losses occurred during sampling, and those losses likely biased toward the loss of fines.

exhibit a similar pattern to Year 0. These data indicate that the ENR+AC material was present, even in the area that had been subjected to scour by the tugboats.

3.2.2 Silt Deposition Patterns

In addition to SPI surveys, silt thickness was measured in the field during SPME deployments and core sampling events in Years 1, 2, and 3. Sites where trace amounts of silt were observed but exact measurements were not possible were assumed to have a 0.5-cm-thick layer. Estimates of silt layer thickness is provided in Table 3.2-2 and shown in Figures 3.2-8 through 3.2-10; the figures interpolate the depositional patterns by plot and year. Thicknesses of the silt layer overlying the ENR and ENR/AC layers by plot and subplot by year are shown in Figures 3.2-11, 3.2-12, and 3.2-13 for Years 1, 2 and 3, respectively.

Differences in silt thicknesses are used to understand and interpret other parameters, including TOC, AC, percent fines, and PCB concentrations. Whether those differences are statistically significant is important only insofar as those differences could influence other measurement comparisons between subplots. The differences are not attributed to the type of material placed in each subplot (i.e., the presence of ENR or ENR+AC would not cause difference in silt accumulation). Generally, siltation was least in the intertidal plot and greatest in the subtidal plot, especially in Year 3. This is consistent with SPI/PV observations and percent fines results for these two plots.

Differences in silt thicknesses between subplots were statistically significant in the scour plot in all 3 years of monitoring (Years 1, 2, and 3) with the ENR subplot having deeper silt deposits than the ENR+AC subplot. This is consistent with SPI/PV observations that showed the northern half the ENR+AC plot was consistently denuded of silt deposits (Figure 3.1-2), likely due to tugboat and other shipping activity in the area. The southern half of the ENR+AC subplot saw silt levels that were comparable to the ENR subplot. These results also are consistent with the percent fines results (ENR percent fines were greater than ENR+AC percent fines in Year 2 and in Type 1 samples in Year 3). Overall, the tugboat disturbances were sufficiently impactful in the northern portion of the scour ENR+AC subplot (i.e., preventing silt accumulation) such that they lowered the average silt thickness and percent fines of the entire subplot.

3.2.3 Carbon Measurements

As discussed in Section 2, the Gustafsson et al. (1997) method did not work for samples containing naturally sourced (coconut) AC. Therefore, the amount of carbon present in the samples was compared using BC in Baseline (Gustafsson et al., 1997 method), TVS in Year 0, and AC/BC during Years 1, 2, and 3 (Grossman and Ghosh 2009 method). The results are shown in Table 3.2-1 and Figures 3.2-14 and 3.2-15. The AC concentrations are represented by black carbon at baseline, TVS at Year 0, followed by AC/BC measurements using the Grossman and Ghosh (2009) method in Years 1 to 3. In general, the AC/BC measurements are best for evaluating the presence of AC in the ENR+AC layers, whereas the TOC measurements provide information on natural organic matter (mixed with any natural BC or added AC) that deposited on or mixed with the ENR and ENR+AC over Years 1, 2, and 3.

In the baseline event, mean BC levels were between 0.092 and 0.36% in all plots using the Gustafsson et al. (1997) method (Figure 3.2-14 and Table 3.2-1), confirming the low levels of BC in sediments prior to addition of the ENR/ENR+AC layers. Average baseline TOC concentrations were 1.4 and 1.5% in the intertidal plot, 2.7 and 2.1% in the scour plot, and 1.8 and 2.1% in the subtidal plot, for the ENR and ENR+AC subplots, respectively.

The ENR subplots had similar mean percentages of BC (Baseline) and AC/BC (Year 1); however, the mean percent TVS (Year 0) was consistently higher than either BC or AC/BC measured at Years 1 through 3 (Table 3.2-1 and Figure 3.2-14). In addition, TVS levels were higher than TOC levels measured at Year 0. This is likely an artifact of the change in methods and does not necessarily reflect appreciable levels of AC/BC at Year 0 in the ENR subplots.

In the ENR+AC subplots, the percent BC at Baseline was comparable to the ENR subplots. At Year 0, the mean percent AC/BC increased substantially, from less than 0.5% at Baseline to between 2 and 3% at Year 0. This increase in AC/BC in the ENR+AC plots is attributed to the addition of AC in the ENR material, though results from the ENR subplots suggests that a fraction of the measured AC/BC may be an artifact of the TVS method.

The TOC results add to the understanding of carbon distributions in the three study plots. In all three ENR subplots, mean TOC levels at Year 0 decreased to close-to-zero levels after placement of the ENR material, which is naturally low in TOC. Between Year 0 and Year 3 in ENR subplots, mean TOC increased significantly (t-test $p < 0.001$; Figure 3.2-15) due to the natural deposition of fine-grained material on the surface of the plots.

In Year 3, measured AC/BC concentrations in the ENR+AC material was 1.5%, 1.3%, and 0.47% in the scour, intertidal, and subtidal plots, respectively. This was lower than the pre-application measurements of 4% in the subtidal plot and 2.7% in the intertidal and subtidal plots. While the target AC concentration was to achieve 3-5% AC by weight, lower levels of 0.25%-1.5% AC have been demonstrated to be effective in reducing PCB availability by up to 97% (Geosyntec, 2016; Geosyntec, 2019; Nybom et al., 2015; Kirtay et al., 2018). Thus, the presence of 0.5 to 1.5% AC at

Year 3 should have been sufficient to enable meaningful levels of PCB bioavailability reduction as a result of PCB sorption by AC.

This difference between measured and targeted concentrations is attributed to multiple possible factors. First, the average concentration of AC/BC measured (by TVS method) in ENR+AC material used at the scour and intertidal plots (as measured from samples obtained from the barge immediately prior to application) was 2.7% (Amec Foster Wheeler et al., 2018b). Samples of the ENR+AC material used at the subtidal, however, averaged 4% (as measured by TVS method). Second, some carbon (especially the finer fractions) was lost to the water column during placement, as indicated by visual plumes of carbon during placement. Third, some carbon may have segregated so it may not be evenly distributed throughout the ENR+AC layers. Fourth, since the gravelly sand material needed to be sieved to remove large particles from the sample prior to analysis, some AC would have been retained on the larger gravel fraction during sample processing. As described in the construction report (Amec Foster Wheeler et al., 2018a), these samples had to be dry-sieved. During dry-sieving, AC adherence to the sieved gravel fraction or airborne particles (dust was observed during processing) may have led to some losses of fine AC material and a resultant underestimation of AC content. Last, different measurement methods may also contribute to variability in the measurements (e.g., AC prior to placement was measured by weight whereas during Years 0 through 3 AC was measured in laboratories using various loss-by-ignition methods). Understanding the differences between in-place AC measurements as achieved (i.e., 2.7%) versus the pre-application design specification (4% by weight) was part of the pilot study goals. Discrepancy in the planned and achieved AC values does not imply the inability to accurately construct ENR+AC treatments in the LDW.

Baseline TOC levels averaged 1.9±0.5% across all plots, and at Year 0, TOC levels averaged 0.07±0.3% in the ENR subplots and 1.8±0.0% in the ENR+AC subplots (Figure 3.2-15 and Table 3.2-1). For Years 1, 2, and 3, data suggest that AC levels decreased over time in the ENR+AC materials from the approximate 2.5 to 3% levels observed in Year 0 to approximately 1.3%, 1.5%, and 0.47% in the intertidal, scour, and subtidal plots, respectively, in Year 3 (Figure 3.2-14 and Table 3.2-1). Differences between the three plots, discussed below, are due to the very different physical conditions to which the three plots were subjected.

Natural sedimentation, including silt deposition onto the surface of the ENR+AC layers and influenced by benthic recolonization and bioturbation seen in the SPI/PV images, led to the accumulation of silt onto the ENR and ENR+AC surfaces and the mixing of surficial silt deposits with the ENR and ENR+AC materials. These processes would have led to the dilution of AC concentrations as AC blended with natural organic carbon. Evidence for these processes can be seen by the measurement of silt on the sediment surfaces using sediment samples

(Figures 3.2-11, 3.2-12, and 3.2-13), increased TOC levels in the ENR subplots over time (Figure 3.2-15), and varying increases in the percentage of fines over time (Figure 3.2-6). These processes contributed to decreasing AC/BC trends in the ENR+AC subplots over time (Figure 3.2-14), in addition to potential AC losses to the overlying water during construction.

General observations regarding AC for each of the three plots are presented below:

- In the intertidal ENR+AC subplot, AC averaged around 2% during Years 1 and 2, and was 1.3% in Year 3 (Figure 3.2-14). The intertidal plot saw the least amount of sedimentation and likely experienced the least amount of physical disturbance compared to the scour and subtidal plots. The Year 3 AC decrease in the intertidal plot is likely attributed to the mixing of silt in the ENR+AC sediment pore structure, and to some extent possible winnowing of AC from the sediment surface.

- AC in the scour ENR+AC subplot averaged approximately 2.5% in Year 1, 2.0% in Year 2, and 1.5% in Year 3. The Year 3 levels shown in Figure 3.2-14 represent the Type 2 samples that involved clearing surface sediment deposits when those deposits were greater than 3 cm, as these data were assumed to best represent the ENR/ENR+AC layers without the influence of the overlying silt layer. Considering the extent to which the northern half of the scour ENR+AC subplot was exposed to propwash from tugs and other boats in the area, the AC in the scour ENR+AC subplot was reasonably stable.

- AC in the subtidal plot experienced the most substantial decreases from Year 0 to Year 3. The Year 0 value is likely influenced in part by the use of TVS to measure AC; an elevated level of ~1% was seen at Year 0 in the subtidal ENR subplot. In the subtidal ENR+AC subplot, AC levels from Year 0 to Years 1 and 2 decreased from 3% to approximately 1% and decreased further to ~0.5% in Year 3. Year 3 had highest percent fines following plot construction. AC decreases in the subtidal ENR+AC subplot are attributed to disturbance and mixing of sediments associated with barge positioning and bridle chain dragging together with the highest natural sedimentation processes of the three Plots that would have diluted AC concentrations at the sediment surface. Unfortunately, it is not possible to quantify how much loss of AC occurred from the chain disturbance compared to sediment dilution or other potential causes.

Despite the AC content of Year 3 surface 10-cm samples averaging in the 0.5 to 1.5% range (below initial target levels), this amount of AC was sufficient to enable meaningful levels of PCB bioavailability reduction as a result of PCB sorption to AC. Although many AC applications generally feature loading rates of 3-5% AC by weight (Patmont et al., 2015), lower levels of AC are also effective. Several laboratory and field applications of AC support the efficacy of lower AC levels:

- A thin-layer sand and PAC amendment constructed in San Diego Bay (San Diego, CA) featured a 1.5% AC amendment rate (Geosyntec, 2019). This resulted in a 90-97% (average 94%) reduction in PCBs bioavailability (as measured with passive samplers) compared to baseline (Geosyntec, 2019). Pre-deployment bench scale results reported a 98% reduction in PCB bioavailability using 1.5% AC (Geosyntec, 2016). In the same laboratory study, a lower AC amendment rate of 0.5% achieved an 80% reduction in PCB availability.
- In a laboratory study by Nybom et al. (2015), three natural sediments collected from PCB contaminated areas in Southern Finland were amended with bitumous, coal-based PAC. The study included a 0.25% AC amendment. This resulted in a reduction in long-term (3 years post-amendment) PCB bioavailability (as measured with passive samplers) by approximately 45 to 70% compared to unamended sediment.
- In recent monitoring work on the Bremerton Activated Pilot Study (Puget Sound Naval Shipyard and Intermediate Maintenance Facility in Bremerton, WA), conducted 7 years following amendment with PAC, AC (measured as Black Carbon in bulk surface sediment samples) was confirmed present at 0.8-1.3% on average (Rosen, 2020). PCB bioavailability in surface sediment was 80-90% lower than baseline (as measured with passive samplers), consistent with three prior post-amendment monitoring events conducted from 10 months to 3 years post-amendment (Kirtay et al., 2018).

These examples show that reductions of PCB availability of 50-90% can be realized with AC contents of 0.25-1.5%. It should be noted that these experiments were conducted with PAC, not GAC. There is a conception that GAC (used in the LDW pilot study) is less effective than PAC. This is due to the slower kinetics of PCB sorption by GAC, which can result in an apparent lower effectiveness compared to PAC in short-term studies lasting weeks to months. As indicated in Section 1.2, over longer time frames (years), similar to this pilot study, GAC will reach the same sorption equilibration as PAC (Kupryianchyk et al., 2013; Kupryianchyk et al., 2015; Thompson et al., 2016). Thus, the expectations for the effectiveness of the lower PAC doses (i.e., doses of 0.25-1.5%) evident in the above studies are applicable to the LDW multi-year pilot study. Given these results, the amount of AC present in the ENR+AC layers at Year 3 (approximately 0.5-1.5%) reflects a sufficient amount to AC to continue to facilitate a reduction in PCB availability due to sorption of PCBs by the AC.

3.2.4 ENR/ENR+AC Layer Thickness

The focus of this study was on the uppermost 10 cm of sediment, consistent with the LDW biologically active zone as well as site-wide cleanup levels articulated in the ROD. The aforementioned lines of evidence (grain size distribution, silt deposition, and carbon analyses) are limited to this layer. These results, along with the SPI penetration results, support the understanding that ENR and ENR+AC gravel and sand materials remained stable. However, these lines of evidence do not provide a vertical delineation of ENR and ENR+AC thicknesses.

An evaluation of thickness was possible by examination of the 36 6-inch-diameter by 18-inch-long cores collected at the subtidal plot in Year 3 for the bioaccumulation study. These cores were collected in a manner that assured penetration and collection of the native underlying sediment (QAPP, Addendum 2), in addition to the ENR and ENR+AC layers and surface silt deposits. Observations of sediment texture and appearance were recorded in field logs (Appendix E); those logs were used to estimate the ENR and ENR+AC thicknesses in each sediment core.

ENR and ENR+AC thicknesses in the Year 3 subtidal sediment cores are shown in Table 3.2-3 and mapped in Figure 3.2-16. Grid cell average thickness of ENR and ENR+AC layers in Year 3 subtidal cores ranged from 0 to 10.6 inches. Visual observations of cores were made through the clear core liner and recorded. Core logs (Appendix E) were reviewed, and layers that were noted as a predominantly coarse-grained sand and/or gravel were assumed to be ENR/ENR+AC material. As discussed further below, some measurements of ENR or ENR+AC layer thickness were below the targeted range of 6 to 9 inches for the pilot study design, especially those in the southern-most portion of the plots that were most impacted by bridle chain dragging.

In the southern portion of the subtidal ENR and ENR+AC subplots (Figure 3.2-16), there were several cores in which the ENR layer was absent resulting in an ENR or ENR+AC layer thickness of 0 inches, consistent with the bridle chain disturbances observed in this area. For cores in which the ENR or ENR+AC material was not detected (i.e., thickness reported as 0 inches), it is possible that the layers have been removed by the bridle chains or buried to a depth of 18 inches or more with silt or sediment that has been moved by the bridle chains from areas adjacent to the plot. Outside of the area disturbed by bridle chains (Figure 3.1-3), 74% of the stations had greater than 6 inches of ENR/ENR+AC material, and the average thicknesses of the ENR and ENR+AC material layers were 8.9 and 7.6 inches, respectively. The average thicknesses of the ENR and ENR+AC layers of the entire area (including the bridle chain disturbed area) were 8.3 and 5.2 inches, respectively. Averages of 9.5 to 13.7 inches were observed in Year 0 in all six subplots (Amec Foster Wheeler et al., 2018a). Thus, aside from the marked impacts of the bridle chain disturbances, the thicknesses of the ENR and ENR+AC materials in Year 3 were consistent with the targeted thickness range and approximate to Year 0, especially considering the potential for settling and compaction and the potential underestimation of Year 3 thicknesses. Differences between Years 0 and 3 may have been due to consolidation, compaction during coring, mixing with surficial or underlying sediment, or losses. Overall, these lines of evidence reflect the stability of the ENR and ENR+AC layers.

Sediment cores also were collected by the Upper Reach Remedial Design team at five intertidal plot locations in July 2021 (Appendix B). Three cores were collected from the ENR+AC subplot (IT-615, IT-617, and IT-618) and two from the ENR subplot (IT-6-24 and IT-626). Determination of layer thickness from draft core logs provided by the Remedial Design team was performed, correcting for percent recovery. The three cores collected in the ENR+AC subplot had ENR layer thicknesses that ranged from about 10 to 14 inches with an average of about 12 inches. This is comparable to the as-built thickness range of 6 to 14 inches with an average of about 10 inches, as reported in the Construction Report (Amec Foster Wheeler et al., 2018a). The two cores collected in the ENR subplot had ENR layer thicknesses that ranged from about 13 to 14 inches with an average of about 13 inches. This is comparable to the as-built thickness range of 8 to 14 inches with an average of about 11 inches, as reported in the Construction Report (Amec Foster Wheeler et al., 2018a). The thicknesses of the ENR and ENR+AC layers in the cores collected in the intertidal subplots indicate that there have been no measurable losses since the material was placed at the onset the study, reflecting stability of the ENR and ENR+AC layers in the intertidal subplot.

Similar measurements were not made at the scour plot, so direct measurement of the ENR and ENR+AC thicknesses are not available. Nonetheless, other measurements, including SPI penetration, grain size distribution, organic carbon, and C_{free} / bioavailability data suggest that the scour plot behaved comparably; hence, the Year 3 ENR and ENR+AC thicknesses in the scour plot are expected to reflect a comparable degree of stability as was observed in the intertidal plot, which was constructed of the same gravely sand mixture.

3.2.5 Porewater Salinity

Salinity was measured to identify areas where groundwater may be upwelling through the ENR and ENR+AC layers. The intertidal plot, which targeted an area of potential groundwater upwelling, had salinity levels that were approximately 2 times lower than those observed at the subtidal and scour plots. The 25 and 75% quartiles in the intertidal plot ranged from 5.75 to 18.27 parts per thousand (ppt), compared to 18.98 to 28.4 ppt in the scour and 22.45 to 28.6 ppt subtidal plots (Table 3.2-4, Figure 3.2-17). The lower salinity concentrations in the intertidal subplots suggest the potential for groundwater upwelling through the ENR and ENR+AC layers. However, another explanation could be that the intertidal plot is more substantially influenced by freshwater associated with freshwater lens or location of the salt wedge and thereby less influenced by ocean water. Tidal pumping of mainly freshwater at this plot as opposed to entirely saltwater at the other two plots could account for this difference. The scour and subtidal plots did not indicate groundwater upwelling occurred during sampling.

3.3 Bulk Sediment PCB Analyses

This section reports on bulk sediment PCB concentrations for baseline, Year 1, Year 2, and Year 3 sampling events. Bulk sediment PCB measurements provided supporting lines of evidence for interpreting passive sampling data used to address DQO-2: *Evaluate the Stability of ENR and ENR+AC Materials* and DQO-3: *Assess Changes in Bioavailability in ENR+AC Compared to ENR Alone*.

3.3.1 Baseline PCB Concentrations

Baseline total bulk sediment PCB concentrations were similar between the ENR and ENR+AC subplots of each plot (Table 3.3-1 and Figure 3.3-1). Comparison by subplot are summarized here:

- *Intertidal Plot*. Baseline surface-sediment PCB concentrations ranged from 80.3 to 414 µg/kg (geometric mean of 196 µg/kg) in the ENR subplot and from 120 to 407 µg/kg (geometric mean of 221 µg/kg) in the ENR+AC subplot.

- *Scour Plot*. Baseline surface-sediment PCB concentrations ranged from 17.5 to 54.7 µg/kg (geometric mean of 29.4 µg/kg) in the ENR subplot and from 19.2 to 27.6 µg/kg (geometric mean of 22.6 µg/kg) in the ENR+AC subplot.

- *Subtidal Plot*. Baseline surface-sediment PCB concentrations ranged from 153 to 468 µg/kg (geometric mean of 257 µg/kg) in the ENR subplot and from 151 to 341 µg/kg (geometric mean of 221 µg/kg) in the ENR+AC subplot.

Baseline PCB concentrations were comparable, though slightly higher in the subtidal plot compared to the intertidal plot. PCB sediment concentrations in the scour plot were almost an order of magnitude lower than both the intertidal and subtidal plots.[16]

3.3.2 Bulk Sediment PCB Concentrations, Years 1 to 3

The comparison of total bulk sediment PCBs In Years 1, 2, and 3 are presented in Figures 3.3-2 through 3.3-5 and in Table 3.3-1. Concentrations in Years 1, 2, and 3 were significantly lower

[16] Bulk sediment PCB concentrations measured during the baseline survey at the scour plot were considerably lower than the concentrations that were identified in the Plot Selection Memo (LDWG, 2015). Due to the lack of an acceptable alternate location, the LDWG elected to proceed with the scour plot location, in consultation with EPA and Ecology.

($p < 0.05$) than baseline concentrations. This was expected because the concentration of PCBs in the ENR and AC material that was used to construct the plots ranged from 0.031 to 0.037 µg/kg (Amec Foster Wheeler et al., 2018b), which are well below baseline concentrations.

PCBs detected in the samples collected from the ENR and ENR+AC layers in Years 1, 2, and 3 were derived primarily from the incorporation of silt deposits into the ENR and ENR+AC layers, or for the subtidal plot the incorporation of underlying sediment into the samples. These processes affected the ENR and ENR+AC subplots relatively uniformly at each plot, respectively. For each plot, the ENR and ENR+AC subplot total bulk sediment PCB concentrations were not statistically different from one another within the Year 1, 2, and 3 events ($p > 0.05$). Concentrations in bulk sediment varied in response to the degree to which the subplots were affected by various physical processes affecting the incorporation of underlying sediment or overlying silt:

- In the intertidal plot, total bulk sediment PCB concentrations in both subplots were significantly lower than baseline (approximately 200 µg/kg) compared to Years 1 through 3 (geomean approximately 5 to 10 µg/kg, $p < 0.01$). The ENR subplot saw 96 to 97% reductions in total bulk sediment PCB concentrations when comparing Years 1, 2, and 3 to baseline, while the ENR+AC subplot saw 93 to 99% reductions. The stability and apparent lower depositional environment of the intertidal plot is exemplified by the consistently low total bulk sediment PCB concentrations in both subplots following construction. Values remained significantly lower than baseline through Year 3 ($p < 0.01$).

- At the scour plot, total bulk sediment PCBs in Year 1 (geometric mean of approximately 9 to 14 µg/kg) were lower than the baseline (approximately 20 to 30 µg/kg). Baseline sediment concentrations in the scour plot were an order of magnitude lower than the intertidal and subtidal plots. In Year 2, total bulk sediment PCBs increased to approximately 40 to 90 µg/kg, especially in the ENR subplot (Figure 3.3-5). The majority of these 10-cm thick sediment samples were likely comprised of deposited silt, as average silt thickness in the scour ENR subplot was 9 cm (Table 3.1-1). The amount of silt deposits in Year 2 was approximately 2 to 3 times higher than in Year 1 particularly in ENR subplot. Silt deposition is expected to have contributed to bulk sediment PCB concentrations in the ENR and ENR+AC subplots. Silt PCB concentrations in Year 2 were 86.7 and 28.8 µg/kg in ENR and ENR+AC subplots respectively. These concentrations were higher than the respective baseline bulk sediment concentrations, and suggest that silt caused the increase in Year 2 bulk sediment concentrations (relative to the baseline levels). Sediment PCB concentrations for the Year 3 samples (Type 2; from which overlying silt layers were cleared) were approximately 10 to 20 µg/kg, lower than the Year 3 Type 1 samples (not cleared of overlying silt). The latter had PCB concentrations which were similar to or higher than concentrations observed in baseline and Year 2. Additional details of Year 3 results are described in Appendix D. Data for the silt depositional material (bulk sediment PCB concentrations and percent fines) can be found in Table 3.3-2.

- The subtidal plot saw more variability than the intertidal and scour plots among Years 1 to 3. Decreases in total bulk sediment PCB concentrations from baseline (geomean approximately 260 µg/kg in the ENR subplot and 220 µg/kg in the ENR+AC subplot) were nonetheless substantial, ranging from 61 to 96% in Years 1, 2, and 3. Following construction, concentrations were highest in Year 2, approximately 80 µg/kg, and lowest in Year 3, approximately 10 to 20 µg/kg. The variability in bulk PCBs may be due to the heterogenous effects of newly deposited sediment and impacts of chain dragging, which may have introduced underlying sediment into the top 10 cm of material sampled.

3.4 Porewater C_{free} PCB Analyses

Porewater total C_{free} PCBs measurements were used to evaluate PCB bioavailability in the ENR and ENR+AC subplots, providing the primary line of evidence to address DQO-3: *Assess Changes in Bioavailability in ENR+AC Compared to ENR Alone*. This section reports porewater results for the baseline, Year 1, Year 2, and Year 3 sampling events using in situ and ex situ SPMEs.[17] As described above in Section 2 and further detailed in Appendix D, total C_{free} PCBs at the scour plot were measured with a Year 3-specific procedure involving two approaches (Type 1 and Type 2) for SPME deployment.[18] The Type 2 approach was intended to minimize the influence of the overlying silt layer on total C_{free} PCBs measurements in the ENR and ENR+AC subplots. Overall, the effects of the overlying silt layer in Year 3 are uncertain or minimal, and additional details on the Type 1 versus Type 2 results are provided in Appendix D. The remainder of this section compares the total C_{free} PCBs between the ENR and ENR+AC results in each plot. Unless specified, the Year 3 Type 2 total C_{free} PCBs results are used for scour plot in figures and discussions in this section, because those results best reflect availability conditions in the ENR and ENR+AC layers without the potential influence of the thicker overlying silt layer.

Total C_{free} PCB concentrations are presented in Table 3.3-1 and are summarized below for each plot. Total C_{free} PCBs are compared during the baseline, Year 1, Year 2, and Year 3 events in the

[17] SPMEs were not used in Year 0.

[18] Type 1 SPMEs were deployed in the top 10 cm of silt or ENR/ENR+AC layers, regardless of the depth of sedimentation on top of the ENR and ENR+AC layers. The Type 2 SPMEs were deployed after clearing silt in areas where silt deposits were deeper than 3 cm; Type 2 areas where silt deposits were less than 3 cm were unaltered. Both SPMEs were deployed to measure Total C_{free} PCBs in the uppermost 10 cm of the remaining silt/ENR/ENR+AC layers.

intertidal, scour, and subtidal plots in Figures 3.4-1 through 3.4-3. Post-construction total C_{free} PCBs was lower than baseline at the intertidal and subtidal plots for (both ENR and ENR+AC). However, in Year 2, the subtidal ENR subplot was not statistically lower than baseline. Total C_{free} PCBs in the scour ENR plot were low in baseline and did not indicate a decrease. In the scour ENR+AC, a significant decrease from baseline was observed for total C_{free} PCBs Year 1, followed by increases in Years 2 and 3 that were still lower (but not significantly so) than baseline.

Data analysis also included comparison of total C_{free} PCBs between the ENR and ENR+AC at each of the plots for all three post-construction monitoring events (Figures 3.4-4 through 3.4-6) to evaluate the effect of AC to further reduce the bioavailability of PCBs. In most cases, total C_{free} PCBs measured in the ENR subplots were not statistically different ($p > 0.05$) from the ENR+AC subplots within a given plot and monitoring event. There were two exceptions – subtidal Year 1 and intertidal Year 3 – as discussed below. Total C_{free} PCBs are discussed for each plot in the following subsections.

3.4.1 Porewater C_{free}: Intertidal Plot

Among the three plots, the intertidal plot showed the most consistent total C_{free} PCBs results over the post-construction monitoring events (Figure 3.4-1). Both the ENR and ENR+AC materials reduced total C_{free} PCBs compared to baseline, reducing geometric mean total C_{free} PCBs from approximately 30 nanograms per liter (ng/L) to approximately 1-2 ng/L. Over the 3-year monitoring period, addition of AC to ENR reduced total C_{free} PCBs by 97-98% from baseline, and ENR reduced total C_{free} PCBs by 95-96% from baseline. In Year 3 (Figure 3.4-6), total C_{free} PCBs in the intertidal ENR+AC subplot was statistically lower ($p = 0.011$) than that of the intertidal ENR subplot. The geometric mean ENR and ENR+AC Year 3 total C_{free} PCBs were 1.6 and 0.8 ng/L, respectively, a difference of 0.8 ng/L (Table 3.3-1). This difference was consistent with differences between the subplots of 0.3 to 0.6 ng/L in Years 1 and 2, respectively (however, they were not statistically different).

Given that overlying silt deposition in the intertidal plot was minimal (approximately 1 to 2 cm) and that bulk PCB concentrations in the ENR and ENR+AC remained low (i.e., approximately 5 to 10 µg/kg) in both subplots, the influence of PCBs from dispositional material and from unamended areas adjacent to the intertidal subplots appeared to be minimal. This is supported by low percent fines and consistent TOC measurements in intertidal plot from Years 1 to 3. The intertidal plot served as a kind of "positive control" demonstrating the effectiveness of the ENR and ENR+AC applications, particularly in an area where physical disturbances were minimal compared to the other two plots. The intertidal plot also was the only plot subject to freshening by groundwater discharge or surface water, as indicated by the low salinity levels measured at baseline and in Years 1 to 3 (Section 3.2.3); however, the potential groundwater upwelling in the vicinity of the intertidal plot did not seem to affect the ability of the ENR and ENR+AC to significantly reduce PCB availability from baseline.

Overall, AC enabled an additional 2% reduction in baseline PCB porewater concentrations compared to ENR alone at the intertidal plot, and differences in total C_{free} PCBs between ENR and ENR+AC were less than 1 ng/L.

3.4.2 Porewater C_{free}: Scour Plot

At the scour plot, total C_{free} PCBs did not differ between the ENR and ENR+AC in the post-construction monitoring events (Figures 3.4-4, 3.4-5, and 3.4-6). A statistically significant decrease in total C_{free} PCBs from baseline was only observed once; this was for the ENR+AC subplot in Year 1 (Figure 3.4-2). In Year 1 in the ENR+AC plot, the geomean total C_{free} PCBs was 0.89 ng/L, reflecting a 90% decrease from the baseline geomean of 8.9 ng/L. This level of performance for ENR+AC was not maintained, however, as total C_{free} PCBs increased to 4.3 and 3.3 ng/L in Years 2 and 3. These values reflect only a 49% and 61% reduction in total C_{free} PCBs from baseline (although they were not statistically different from baseline). This increase appears to be influenced by deposition of silt in the subplots.

Conditions at the scour plot make for a complicated and potentially problematic comparison of ENR and ENR+AC performance. The study was complicated by three factors, as described below.

First, total C_{free} PCBs and PCBs concentrations in bulk sediment were low in the baseline study, averaging 1.5 to 8.5 ng/L and approximately 20 to 30 µg/kg. These levels are an order of magnitude lower than baseline levels observed in the intertidal and subtidal plots. The baseline total C_{free} PCB concentrations in the scour ENR and ENR+AC subplots were comparable to the post-construction concentrations measured in the intertidal and subtidal plots (which were noted as meaningful improvements from their respective baseline levels). In addition, baseline total C_{free} PCBs at the scour ENR plot was 1.5 ng/L, comparable to concentrations measured in the overlying LDW surface water[19] (Windward, 2019). As total C_{free} PCBs in the upper layers of the ENR and ENR+AC material are likely influenced by surface water through diffusion and tidal pumping, the approximate 1 ng/L may represent the lowest currently-achievable total C_{free} PCBs within the uppermost portion of the sandy material layers applied in a pilot study. This is supported by the

[19] During pre-design studies, Total C_{free} PCBs in surface water were measured at two locations in 2017 and 2018 using polyethylene passive samplers deployed in LDW surface water, approximately 1 meter above the sediment-water interface (Windward, 2019). The average concentration at the South Park Bridge (approximately 0.5 mile downstream of the intertidal plot) and Sea-Freeze dock (approximately 0.75 mile upstream of the subtidal plot, 1.75 miles upstream of the scour plot) locations in 2017 and 2018 were very similar to the baseline, at 1.13 (SD = 0.17).

observation that ENR+AC was only able to reduce total C_{free} PCBs to 0.89 ng/L in Year 1. Given the likelihood that surface water PCBs affect the study, the low baseline scour plot total C_{free} PCBs, particularly in the ENR subplot, made it impossible to meaningfully evaluate post-construction reductions from baseline and enable comparisons with ENR+AC.

Second, layers of relatively contaminated silt (average concentrations of total PCB of 10 to 87 µg/kg) blanketed most of the scour plot in Years 2 and 3. Silt was particularly thick in the ENR subplot – on average, as high as 4 to 5 cm in Years 2 and 3, compared to 2 cm in Year 1. Resuspended bed material and incoming depositional material are the sources of this silt, which has infiltrated the ENR/ENR+AC layers, as indicated by an approximate 2-fold increase in the percentage of fines from Year 1 to Year 2 and bulk concentrations of PCBs that have returned to similar or higher concentrations in Years 2 and 3 compared to those observed in the baseline monitoring event.

Third, to further complicate matters related to the Years 2 and 3 silt deposition, a portion of the scour ENR+AC subplot was affected by propeller wash, effectively keeping approximately half of that subplot silt-free. This likely contributes additional variability in the PCB measurements, which are based on compositing samples obtained from all areas of the ENR+AC subplot (some of which were silt free and some of which were affected by silt).

Overall, results at the scour plot do not enable a robust comparison of ENR and ENR+AC performance. Although total C_{free} PCBs did not differ between the ENR and ENR+AC in the post-construction monitoring events, the low baseline concentrations (especially in the ENR subplot) limited the amount of reduction from baseline that could be attained. Post-construction results do not necessarily reflect poor performance of either remedy. Given the influences of surface water and silt, coupled with relatively low baseline total C_{free} PCB levels, PCB availability in the upper layers of the ENR and ENR+AC layers are already likely as low as current conditions will allow.

3.4.3 Porewater C_{free}: Subtidal Plot

At the subtidal plot, the ENR and ENR+AC materials reduced PCB porewater concentrations by 53 to 96% from baseline among all three post-construction monitoring events (Figure 3.4-3). Total C_{free} PCBs results were complicated by silt deposition and physical disturbances (e.g., barge bridle chains dragged across the bottom of waterway) that mixed a portion of both the ENR and ENR+AC subplots. This appears to have resulted in mixing of the ENR and ENR+AC layers with recently deposited sediments and underlying sediment, and possible displacement of some of the ENR/ENR+AC material.

Reductions in total C_{free} PCBs were achieved despite the physical disturbances. Total C_{free} PCB values at the subtidal ENR and ENR+AC subplots varied from year to year, and total C_{free} PCB values were statistically lower than baseline in Years 1 and 3 for both subplots (Figure 3.4-3). In Year 1 (Figure 3.4-4), total C_{free} PCBs in the subtidal ENR+AC subplot was statistically lower (p = 0.024) than that of the subtidal ENR subplot by a factor of approximately 2.5.

The ENR and ENR+AC Year 1 total C_{free} PCBs were 3.8 and 9.6 ng/L, reflecting 72% and 96% reductions compared to baseline, respectively (Figure 3.4-4). Thus, based on Year 1 results, AC enabled an additional 24% reduction in baseline PCB availability compared to ENR alone, reducing total C_{free} PCBs 5.8 ng/L lower (p = 0.023). This difference between ENR and ENR+AC was not maintained in Years 2 and 3. The Year 2 ENR and ENR+AC total C_{free} PCBs (16 and 14 ng/L, respectively) and Year 3 ENR and ENR+AC total C_{free} PCBs (3.8 and 4.2 ng/L, respectively) were not statistically different (Figures 3.4-5 and 3.4-6). The higher Year 2 total C_{free} PCB concentrations in both subplots (Figure 3.4-3) is consistent with the higher ENR and ENR+AC bulk sediment PCB concentrations in Year 2 (Figure 3.4-7), which were 75 µg/kg and 86 µg/kg, respectively; these values were approximately 2 to 8 times higher than the concentrations measured in Years 1 and 3. This could indicate larger proportions of underlying sediment and newly deposited material (due to mixing) in the upper 10 cm of the sample locations evaluated in Year 2.

Although AC indicated an additional 24% reduction in baseline PCB availability compared to ENR alone in Year 1 of the subtidal plot (and a 5.8-ng/L difference in total C_{free} PCBs), this difference in performance was not maintained. By Year 3, the difference in total C_{free} PCBs between the ENR and ENR+AC subplot was 0.4 ng/L and was not statistically different.

3.5 BIOLOGICAL RESULTS

The biological studies addressed DQO-4: *Assess the Potential Impacts of AC on Benthic Communities*. This was accomplished primarily through a benthic community survey in all three plots. In addition, the responses (survival and growth) of benthic organisms (polychaetes and clams) exposed to subtidal ENR and ENR+AC materials under laboratory-controlled conditions was also used.

The laboratory bioaccumulation study also provided an additional line of evidence to evaluate DQO-3: *Assess Changes in Bioavailability in ENR+AC Compared to ENR Alone*. This was accomplished by measuring tissue PCB concentrations in polychaetes and clams as a direct measure of bioaccumulation from sediments, after exposure to subtidal ENR and ENR+AC materials in a laboratory test.

3.5.1 Laboratory Bioaccumulation Study

This section describes the laboratory bioaccumulation study.

3.5.1.1 Organism Responses

Organism response results are summarized in Table 3.5-1 and described in this section. There were no adverse effects on polychaetes and clams exposed to the subtidal ENR or ENR+AC subplot sediments, and no indication that the addition of AC reduced survival or growth compared to ENR alone. Survival of polychaetes and clams in the ENR and ENR+AC material was not statistically different ($p > 0.05$) between the two subplots, and survival was greater than 90% and similar to that of animals exposed to control sediment (Figure 3.5-1). Similarly, growth of polychaetes and clams, as measured by the final total tissue mass of all polychaetes or clams from each replicate, was not statistically different ($p > 0.05$) between the ENR and ENR+AC subplots, and growth of organisms exposed to test sediments was similar to that of animals exposed to control sediment (Figure 3.5-2).

3.5.1.2 Comparison of PCB Concentrations in Clams and Polychaetes

PCB geomean concentrations in clams were 7.2 µg/kg wet weight (ww) and 5.6 µg/kg ww in the ENR and ENR+AC subplots, respectively, and were not statistically different between the subplots (Figure 3.5-3). PCB geomean concentrations in polychaetes were approximately 4 to 6 times higher than clams. This is likely because 1) polychaetes had higher lipid concentrations (the average polychaete lipid content was 0.6% (0.006 g lipid/g tissue ww), versus an average clam lipid content of 0.2%) and 2) the species of clam deployed, as filter feeders, were significantly exposed to overlying laboratory water.[20] Given the overlying water low total C_{free} PCBs, the exchange rate, slow desorption kinetics of PCBs, and limited solubility of PCBs, exposure to water overlying each test sediment was likely lower than total C_{free} PCBs measured in the ENR and ENR+AC material. PCB geomean concentrations in polychaetes was 43 µg/kg ww and 23 µg/kg ww in the ENR and ENR+AC subplots, respectively. The polychaete geomean PCB concentrations from ENR subplot were approximately twice as high as the mean PCB concentration from ENR+AC subplot ($p = 0.07$) (Figure 3.5-3). Total Bulk PCBs averaged 26 µg/kg in the ENR subplot and 20 µg/kg in the ENR+AC subplot; the difference was not statistically significant ($p = 0.515$).

Although the polychaete results suggest that the AC may have the potential to lower tissue PCB concentrations in polychaetes ($p = 0.07$, Figure 3.5-3), the potential difference between ENR and ENR+AC for the polychaetes was strongly influenced by the results of one of the three ENR

[20] The filter water used in the study contained trace PCBs; the total C_{free} PCB was 0.003 ng/L.

composites, identified as ENR replicate B. The ENR replicate B polychaete concentration (61 µg/kg ww) was 1.5 to 1.9 times higher than the other two ENR subplot composites. In addition, the ENR replicate B composite clam concentration (23 µg/kg ww) was 6 times higher than for the other two ENR subplot composites. To understand these higher concentrations, total bulk sediment PCB concentrations and other physical parameters were measured (Table 3.5-2). The sediment total PCB concentrations averaged 26 µg/kg in the ENR subplot and 20 µg/kg in the ENR+AC subplot; the difference was not statistically significant ($p = 0.515$). The bulk sediment total PCB concentration in the ENR replicate B (159 µg/kg) was 12 to 16 times higher than other replicate samples from the ENR subplot, measured at 9.0 and 12.7 µg/kg, respectively. The unusually high bulk sediment total PCB concentration in the ENR replicate B strongly influenced total C_{free} PCBs (see below), clam tissue, and polychaete tissue concentrations, respectively (Table 3.5-2). An explanation for this difference could be that the ENR replicate B contained more underlying sediment and/or recently deposited silt than the other replicates. This is not unexpected due to the high degree of physical disturbance in this area of the subtidal plot.

To evaluate the effects of ENR replicate B on the statistical analysis, a sensitivity evaluation was conducted in which the results from ENR replicate B were excluded. This does not imply that the ENR replicate B sample results were compromised or should be removed from consideration. However, only the ENR replicate B replicate had bulk sediment PCB concentrations approximately 10 times the average of all the other samples, suggesting that the ENR replicate B contained unusually high PCB concentrations compared to the other replicates in the ENR and ENR+AC composites. As explored below through sensitivity analysis is how the ENR and ENR+AC test chambers compared if ENR replicate B results were not included in the ENR average.

Excluding the ENR replicate B, the geomean polychaete PCB concentration from the ENR subplot was 36 µg/kg ww, which is 36% higher than the geomean PCB concentration from ENR+AC subplot of 23 µg/kg ww ($p = 0.12$). In addition, if ENR replicate B is excluded from the clam results, the geomean clam PCB concentration from ENR subplot (4.0 µg/kg ww) is comparable to if somewhat lower than the geomean PCB concentration from ENR+AC subplot (5.6 µg/kg ww) ($p = 0.11$). Thus, if ENR replicate B is excluded from the analysis, the tentative evidence supporting a significant difference in concentrations of PCBs in tissues between the ENR and ENR+AC subplots is weakened.

Total C_{free} PCBs Differences were not significant ($p = 0.43$) when comparing total C_{free} PCB concentrations measured in the ENR and ENR+AC cores (Table 3.5-1; Figure 3.5-4); geomean values were 10 and 6.2 ng/L, respectively. As with the polychaete and clam results, total C_{free} PCB in the ENR replicate B sample was higher than the other sample results, at 26 ng/L. Without this sample, the revised ENR geomean total C_{free} PCB would be 6.2 ng/L, equal to that of the ENR+AC geomean.

As detailed in Appendix I, total C_{free} PCB measurements from the bioaccumulation study correlated with concentrations of PCBs in polychaetes and clams. Furthermore, a good relationship between passive sampling total C_{free} PCB results and organism uptake was found by using total C_{free} PCB measurements with standard bioaccumulation model-derived uptake factors to predict concentrations of PCBs in polychaetes and clams (Appendix I). When total C_{free} PCB measurements in the six bioaccumulation study samples were used to predict concentrations in polychaetes and clams in this manner, all six of predicted total PCB concentrations in polychaetes were within a factor of approximately 2 of measured values (Figure 3.5-5). Model-predicted concentrations in polychaetes and clams confirmed the conclusions reached with total C_{free} PCBs regarding the effectiveness of ENR and ENR+AC. Results demonstrate that total C_{free} measurements predicted tissue concentrations at this site, and that passive samplers may be a good surrogate for evaluating PCB bioavailability and uptake by benthic organisms to evaluate effectiveness of ENR+AC compared to ENR alone.

3.5.2 Benthic Macroinvertebrate Community Survey

The benthic macroinvertebrate community survey is the primary line of evidence to support DQO-4: *Assess the Potential Impacts of AC on Benthic Communities*. To evaluate the benthic taxonomy data, various benthic community metrics were calculated for each plot by subplot. Specifically, six metrics were calculated with the benthic data as summarized in Table 3.5-3 and described briefly in this section. These metrics were useful in evaluating the effects of AC on benthic community health in the Puget Sound Naval Shipyard and Intermediate Maintenance Facility in Bremerton, WA (Kirtay et al., 2018). The details of the calculation of the indices are described in Appendix F.

- Total abundance is evaluated on a total individuals per sample basis. Higher values generally indicate ecological health.
- Total Annelid abundance is evaluated on a total individuals per sample basis. Annelids such as polychaetes are recognized as sensitive to the adverse effects of high levels of AC because they actively ingest AC particles with sediment as they feed (Rakowska et al., 2012; Janssen et al., 2012). Lower values can indicate a potential effect from AC.
- Shannon-Wiener (H’) is an index of species diversity. Higher values generally indicate ecological health.

- Taxa richness is expressed as the number of taxa represented in a sample. Higher values generally indicate ecological health.
- Pielou's J' is an index of the species evenness (the extent to which individuals in a community are uniformly distributed among species). Higher values generally indicate ecological health.
- Swartz Dominance Index is the number of taxa accounting for 75% of total abundance in a sample. Lower values indicate that the benthic invertebrate community is dominated by fewer taxa and is considered to be an indicator of lower ecological health or indications of disturbance. Higher values generally indicate greater diversity and ecological health.

Additionally, the percent abundance by major taxa groups were plotted using abundance values and inspected visually.

As shown in Figures 3.5-6 to 3.5-12 and in Table 3.5-4**,** metrics indicated that the benthic communities present at each plot were similar between the ENR and ENR+AC subplots. The distribution of the major taxa abundance among the samples (Figure 3.5-8) indicated a lack of major differences among between ENR and ENR+AC at each plot. Among the 18 statistical comparisons of the metrics between ENR and ENR+AC, only four indicated a statistically significant difference ($p < 0.05$) between ENR and ENR+AC: (1) Diversity and Swartz Dominance Index in the scour plot; and (2) Pielou's (J) and Swartz Dominance Index in the subtidal plot. These differences can be explained by differences in physical conditions and silt deposition in the two subplots as described in subsections below.

3.5.2.1 Scour Plot: Diversity and Swartz Dominance Index

At the scour plot, diversity (H') in the ENR subplot (2.8) was statistically higher than that of the ENR+AC subplot (2.3) (Figure 3.5-6). Swartz Dominance Index in the ENR subplot (11) also was statistically higher than that of the ENR+AC subplot (7) (Figure 3.5-12), which is not surprising because diversity and Swartz Dominance Index values were correlated in this dataset. Diversity and Swartz Dominance Index at the scour ENR subplot (2.8 and 11, respectively) were the highest measured in the study, and this is likely a result of the thick (4.4 cm, nearly half the upper 10 cm layer of compliance) silt layers observed in this plot in Year 3. This fine-grained substrate appears to favor a higher proportion of mollusks compared to the ENR+AC subplot (Figure 3.5-8). In contrast, while silt deposits were also evident at the upstream portion of the ENR+AC subplot, the chronic propeller wash disturbances in the downstream portion of the ENR+AC subplot appears to prevent the accumulation of silt deposits (see Sections 3.1.4 and 3.1.5) resulting in a different assemblage of benthic macroinvertebrates. The two benthic community sample locations most likely to be affected by propeller wash were ENR+AC replicates A and C (Figure 2.5-2). No silt was observed in this portion of the ENR+AC subplot. However, removing these two data points from the comparison of diversity between the ENR and ENR+AC subplots does not change the overall conclusion that ENR diversity and Swartz Dominance Index were statistically higher. Despite this condition and the fact that it was statistically lower than the ENR subplot, diversity and Swartz Dominance Index in the ENR+AC subplot was the second highest in the study (Figure 3.5-12).

Additionally, it may also be possible that diversity and Swartz Dominance Index in the scour ENR+AC subplot are lower because conditions at the ENR plot favor mollusks which were more than twice as abundant in the ENR subplot compared to the scour ENR+AC subplot (Figure 3.5-8). Mollusks averaged 19 individuals/ sample in the ENR+AC subplot versus vs 54 individuals/sample in the ENR subplot. The number of mollusks at scour ENR+AC replicates A and C were among the lowest (4 and 1 individuals/ sample, respectively), suggesting that the propeller wash disturbances in these areas affect the benthic community. The dominant taxa group in both scour subplots was the Annelids (Figure 3.5-8). Annelid abundance was similar in both subplots (120 individuals/sample in the ENR versus 140 individuals/sample in the ENR+AC subplot). Annelid abundance (Figure 3.5-9) was similar between ENR and ENR+AC at all three plots. AC ingestion in high amounts is hypothesized to affect the efficacy of Annelids' digestive system. If AC were responsible for negative effects on benthic invertebrates, one would expect lower numbers of Annelids in the scour ENR+AC subplot, however, no meaningful differences in Annelid abundance was observed (Figure 3.5-9). Overall, the results indicate that the benthic community in the scour ENR+AC subplot is healthy compared to that of the ENR subplot (and other subplots measured in this study) and not adversely affected by AC. The differences in benthic communities (i.e., on mollusks) between the scour ENR and ENR+AC subplots may be due to the effects of propeller wash disturbances and lack of silt in portions of the ENR+AC subplot.

3.5.2.2 Subtidal Plot: Pielou's (J) and Swartz Dominance Index

The other two statistically significant differences in metrics between the ENR and ENR+AC subplots were found at the subtidal plot. At this plot, Pielou's (J) evenness in the ENR subplot (0.91) was statistically higher than that of the ENR+AC subplot (0.73), as shown in Figure 3.5-7. The mean evenness observed at the subtidal ENR subplot was the highest measured in the entire study, and, while statistically lower than this value, the mean evenness observed at the subtidal ENR+AC subplot was the third highest value measured in this study.

Swartz Dominance Index in the ENR subplot (7) was statistically higher than that of the ENR+AC subplot (5), as shown in Figure 3.5-12. Other metrics indicate that ecological health in the

ENR+AC subplot is equivalent or better than the ENR subplot; for example, total abundance, Annelid abundance, and richness were approximately 2-3 times higher at ENR+AC subplot compared to the ENR subplot. One of the ENR+AC sample replicates indicated very low values for these metrics. This was ENR-AC replicate E (Figure 2.5-3), collected from an area affected by a high level of disturbance from barge bridle chain dragging (see Sections 3.1.1 and 3.15). It is notable that both replicate E samples in the ENR and ENR+AC subplots exhibited the lowest values for four metrics (diversity, abundance, Annelid abundance, and richness), suggesting that the low values are due to the high level of physical disturbance in this area. As noted above, if AC were responsible for negative effects on benthic invertebrates, one would expect lower numbers of Annelids in the ENR+AC subplot, but this analysis indicates the converse. Richness in the ENR+AC subplot (21) was approximately 2 times higher (p = 0.0053) than that in the ENR subplot (13). Lastly, mean diversity in the ENR+AC subplot is not statistically different (p = 0.27) from ENR (2.0 and 2.3, respectively). Thus, three of the six ecological metrics actually point to significantly healthier benthic conditions in the subtidal ENR+AC subplot, indicating that AC is not exerting a detrimental effect on the benthic community.

4.0 FINDINGS

Section 1.0 presents the DQOs that guided and informed the pilot study design, implementation, and monitoring requirements and methods. This section discusses the extent to which the pilot study satisfied the DQO requirements and uses the study results to answer the DQOs.

4.1 DQO-1: VERIFY PLACEMENT OF ENR AND ENR+AC MATERIALS

As described in the Construction Report (Amec Foster Wheeler et al., 2018a) measurements and observations throughout the placement process and inspections performed after the placement in each plot was complete verified that ENR and ENR+AC material was successfully applied in the LDW. Measurements of AC after placement showed that AC was not introduced into the ENR subplots, and was introduced and measurable in the ENR+AC subplots. AC was incorporated into the ENR material at a planned 4% AC content by weight. As indicated above in Section 1.3, 4% was selected, as it is within the typical range that has been initially applied to sediments to achieve reductions in PCB bioavailability. As measured in the barge immediately prior to placement, AC in the ENR+AC material was 2.7% at the scour and intertidal and 4% at the subtidal. Measurements post-construction (Year 0) showed that there was some loss of AC during placement (i.e., AC was measured at 2.6% in the intertidal subplot, 2.4% in the scour subplot, and 3% in the subtidal subplot, as estimated using TVS data). As described in Section 3.2.3, previous studies suggest that these decreased AC values are well within the range of effective levels for reduction of PCB availability. Such losses were anticipated with this application method, as AC has a relatively low specific gravity and some portion of the AC was likely lost to the water column during placement.

Methods to minimize AC losses, such as premixing and prewetting the ENR and ENR+AC materials before placement, and careful placement at the bottom of the waterway, were successful in retaining AC in the ENR+AC materials.

4.2 DQO-2: Evaluate Stability of ENR and ENR+AC Materials

The scour plot was intended to evaluate the stability of ENR and AC material under DQO-2. However, similar field parameters measured among all three plots provide an opportunity to evaluate stability in three distinct physical environments in the LDW. The discussion below includes stability evaluations in the intertidal and subtidal plots, in addition to the scour plot.

Study results from Years 0 through 3 show that the ENR and ENR+AC materials remained stable over the majority of the three plots. While conditions varied by plot, several lines of evidence indicate that the material in each plot is stable overall and has not eroded from the plots in an appreciable manner:

- The ENR and ENR+AC material is present and generally stable. The Year 1 through 3 SPI/PV images revealed the presence of ENR and ENR+AC material in all images from all subplots except for grid cells 5 and 6 of the ENR+AC subtidal subplot where barge bridle chain dragging likely affected the bottom substrate (Amec Foster Wheeler et al., 2016b). SPI/PV images at the scour plot showed the ENR+AC material remained in the northern section of subplot where the impacts of propwash were most severe.

- Fine-grained material deposition was observed in all 3 years and across most of the plots, at varying degrees. In areas where silt deposition was observed and measured, the plot areas were depositional, representing a line of evidence of stability of the placed material. SPI images, field measurements of silt deposition, and analytical results for TOC and percent fines indicate deposition and mixing of newly deposited material into the ENR and ENR+AC layers. Because TOC was virtually absent from the ENR material at the time of placement, TOC increases in the ENR subplots is the most direct evidence of mixing between silt deposits and ENR material.

- The amount of AC/BC decreased over time in all three plots, with the decreases greatest in the subtidal plot. However, AC/BC remained at levels that have been previously demonstrated to be effective for reduction of PCB availability in sediment (Section 3.2.3). At the subtidal plot AC/BC levels decreased between Year 0 and Year 1 potentially due to chain dragging that could have mixed underlying or newly deposited material into the ENR+AC material, or could have suspended material into the water column where it was transported away from the subplot.

- Development of Stage 3 infauna, as demonstrated in the SPI/PV images, and benthic colonization as demonstrated in the Year 3 benthic community study, are indicators of a stable environment that supports natural sedimentation, benthic recolonization, and benthic community development.

The pilot study satisfied the DQO-2 requirements using multiple lines of evidence including SPI/PV survey results, particle size distribution, TOC, and AC/BC measurements. With few exceptions, these multiple lines of evidence demonstrated that both the ENR and ENR+AC materials were generally stable over the 3-year monitoring period, in all three plot environments. Environmental conditions unique to each location introduced different physical forces (wakes/waves, propwash, chain dragging) under which both ENR and ENR+AC placement performed across the entirety of the plots as ENR is intended—to enhance natural recovery. Results of the scour plot demonstrated that ENR and ENR+AC may be stable in some scour areas; application would require site-specific assessment during remedial design.

4.3 DQO-3: Changes in Bioavailability in ENR+AC Compared to ENR Alone

Study results from Years 1 through 3 indicate that the ENR (without AC) achieved 95 to 96% reductions in total C_{free} PCB concentrations in the intertidal subplot, and 53 to 89% reduction in the subtidal subplot. The low baseline Total C_{free} PCB concentration in the scour ENR subplot made it almost statistically impossible to determine whether the ENR material was able to contribute to reduced C_{free} concentrations in the scour plot. The addition of AC improved the ability of ENR to reduce PCB bioavailability in some situations, though such improvements were small and varied by plot:

- At the **intertidal plot**, both the ENR and ENR+AC materials reduced total C_{free} PCB levels by 95% or greater from baseline, and results were consistent among all three post-construction monitoring events. In general, AC provided an additional few percent (i.e., ~2%) reduction in total C_{free} PCB. While there was a statistically detectable difference in total C_{free} PCBs in Year 3, the difference was very small, resulting in a total C_{free} PCB geometric mean value of 0.77 ng/L in the ENR+AC subplot compared to 1.6 ng/L in the ENR subplot. Surface water C_{free} in the LDW reported by baseline studies (Windward, 2019) was similar to this range, at approximately 1 ng/L.

- At the **scour plot**, results were complicated by the low baseline bulk sediment and C_{free} PCB concentrations, particularly in the ENR subplot. The scour plot was influenced by silt deposition in both subplots during Years 2 and 3, and the physical disturbances (propeller wash) that appears to have prevented the accumulation of an overlying silt layer in approximately half of the ENR+AC subplot. Year 1 results offer the clearest picture of ENR+AC performance and indicated that the ENR+AC reduced PCB bioavailability by approximately 90% from baseline; Years 2 and 3 saw 49% and 61% decreases from baseline, respectively, although the results were not statistically different from baseline. Additionally, no statistical differences in total C_{free} PCBs were observed between ENR and ENR+AC over all 3 years of monitoring. For ENR, it was not possible to discern a clear reduction in PCB bioavailability from baseline in Years 1, 2, or 3. Scour ENR subplot C_{free} in the baseline event was similar to that of overlying water (approximately 1 ng/L), and it was possible that this level of PCB availability in the overlying water represented a minimum "floor" value below which C_{free} could not be reduced.

- At the **subtidal plot**, results were complicated by physical disturbances (bridle chains) that frequently mixed a portion of both ENR and ENR+AC subplots. In Years 1 and 3, which were the monitoring events that appeared to be least impacted by physical disturbances, ENR reduced bioavailability 70 to 90% from baseline, and ENR+AC provided an additional 5 to 25% reduction, reducing PCB bioavailability by approximately 96% from baseline. These results suggest that AC may have contributed to reduced PCB bioavailability in a setting where the ENR layers had more apparent mixing than other plots. There was a statistical difference in total C_{free} PCBs between the two subplots in Year 1 but not Years 2 and 3. Year 3 saw a reduction of 89% from baseline in the ENR subplot and a 96% reduction in the ENR+AC subplot. This reflects a 7% difference in the reduction from baseline, though the difference in total C_{free} PCBs in Year 3 between the two subplots (3.8 versus 4.2 ng/L) was not statistically significant.

  In addition, the laboratory bioaccumulation study exposed live organisms (polychaetes and clams) and SPMEs to subtidal plot ENR and ENR+AC material collected in Year 3. Concentrations of PCBs in clams and polychaetes were not statistically different between the subplots, confirming the Year 3 study findings of no statistically significant differences in PCB bioavailability between ENR and ENR+AC. Total C_{free} PCB measurements were made with SPMEs deployed in the same exposure chambers as the clams and polychaetes. As with the concentrations in tissues, total C_{free} PCB did not differ significantly between ENR and ENR+AC. The data also provided support that the passive sampling results correlated with bioavailability measurements using the organisms.

Reports by others (Patmont et al., 2015; Kirtay et al., 2018) have shown that the addition of AC to sediment (either directly or as a mixture with sand) generally reduces the bioavailability of hydrophobic organic chemicals by approximately 90% or more, compared to untreated sediment.

In this pilot study, the ENR+AC performance was consistent with these findings (i.e., approximate reduction in PCB bioavailability of 86-98% for intertidal and subtidal plots).

In prior field-scale pilot studies, the use of thin sand amendments (ENR) alone, without the addition of AC, has also been found to be effective in reducing the bioavailability of hydrophobic organic compounds by approximately 50 to 90% (Merritt et al., 2010; Fetters et al., 2019; Rosen et al., 2020). In this pilot study, the ENR performance was towards the upper end of this range (i.e., approximate reduction in PCB bioavailability of 70-95% for intertidal and subtidal plots).

While the addition of AC may have improved ENR performance in the intertidal plot, the differences between ENR and ENR+AC performances were very small. Comparison of ENR+AC results to results reported by others for the use of AC is challenging, because most AC applications reported in the literature relied either on the direct application of AC to the sediment surface or involved the integration of AC into an engineered sediment cap rather than ENR layer. The results of the intertidal plot, which showed a 97% decrease from baseline in Year 3 in the ENR+AC subplot is certainly consistent with results of greater than 90% reduction reported in the literature. However, because the ENR-only intertidal subplot saw a 95% decrease from baseline the same year, the added contribution of AC was relatively small.

In the subtidal plot, total C_{free} PCB Year 1 results showed a 72% reduction in the ENR subplot and a 96% reduction in the ENR+AC subplot compared to baseline (Figure 3.4-3); in Year 2, those reductions were 53% and 86%, respectively. While these results suggest the addition of AC may have improved performance in the subtidal plot in Years 1 and 2, the differences diminished by Year 3 (reductions were 89% and 96%, respectively). Furthermore, those differences may have been influenced by the different baseline concentrations measured in both plots. The baseline total C_{free} PCB concentrations in the ENR and ENR+AC subplots were 34 ng/L and 100 ng/L, respectively. When the post-remediation C_{free} concentrations in both subplots are compared (Figures 3.4-4 through 3.4-6), only Year 1 showed a statistically significant improvement associated with the addition of AC; AC did not contribute to statistically lower C_{free} concentrations in Years 2 and 3. By Year 3, the difference in total C_{free} PCBs between the ENR and ENR+AC subplot was 0.4 ng/L and not statistically different.

Overall, results of this 3-year study indicate that both ENR and ENR+AC were both successful in reducing PCB bioavailability in a wide variety of conditions in the LDW. In fact, ENR reduced PCB bioavailability so much (resulting in decreases in baseline PCB bioavailability of approximately 90% or more in many cases) that no major improvements as a result of adding AC could be detected. Only slight differences as a result of AC addition could be found – statistically significant changes in bioavailability were minor in the intertidal plot and appeared intermittently in the subtidal plot.

4.4 DQO-4: Assess the Potential Impacts of AC on Benthic Communities

Based on multiple lines of evidence, Year 3 data showed that AC did not negatively impact the benthic invertebrate community.

- In the Year 3 bioaccumulation study using sediment cores collected from subtidal plot, there were no differences in clams and polychaetes survivability (>90% on average) or growth when comparing the ENR and ENR+AC subplots.
- A variety of metrics evaluated for the Year 3 benthic macroinvertebrate community survey results showed no adverse effects of adding AC to ENR in any of the three plots, under the AC amounts applied for this study. Minor differences in the metrics were noted between ENR and ENR+AC in four instances (of 18), but these differences were due to the effects of physical disturbances and differences in silt accumulations, not AC, affecting habitat conditions in the subtidal and scour plots. One of the key metrics evaluated was the abundance of Annelids (worms), as they are considered uniquely sensitive to AC. Annelid abundance showed no negative effects in the benthic invertebrate taxonomy samples.

Additionally, the SPI data did not indicate an adverse impact of AC on the benthic community. Over the 3 years of monitoring, all three plots showed signs of benthic community recolonization after placement of the ENR and ENR+AC materials. At the intertidal plot, the SPI benthic community indicators – aRPD depths, successional stages, and feeding void density – are similar between the ENR and ENR+AC subplot for Years 1 through 3. At the scour plot, the more widespread Stage 3 infauna in Years 1 through 3 at the ENR subplot versus the ENR+AC subplot appears to be due to differences in the physical substrate between the subplots; i.e., more widespread silt deposits over the ENR subplot. At the subtidal plot, Stage 3 infauna presence is comparable between the subplots in Years 1 and 2, and more widespread Stage 3 infauna in Year 3 at the ENR+AC subplot appears to be due to thicker silt deposits on the ENR+AC subplot versus the ENR subplot in that year. The Stage 3 fauna, and especially their structures, are more readily detected in the SPI images from the thicker silt substrates but this does not mean that higher-order successional Stage 3 infauna are absent from the less silty areas. Other lines of evidence, such as the benthic community data, indicate benthic recolonization of all plots.

Overall, the lack of any clear effects of AC on the benthic community is consistent with previous research (Rakowska et al., 2012; Janssen and Beckingham, 2013; Kupryianchyk et al., 2015; Patmont et al., 2015; Kirtay et al., 2018) that has documented AC amendments do not adversely impact benthic biota, especially with amendments using coarser granular AC (a grain size range of 200 to 1,000 µm in this study; Amec Foster Wheeler et al., 2015a) and AC dosage levels of approximately 5% by weight or less (dosage was approximately 1-3% AC ; Section 3.2.2).

4.5 Additional Findings

Although the evaluation of ENR as a remedial technology was not a specific goal addressed in the pilot study, ENR alone performed well when compared to ENR+AC at both the intertidal and subtidal plots. ENR alone reduced total C_{free} PCBs by 95% in the intertidal plot and by 89% in the subtidal plot.[21] These results demonstrate the effectiveness of the ENR technology in the LDW. As indicated in Section 4.3, these results are supported by prior field-scale pilot studies, where ENR has been found to be effective in reducing the bioavailability of hydrophobic organic compounds by approximately 50 to 90% (Merritt et al., 2010; Fetters et al., 2019; Rosen et al., 2020).

Based on data collected prior to the study (as reviewed in Amec Foster Wheeler et al., 2015a), bulk sediment PCB concentrations in some of the samples collected from point locations in the intertidal and subtidal plots[22] exceeded the upper limit for ENR that was identified in the ROD by as much as a factor of 4 to 5. The samples with the highest concentrations in these plots were collected in 2014. Spatial or temporal variability and improving trends in the LDW could have contributed to lower composite concentrations measured in 2016. Still, it is likely that if point samples had been collected for the 2016 baseline event (instead of composite samples), some of the 2016 point-sample results would have exceeded the upper limit for ENR. Thus, assuming both the 2014 and 2016 data sets reflect pre-construction sediment conditions, which included concentrations above upper limit for ENR, it is notable that ENR and ENR+AC applications reduced intertidal and subtidal plot porewater (total C_{free} PCB) concentrations by 90% or more compared to baseline. In Year 3, the intertidal plot ENR and ENR+AC applications reduced total C_{free} PCB concentrations by 95% and 97% from baseline, respectively. In Year 3, the subtidal plot ENR and ENR+AC applications reduced total C_{free} PCB concentrations by 90% and 96% from baseline, respectively.

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[21] ENR subplot results could not be evaluated in the scour plot, because of low baseline PCB concentrations, particularly in the ENR subplot. C_{free} conditions in the overlying water likely represents the lowest achievable concentrations in treated sediments. The baseline scour ENR subplot C_{free} was comparable to overlying water concentrations (Section 4.3).
[22] The scour plot had also had one sample location above the PCB upper limit of ENR.

5.0 SUMMARY

This pilot study successfully satisfied the DQOs for the ENR/AC Pilot Study, with the main goal of helping inform whether AC can enhance ENR effectiveness in the LDW. In addition to a baseline and immediate post-construction (Year 0) monitoring event, the study conducted annual post-construction monitoring events (Years 1, 2, and 3) using multiple lines of evidence to address study goals. A summary of the conclusions of the pilot study is presented in the table below.

<table>
<tr><th rowspan="2">Key Line of Evidence</th><th colspan="3">Plot</th></tr>
<tr><th>Intertidal</th><th>Scour</th><th>Subtidal</th></tr>
<tr><td rowspan="3">DQO 1 & 2
ENR and ENR+AC Placement & Stability</td>
<td>▪ Layers placed successfully
▪ Stable Y1-Y3
▪ ENR+AC AC content
– Started at 2.6%
– Y1 & Y2 at ~2%
– Y3 at 1.3%</td>
<td>▪ Layers placed successfully
▪ Stable Y1-Y3
▪ ENR+AC AC content
– Started at 2.4%
– Y1 at 2.6%
– Y2 at 2%
– Y3 at 1.5%</td>
<td>▪ Layers placed successfully
▪ Reasonably stable Y1-Y3
▪ Mixing/furrowing by barge bridle chains
▪ ENR+AC AC content
– Started at 3%
– Y1 & Y2 at ~1%
– Y3 at 0.5%</td></tr>
<tr><td colspan="2">Decreasing trend in AC are attributed in part to mixing and dilution of silt deposited on the ENR and ENR+AC bed surfaces</td><td>Decreasing trend in AC likely due to silt deposition/dilution and physical disturbance</td></tr>
<tr><td colspan="3">Layers successfully placed and remained stable over the 3-year monitoring period; Although AC levels decreased due to mixing and dilution, levels were sufficient for ENR vs. ENR+AC evaluations</td></tr>
<tr><td rowspan="3">DQO-3
PCB Bioavailability: ENR vs. ENR+AC</td>
<td>▪ C_{free} total PCBs decreased from 31 to 1-1.6 ng/L (ENR) and from 28 to ~1 ng/L (ENR+AC)
▪ ENR+AC reduced C_{free} by 97-98% from baseline, and to 95-96% for ENR
▪ C_{free} total PCBs for ENR and ENR+AC subplots were 1.6 and 0.8 ng/L, respectively, in Y3</td>
<td>▪ ENR: Baseline C_{free} total PCBs was similar to overlying water at 1.5 ng/L, then fluctuated between 1 and 7 ng/L, Y1-Y3
▪ ENR+AC: C_{free} total PCBs decreased from 8.5 to 0.9 ng/L in Y1 (90% reduction), then fluctuated between 3 and 4 ng/L Y1-Y3
▪ C_{free} total PCBs for both subplots were 3 ng/L in Y3</td>
<td>▪ ENR: C_{free} total PCBs decreased from 34 ng/L to 4 to 16 ng/L (53 to 89% reduction) in Y1-Y3
▪ ENR+AC: C_{free} total PCBs decreased from 100 ng/L to 4 to 14 ng/L (86 to 96% reduction) in Y1-Y3
▪ C_{free} total PCBs for both subplots were 4 ng/L in Y3
▪ No statistical difference in ENR and ENR+AC in Years 2 and 3
▪ No statistical difference in PCB tissue concentrations in clams and polychaetes between the subplots</td></tr>
<tr><td>Very slight improvement with AC (< 2-5% additional availability reduction)</td><td>Results inconclusive due to low baseline ENR subplot PCB concentrations</td><td>Results complicated by physical disturbances; no clear advantage for AC</td></tr>
<tr><td colspan="3">ENR alone reduced PCB bioavailability so much that no major improvements in reducing C_{free} as a result of adding AC could be detected</td></tr>
</table>

Key Line of Evidence	Plot		
	Intertidal	**Scour**	**Subtidal**
DQO-4 AC Effect on Benthic Communities	▪ SPI/PV: no differences in ENR and ENR+AC successional stages ▪ Y3 Benthic Community study showed no differences among 6 community metrics	▪ SPI/PV: no differences in ENR and ENR+AC successional stages ▪ Y3 Benthic Community study showed no differences among 4 of 6 community metrics ▪ Benthic community diversity and Swartz dominance indices were higher in ENR; these were attributed to differences in silt deposition and prop wash in the subplots	▪ SPI/PV: no differences in ENR and ENR+AC successional stages ▪ Y3 Benthic Community study showed no differences among 4 of 6 community metrics ▪ Benthic community evenness and Swartz dominance indices were higher in ENR subplot; these were attributed to varying levels of mixing by physical disturbances and silt deposition in both subplots ▪ Y3 bioaccumulation study: no impact on polychaete and clam survival and growth
	No adverse impacts of AC on the benthic community		

The following conclusions can be made from these data:

1. **Placement was Successful and Material Remained In-Place**: The ENR and ENR+AC layers were successfully placed and remained in place over the 3-year post-construction monitoring period. AC was incorporated into the ENR material at a planned 4% AC content by weight. As measured in the barge immediately prior to placement, AC in the ENR+AC material was 2.7% at the scour and intertidal and 4% at the subtidal. Measurements post-construction (Year 0) showed that there was some loss of AC during placement, but such losses were anticipated with this application method. Environmental conditions unique to each location introduced different physical forces (wakes/waves, propwash, bridle chain dragging) under which both ENR and ENR+AC placements demonstrated stability and performed as intended—to enhance natural recovery. While levels decreased over Years 1 to 3 due to mixing and dilution, levels remained sufficient for addressing DQOs comparing ENR versus ENR+AC. Results of the scour plot demonstrated that ENR and ENR+AC can be applied to some scour areas, pending a site-specific assessment during remedial design.

   The decreases in AC concentrations over time in the three ENR+AC subplots is attributed to natural dilution from silt deposits and biological mixing, and not to a gross loss of AC from the ENR+AC subplots. There are several lines of evidence supporting this observation:

   - Increased TOC concentrations and increased percent fines corresponded with decreased AC concentrations suggesting surface sediment mixing with natural sediment deposits on the pilot surfaces.

- Analysis of sediment cores collected from the subtidal plot for the Year 3 biological study showed that the ENR and ENR+AC materials were substantially intact, making the selective removal of AC from the ENR+AC subplot layer very unlikely. This was also verified by five cores recently collected in the intertidal plot in 2021 as part of LDW Upper Reach remedial design investigation.
- Not finding AC in ENR only subplots could suggest that the AC remained in place, or that it was moved beyond the adjacent ENR subplots.

2. **AC did not Greatly Improve ENR:** Year 1 to 3 passive sampling results indicate that ENR reduced PCB bioavailability so much that no major improvements as a result of adding AC could be detected. In the intertidal and subtidal plots, both ENR and ENR+AC reduced baseline PCB bioavailability by approximately 90% or more, limiting the potential for additional detectable improvements by adding AC. In both cases, Year 3 results at these ENR and ENR+AC subplots were not meaningfully different. These conclusions were supported by an additional Year 3 bioaccumulation study using clams and polychaetes exposed to subtidal ENR and ENR+AC samples. The bioaccumulation study confirmed the ability of passive sampling lines of evidence to provide an effective measure of PCB bioavailability. Results at the scour plot were statistically inconclusive due to low baseline PCB porewater concentrations, especially in the ENR plot. At the scour plot, the low levels of PCB bioavailability are primarily controlled by overlying water and PCBs present in accumulating silt.

   The observation that AC did not substantively improve ENR performance was unexpected. When designing the study, the overriding hypothesis was that ENR alone could achieve remedial goals, and that the addition of AC would further enhance ENR performance. The latter was not generally observed. We hypothesize the following:

   - Because ENR-only plots achieved 90% reductions in PCB bioavailability in the LDW pilot study, the opportunity to see improvements due to AC addition would have required concentration reductions greater than 90%. In general, ENR performed better than anticipated. The ENR subplots achieved 90% reductions in PCB bioavailability compared to baseline, which is comparable to results often reported for AC-only remedies at sediment sites. For example, at the Bremerton, WA site, AC reduced PCB bioavailability in the upper 10 cm of the sediment bed by an average 81±11% in the first 10 months after treatment, and by 90±6% after 33 months, reflecting a slight increase in performance and showing the stability of the amendment (Kirtay et al., 2018).

- The ENR and ENR+AC pilot study results were influenced by surface sedimentation, dilution from surface sediment silt deposits, biological mixing, and overlying surface water dissolved PCB concentrations. Sediment cores collected from the subtidal plot for the Year 3 biological study showed that the subtidal ENR and ENR+AC layers were substantially intact, except for the upstream most corner of the subtidal plot. In addition, five cores recently collected from the intertidal plot during the upper reach remedial design showed intact ENR and ENR+AC layers.

- Baseline whole sediment and porewater total PCB concentrations were relatively low compared to baseline levels in other AC studies, making the measurement of differences between subplot conditions difficult. A 90% reduction in bioavailable total PCB concentrations resulted in porewater concentrations that were relatively close to concentrations measured in the overlying LDW surface water. Further reductions contributed by AC were difficult to measure.

3. **AC did not Adversely Impact Benthic Communities**: SPI/PV evaluations conducted in Years 1 through 3 did not indicate an adverse impact of AC on the benthic community and provided evidence for benthic community recolonization with time. A benthic community survey conducted in Year 3 also confirmed a lack of an AC impact. The few minor differences that were noted (i.e., in 4 of 18 metrics evaluated) were likely due to the impacts of physical disturbances, not AC, affecting habitat conditions in portions of the subtidal and scour plots. These conclusions were also supported by the Year 3 bioaccumulation study, which observed no adverse effects on mortality or growth in clams and polychaetes exposed to the ENR or ENR+AC layers.

Overall, results indicate that both ENR and ENR+AC were both successful in reducing PCB bioavailability in a wide variety of conditions in the LDW. ENR reduced PCB bioavailability so much that no major improvements as a result of adding AC could be detected. No evidence was found for adverse effects of AC in benthic communities. These conclusions echo results of several other pilot studies conducted in the past 5-10 years, although this study blended AC with ENR and used GAC while most others used the much finer PAC without an ENR layer.

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TABLES

Table 1.2-1
Thickness of the Placed Material for Each of the Subplots

Plot	Subplot	Average Thickness (Inches)	Minimum Thickness (Inches)	Maximum Thickness (Inches)	Percent Less than 6 Inches	Percent Between 6 and 9 Inches	Percent Greater than 9 Inches
Intertidal	ENR	10.9	8	14	0%	27%	73%
	ENR+AC	9.7	6	14	0%	47%	53%
	Combined	10.3	6	14	0%	37%	63%
Scour	ENR	11.5	7	18	0%	47%	53%
	ENR+AC	9.5	7	13	0%	53%	47%
	Combined	10.5	7	18	0%	50%	50%
Subtidal	ENR	12.7	6	16	0%	20%	80%
	ENR+AC	13.7	11	16	0%	0%	100%
	Combined	13.2	6	16	0%	10%	90%

Abbreviations:

ENR = Enhanced natural recovery

ENR+AC = Enhanced natural recovery amended with activated carbon

Table 2.1-1
Sampling Activity Timeline

Plot	Subplot	Baseline Activity: SPI/PV Date	Sediment Collection Start	Sediment Collection Finish	SPME Deployment Start	SPME Deployment Finish	SPME Retrieval Start	SPME Retrieval Finish
Intertidal	ENR+AC	07/12/16 - 07/13/16	09/04/16	09/09/16	07/26/16	07/26/16	09/04/16	09/09/16
	ENR		09/04/16	09/09/16	07/25/16	07/26/16	09/04/16	09/09/16
Scour	ENR+AC	07/12/16	09/01/16	09/05/16	07/27/26	07/29/16	09/01/16	09/05/16
	ENR		08/29/16	09/01/16	07/26/16	07/29/16	08/29/16	09/01/16
Subtidal	ENR+AC	07/13/16	11/16/16	11/18/16	11/28/16	11/28/16	01/18/17	01/18/17
	ENR		11/17/18	11/18/16	11/28/16	11/28/16	01/18/17	01/18/17

Plot	Subplot	Construction Activity: Material Placement Start	Material Placement Finish	Stake Measurement/ Observation Start	Stake Measurement/ Observation Finish	Year 0 Activity: Year 0 SPI/PV Date	Year 0 Sediment Collection Start	Year 0 Sediment Collection Finish
Intertidal	ENR+AC	12/01/16	12/15/16	12/13/16	12/27/16	01/11/17	01/12/17	01/13/17
	ENR	12/08/16	12/19/16					
Scour	ENR+AC	12/20/16	12/28/16	01/09/17	01/09/17	01/16/17	01/17/17	01/23/17
	ENR	12/29/16	01/06/17					
Subtidal	ENR+AC	01/09/17	01/19/17	01/30/17	01/31/17	02/01/17	02/02/17	02/03/17
	ENR	01/20/17	01/26/17					

Table 2.1-1
Sampling Activity Timeline

Plot	Subplot	SPI/PV Date	Year 1					
			Activity					
			Sediment Collection		SPME Deployment		SPME Retrieval	
			Start	Finish	Start	Finish	Start	Finish
Intertidal	ENR+AC	03/29/18 - 03/30/18	06/28/18	07/09/18	05/17/18	05/17/18	06/28/18	06/29/18
	ENR		06/28/18	07/09/18	05/16/18	05/17/18	06/29/18	06/29/18
Scour	ENR+AC	03/30/18	06/26/18	07/09/18	05/15/18	05/16/18	06/26/18	06/28/18
	ENR		06/24/18	07/09/18	05/14/18	05/15/18	06/24/18	06/26/18
Subtidal	ENR+AC	03/29/18	05/01/18	05/02/18	05/03/18	05/03/18	06/30/18	06/30/18
	ENR		04/30/18	05/01/18	05/03/18	05/03/18	06/30/18	06/30/18

Plot	Subplot	SPI/PV Date	Year 2					
			Activity					
			Sediment Collection		SPME Deployment		SPME Retrieval	
			Start	Finish	Start	Finish	Start	Finish
Intertidal	ENR+AC	03/07/19 - 03/08/19	06/17/19	06/19/19	05/09/19	05/09/19	06/17/19	06/19/19
	ENR		06/18/19	06/19/19	05/09/19	05/09/19	06/18/19	06/19/19
Scour	ENR+AC	03/08/19	06/22/19	06/25/19	05/13/19	05/15/19	06/22/19	06/25/19
	ENR		06/20/19	06/22/19	05/13/19	05/15/19	06/20/19	06/22/19
Subtidal	ENR+AC	03/07/19	06/22/19	06/22/19	04/26/19	04/26/19	06/22/19	06/22/19
	ENR		06/22/19	06/22/19	04/26/19	04/26/19	06/22/19	06/22/19

Table 2.1-1
Sampling Activity Timeline

Plot	Subplot	Year 3						
		Activity						
		SPI/PV Date	Sediment Collection		SPME Deployment		SPME Retrieval	
			Start	Finish	Start	Finish	Start	Finish
Intertidal	ENR+AC	06/27/20	09/16/20	09/16/20	08/03/20	08/03/20	09/16/20	09/16/20
	ENR		09/16/20	09/16/20	08/03/20	08/03/20	09/16/20	09/16/20
Scour	ENR+AC	06/27/20 - 06/29/20	09/21/20	09/24/20	08/05/20	08/06/20	09/21/20	09/24/20
	ENR		09/21/20	09/24/20	08/06/20	08/07/20	09/21/20	09/24/20
Subtidal	ENR+AC	06/28/20	09/16/20	09/16/20	07/24/20	07/24/20	09/16/20	09/16/20
	ENR		09/25/20	09/25/20	07/24/20	07/24/20	09/25/20	09/25/20

Abbreviations:
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
SPI/PV = Sediment profile imaging/plan view
SPME = Solid-phase micro extraction

Table 3.1-1
SPI/PV Image Observations of ENR/ENR+AC Stability and Silt Deposits – Years 0 to 3

Survey	ENR Material Presence					
	Intertidal Plot		Scour Plot		Subtidal Plot	
	ENR	ENR+AC	ENR	ENR+AC	ENR	ENR+AC
Year 0	present in all cells*	present in all cells	present in all cells	present in all cells	present in all cells	present in all cells
Year 1	present in all cells	present in all cells	present in all cells	present in all cells	Disturbed in Cell 6	Disturbed in Cells 5 & 6
Year 2	present in all cells	present in all cells	present in all cells	present in all cells	Disturbed in Cell 6	Disturbed in Cells 5 & 6
Year 3	present in all cells	present in all cells	present in all cells	present in all cells	Disturbed in Cells 5 & 6	Disturbed in Cells 5 & 6
Survey	**Silt Layer Thickness in cm. #-# equals range, (#) = average**					
	Intertidal Plot		**Scour Plot**		**Subtidal Plot**	
	ENR	**ENR+AC**	**ENR**	**ENR+AC**	**ENR**	**ENR+AC**
Year 0	<1	<1	<1	<1	1	1-2
Year 1	Silt mixed into ENR Material	Silt mixed into ENR+AC Material	7-12 (9)	0-11 (4)	Silt mixed into ENR Material	Silt mixed into ENR+AC Material
Year 2	Silt mixed into ENR Material	Silt mixed into ENR+AC Material	4-8 (5)	0-7 (2)	0-4 (1)	0-6 (2)
Year 3	Silt mixed into ENR Material	Silt mixed into ENR+AC Material	7-12 (9)	0-10 (4)	0-5 (1)	0-15 (6)

Abbreviations/Notes:
cm = centimeter(s)
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
PV = Plan view
SPI = Sediment-profile imaging
* cells and sample location are shown in Figures 1.2-3, 1.2-3, and 1.2-4 for the Intertidal, Scour, and Subtidal Plots, respectively.

Table 3.1-2
Key SPI/PV Image Measurements – Baseline through Year 3

Survey	Average Penetration Depth (cm)					
	Intertidal Plot		Scour Plot		Subtidal Plot	
Survey	ENR	ENR+AC	ENR	ENR+AC	ENR	ENR+AC
Baseline	9.7		13.8		12.7	
Year 0	7.4	8.0	9.9	9.9	10.5	10.8
Year 1	5.1	5.6	9.3	7.8	5.4	7.4
Year 2	2.5	2.8	5.2	3.9	2.4	3.0
Year 3	3.4	2.8	9.0	5.9	3.2	9
	Average aRPD Depth (cm)					
	Intertidal Plot		**Scour Plot**		**Subtidal Plot**	
Survey	**ENR**	**ENR+AC**	**ENR**	**ENR+AC**	**ENR**	**ENR+AC**
Baseline	2.2		2.0		1.3	
Year 0	Ind	3.8	Ind	0.8	1.5	1.4
Year 1	2.5	2.3	1.9	1.4	2.6	1.3
Year 2	1.1	1.6	1.5	2.1	1.2	1.5
Year 3	1.5	1	1.6	0.8	0.8	1.3
	Percent of Stations with Stage 3 Infauna (% of Stations where Successional Stage is Ind)*					
	Intertidal Plot		**Scour Plot**		**Subtidal Plot**	
Survey	**ENR**	**ENR+AC**	**ENR**	**ENR+AC**	**ENR**	**ENR+AC**
Baseline	67% (17%)		100% (0%)		50% (0%)	
Year 0	0% (100%)	0% (100%)	0% (100%)	0% (100%)	0% (100%)	0% (100%)
Year 1	92% (8%)	67% (17%)	100% (0%)	75% (25%)	58% (25%)	50% (25%)
Year 2	33% (58%)	33% (50%)	100% (0%)	58% (33%)	33% (58%)	17% (33%)
Year 3	25% (67%)	25% (75%)	100% (0%)	67% (33%)	25% (58%)	67% (0%)

Abbreviations/Notes:
aRPD = Apparent redox-potential discontinuity
cm = centimeter(s)
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
Ind. = Indeterminate
* - Percent of stations with Stage 3 infauna in at least replicate (percent of stations where successional stage was indeteminate in all replicates)

Table 3.1-3
SPI Observations Feeding Void Data

Intertidal Plot				
	Total Number of Feeding Voids per Subplot		Number of Feeding Voids/cm^2	
Year	**ENR**	**ENR+AC**	**ENR**	**ENR+AC**
Year 1	20	29	0.22	0.39
Year 2	7	6	0.14	0.14
Year 3	7	7	0.12	0.12
Scour Plot				
	Total Number of Feeding Voids per Subplot		Number of Feeding Voids/cm^2	
Year	**ENR**	**ENR+AC**	**ENR**	**ENR+AC**
Year 1	162	55	1.15	0.41
Year 2	74	24	0.92	0.38
Year 3	162	64	1.26	0.60
Subtidal Plot				
	Total Number of Feeding Voids per Subplot		Number of Feeding Voids/cm^2	
Year	**ENR**	**ENR+AC**	**ENR**	**ENR+AC**
Year 1	6	12	0.09	0.14
Year 2	1	0	0.04	0.00
Year 3	13	36	0.25	0.28

Abbreviations:
- cm^2 = square centimeter(s)
- ENR = Enhanced natural recovery
- ENR+AC = Enhanced natural recovery amended with activated carbon

Table 3.2-1
Data Summary – Conventionals

Parameter	Plot	Subplot	Event	Average	Minimum	Maximum	Standard Deviation
Gravel (%)	Intertidal	ENR	Baseline	1.3	0.60	2.5	1.0
			Year 0	66	63	71	4.5
			Year 1	53	50	61	4.7
			Year 2	61	60	61	0.60
			Year 3	67	59	71	4.8
		ENR+AC	Baseline	1.3	0.90	1.6	0.35
			Year 0	68	67	68	0.58
			Year 1	60	57	64	3.6
			Year 2	60	53	65	6.1
			Year 3	64	57	71	7.1
	Scour	ENR	Baseline	1.4	0.60	2.3	0.86
			Year 0	66	65	67	1.2
			Year 1	67	65	71	3.4
			Year 2	56	51	61	5.2
			Year 3 [1]	69	62	73	5.9
		ENR+AC	Baseline	5.1	1.4	12	6.4
			Year 0	66	64	67	1.9
			Year 1	64	55	70	7.7
			Year 2	70	67	75	4.8
			Year 3 [1]	69	66	71	2.1
	Subtidal	ENR	Baseline	5.2	2.2	7.1	2.6
			Year 0	23	22	24	1.2
			Year 1	22	20	23	1.2
			Year 2	21	20	25	2.2
			Year 3	21	19	23	2.3
		ENR+AC	Baseline	1.5	0.30	3.3	1.6
			Year 0	22	21	24	1.2
			Year 1	20	15	24	4.5
			Year 2	17	14	19	2.8
			Year 3	15	7.3	18	4.4

Table 3.2-1
Data Summary – Conventionals

Parameter	Plot	Subplot	Event	Average	Minimum	Maximum	Standard Deviation
Sand (%)	Intertidal	ENR	Baseline	46	43	48	2.9
			Year 0	34	29	37	4.5
			Year 1	44	36	48	5.0
			Year 2	37	36	37	0.55
			Year 3	31	27	36	3.8
		ENR+AC	Baseline	46	38	52	7.3
			Year 0	32	32	33	0.55
			Year 1	38	34	41	3.5
			Year 2	37	32	40	3.8
			Year 3	34	27	40	6.4
	Scour	ENR	Baseline	17	12	26	7.1
			Year 0	34	33	35	1.3
			Year 1	29	26	31	2.8
			Year 2	34	31	36	2.7
			Year 3 [1]	29	25	36	6.2
		ENR+AC	Baseline	34	29	41	6.6
			Year 0	34	32	36	1.8
			Year 1	33	28	41	6.9
			Year 2	28	24	30	3.6
			Year 3 [1]	28	27	31	1.4
	Subtidal	ENR	Baseline	30	27	32	2.6
			Year 0	76	74	77	1.7
			Year 1	72	70	75	2.3
			Year 2	70	64	74	4.9
			Year 3	61	59	63	2.5
		ENR+AC	Baseline	19	15	25	5.4
			Year 0	76	75	78	1.7
			Year 1	64	63	65	0.80
			Year 2	66	65	68	1.4
			Year 3	51	38	57	7.8

Table 3.2-1
Data Summary – Conventionals

Parameter	Plot	Subplot	Event	Average	Minimum	Maximum	Standard Deviation
Fines (%)	Intertidal	ENR	Baseline	52	50	56	3.4
			Year 0	0.27	0.20	0.30	0.058
			Year 1	3.1	2.5	4.1	0.63
			Year 2	2.6	2.5	2.7	0.075
			Year 3	2.7	2.1	5.0	1.3
		ENR+AC	Baseline	53	47	62	7.6
			Year 0	0.40	0.30	0.50	0.10
			Year 1	2.0	1.8	2.2	0.21
			Year 2	3.9	2.2	7.0	2.7
			Year 3	2.7	1.7	3.5	0.93
	Scour	ENR	Baseline	81	72	87	8.0
			Year 0	0.30	0.30	0.30	<0.0001
			Year 1	4.1	3.3	4.8	0.76
			Year 2	9.7	7.3	14	3.3
			Year 3 [1]	1.9	1.5	2.1	0.3
		ENR+AC	Baseline	61	57	70	7.4
			Year 0	0.47	0.40	0.50	0.058
			Year 1	2.7	2.0	3.5	0.75
			Year 2	2.7	1.3	3.6	1.2
			Year 3 [1]	2.4	1.6	3.9	1.1
	Subtidal	ENR	Baseline	65	61	67	3.2
			Year 0	1.3	0.90	2.0	0.59
			Year 1	6.7	5.0	8.3	1.5
			Year 2	9.4	6.5	16	4.1
			Year 3	17	14	23	4.7
		ENR+AC	Baseline	79	72	84	7.0
			Year 0	1.4	0.90	1.7	0.42
			Year 1	16	12	20	4.2
			Year 2	17	16	19	1.8
			Year 3	34	26	55	12

Table 3.2-1
Data Summary – Conventionals

Parameter	Plot	Subplot	Event	Average	Minimum	Maximum	Standard Deviation
Black Carbon (Baseline), Total Volatile Solids (Year 0) and Activated Carbon/Black Carbon (Year 1, 2, and 3) (%)	Intertidal	ENR	Baseline	0.12	0.041	0.26	0.12
			Year 0	0.51	0.49	0.55	0.035
			Year 1	0.056	0.012	0.14	0.073
			Year 2	0.044	0.043	0.045	<0.0001
			Year 3	0.041	0.037	0.045	0.0040
		ENR+AC	Baseline	0.092	0.057	0.11	0.031
			Year 0	2.6	2.4	3.0	0.30
			Year 1	2.1	1.6	2.8	0.61
			Year 2	1.9	1.6	2.2	0.30
			Year 3	1.3	0.92	1.8	0.44
	Scour	ENR	Baseline	0.20	0.14	0.30	0.087
			Year 0	0.49	0.46	0.55	0.054
			Year 1	0.19	0.088	0.33	0.13
			Year 2	0.27	0.20	0.39	0.10
			Year 3 [1]	0.040	0.037	0.042	0.0025
		ENR+AC	Baseline	0.36	0.22	0.49	0.14
			Year 0	2.4	1.6	2.9	0.75
			Year 1	2.6	2.0	3.4	0.72
			Year 2	2.0	1.4	2.8	0.59
			Year 3 [1]	1.5	0.95	2.0	0.46
	Subtidal	ENR	Baseline	0.13	0.063	0.18	0.063
			Year 0	1.1	1.0	1.1	0.058
			Year 1	0.25	0.13	0.34	0.11
			Year 2	0.14	0.076	0.22	0.074
			Year 3	0.23	0.097	0.39	0.15
		ENR+AC	Baseline	0.11	0.046	0.16	0.057
			Year 0	3.0	3.0	3.0	0
			Year 1	1.1	0.93	1.2	0.14
			Year 2	0.99	0.88	1.1	0.11
			Year 3	0.47	0.19	0.70	0.21

Table 3.2-1
Data Summary – Conventionals

Parameter	Plot	Subplot	Event	Average	Minimum	Maximum	Standard Deviation
Total Organic Carbon (%)	Intertidal	ENR	Baseline	1.4	1.3	1.4	0.058
			Year 0	0.056	0.054	0.057	0.0016
			Year 1	0.20	0.15	0.28	0.070
			Year 2	0.21	0.20	0.22	0.010
			Year 3	0.20	0.16	0.26	0.053
		ENR+AC	Baseline	1.5	1.5	1.6	0.058
			Year 0	1.8	1.4	2.2	0.40
			Year 1	1.9	1.6	2.5	0.50
			Year 2	2.0	1.4	2.7	0.65
			Year 3	1.8	1.1	2.3	0.61
	Scour	ENR	Baseline	2.7	2.6	2.8	0.100
			Year 0	0.054	0.053	0.055	0.0015
			Year 1	0.33	0.27	0.37	0.053
			Year 2	0.71	0.62	0.88	0.14
			Year 3 [1]	0.16	0.12	0.21	0.045
		ENR+AC	Baseline	2.1	1.9	2.2	0.17
			Year 0	1.8	1.5	2.1	0.26
			Year 1	1.4	0.38	2.0	0.86
			Year 2	1.4	1.1	1.6	0.26
			Year 3 [1]	1.2	0.89	1.5	0.31
	Subtidal	ENR	Baseline	1.8	1.7	2.1	0.23
			Year 0	0.11	0.10	0.12	0.012
			Year 1	0.40	0.38	0.42	0.021
			Year 2	0.47	0.35	0.66	0.17
			Year 3	0.72	0.59	0.90	0.16
		ENR+AC	Baseline	2.1	2.0	2.2	0.10
			Year 0	1.8	1.6	1.9	0.16
			Year 1	1.7	1.4	2.0	0.31
			Year 2	1.7	1.7	1.8	0.058
			Year 3	2.0	1.8	2.1	0.15

Notes:
1. Scour Year 3 Data are Type 2 (cleared).

Abbreviations:
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

Table 3.2-2

Silt Layer Thicknesses Estimates [1, 2]

		Average Thickness [3] (cm)			Thickness Range (cm)		
Year	**Subplot**	**Intertidal**	**Scour**	**Subtidal**	**Intertidal**	**Scour**	**Subtidal**
Year 1	ENR	1.4	2.2	0.61	0.5 - 6.3	0 - 5	0 - 5
	ENR+AC	1.0	1.2	1.6	0.3 - 6.3	0 - 4.4	0 - 15
Year 2	ENR	0.7	4.7	2.8	0 - 2.5	2 - 11	0.5 - 8
	ENR+AC	1.7	2.6	3.4	0 - 9	0 - 9	0.5 - 8.5
Year 3	ENR	1.1	4.4	6.3	0 - 9	0.5 - 9	0.5 - 25
	ENR+AC	1.2	1.4	9.2	0 - 6	0 - 8	0.5 - 27

Notes:
1. Silt layer thicknesses are based on field measurements during SPME retrieval, not sediment profile imaging.
2. The low and high values of the silt layer thickness at each location were averaged to represent an average silt layer.
3. Arithmetic mean of 28 - 30 samples.

Abbreviations:
cm = centimeter(s)
ENR+AC = Enhanced natural recovery amended with activated carbon
ENR = Enhanced natural recovery

Table 3.2-3
Thickness of ENR and ENR+AC Layer
Observed in the Year 3 Subtidal Bioaccumulation Cores

Subtidal ENR Subplot Bioaccumulation Core Log Observations				Subtidal ENR+AC Subplot Bioaccumulation Core Log Observations			
Station	Disturbed Area?	Sand/ENR (inches)	Grid Cell Average Sand/ENR (inches)	Station	Disturbed Area?	Sand/ENR (inches)	Grid Cell Average Sand/ENR (inches)
ENR-1A	No	9.6	8.5	ENR+AC-1A	No	3.1	6.4
ENR-1B	No	10.2		ENR+AC-1B	No	6.7	
ENR-1C	No	5.5		ENR+AC-1C	No	9.4	
ENR-2A	No	9.4	10.6	ENR+AC-2A	No	5.9	6.4
ENR-2B	No	12.2		ENR+AC-2B	No	5.1	
ENR-2C	No	10.2		ENR+AC-2C	No	8.3	
ENR-3A	No	9.1	10.6	ENR+AC-3A	No	8.5	8.2
ENR-3B	No	8.1		ENR+AC-3B	No	5.9	
ENR-3C	No	14.6		ENR+AC-3C	No	10.2	
ENR-4A	No	8.5	10.0	ENR+AC-4A	No	10.2	9.3
ENR-4B	No	10.4		ENR+AC-4B	No	6.3	
ENR-4C	No	11.2		ENR+AC-4C	No	11.2	
ENR-5A	No	5.1	4.6	ENR+AC-5A	Yes	0.0	0.0
ENR-5B	No	0.0		ENR+AC-5B	Yes	0.0	
ENR-5C	No	8.7		ENR+AC-5C	Yes	0.0	
ENR-6A	Yes	0.0	5.2	ENR+AC-6A	Yes	2.0	0.7
ENR-6B	Yes	8.7		ENR+AC-6B	Yes	0.0	
ENR-6C	Yes	7.1		ENR+AC-6C	Yes	0.0	

Abbreviations:

ENR+AC = Enhanced natural recovery amended with activated carbon

ENR = Enhanced natural recovery

Table 3.2-4
Summary of Salinity Data

Year	Plot	Subplot	Minimum	Maximum	Arithmetic Mean	Geometric Mean
Baseline	Intertidal	ENR	6.1	25.8	14.77	13.77
		ENR+AC	6.9	23.3	15.37	14.66
	Scour	ENR	22.5	28.7	27.3	27.26
		ENR+AC	22.1	28.6	27.02	26.97
	Subtidal	ENR	27.8	28.3	28.13	28.12
		ENR+AC	27.9	28.7	28.36	28.36
Year 1	Intertidal	ENR	4.5	13.3	7.72	7.38
		ENR+AC	4.5	19.1	9.71	8.88
	Scour	ENR	17.7	25.9	22.52	22.24
		ENR+AC	19.9	24.8	21.76	21.69
	Subtidal	ENR	25.4	26.7	26.08	26.07
		ENR+AC	25.5	27.3	26.3	26.29
Year 2	Intertidal	ENR	4.8	16.8	8.55	8.02
		ENR+AC	2.4	14.1	8.28	7.55
	Scour	ENR	19.2	20.5	19.88	19.87
		ENR+AC	18.4	20.7	19.55	19.52
	Subtidal	ENR	26.8	28.5	27.67	27.66
		ENR+AC	26.6	27.7	27.03	27.03
Year 3	Intertidal	ENR	5.4	21.4	12.04	11.5
		ENR+AC	2.5	21.3	10.39	9.09
	Scour	ENR	21.4	27.6	26.15	26.05
		ENR+AC	22.5	27.6	26	25.94
	Subtidal	ENR	21.9	27.9	26.5	26.41
		ENR+AC	19.3	27.9	24.77	24.53

Abbreviations:
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

Table 3.3-1
Data Summary – Total PCBs

Chemical	Plot	Subplot	Event	Geometric Mean	Median	Minimum	Maximum	Standard Deviation
Sediment PCBs (Total PCB, µg/kg dw) [1, 2]	Intertidal	ENR	Baseline	196	225	80	414	167
			Year 1	5.0	4.5	3.2	8.3	2.6
			Year 2	8.4	6.0	6.0	17.0	5.5
			Year 3	4.9	4.1	3.1	9.0	3.2
		ENR+AC	Baseline	221	222	120	407	145
			Year 1	3.3	3.4	2.6	4.2	0.8
			Year 2	15.9	15.0	8.9	30.0	8.9
			Year 3	4.8	5.9	2.3	8.2	3.0
	Scour	ENR	Baseline	29.4	26.6	17.5	54.7	19.4
			Year 1	14.1	10.9	9.0	28.7	10.9
			Year 2	87.7	94.0	71.0	101.0	12.6
			Year 3 [3]	8.1	8.3	6.5	9.8	1.7
		ENR+AC	Baseline	22.6	21.7	19.2	27.6	4.3
			Year 1	9.2	9.1	6.7	12.7	3.0
			Year 2	37.9	50.0	21.0	53.0	14.4
			Year 3 [3]	24.0	23.2	19.4	30.0	5.4
	Subtidal	ENR	Baseline	257	237	153	468	163
			Year 1	45.1	45.0	26.8	76.3	25.0
			Year 2	74.9	91.0	20.0	228.0	86.0
			Year 3	9.5	7.2	3.8	31.7	15.2
		ENR+AC	Baseline	221	210	151	341	97
			Year 1	39.4	40.6	31.1	48.5	8.7
			Year 2	85.8	78.0	49.0	165.0	49.2
			Year 3	20.0	13.8	11.4	52.7	23.2

Table 3.3-1
Data Summary – Total PCBs

Chemical	Plot	Subplot	Event	Geometric Mean	Median	Minimum	Maximum	Standard Deviation
C_{free} PCBs (Total PCB, ng/L) [1, 2]	Intertidal	ENR	Baseline	31	25.4	15.0	75.0	32.1
			Year 1	1.1	1.1	0.8	1.3	0.2
			Year 2	1.2	7.3	5.1	7.8	0.8
			Year 3	1.6	1.5	1.4	1.9	0.3
		ENR+AC	Baseline	28	28.9	18.0	41.0	11.5
			Year 1	0.49	0.5	0.3	0.8	0.3
			Year 2	0.93	0.9	0.8	1.2	0.2
			Year 3	0.77	0.7	0.7	1.0	0.2
	Scour	ENR	Baseline	1.5	1.5	1.2	1.9	0.4
			Year 1	1.4	1.2	1.0	2.4	0.8
			Year 2	6.6	7.3	5.1	7.8	1.4
			Year 3 [3]	3.3	2.9	2.7	4.5	1.0
		ENR+AC	Baseline	8.5	8.5	3.7	20.0	8.4
			Year 1	0.89	0.9	0.6	1.3	0.4
			Year 2	4.3	4.7	3.4	5.1	0.9
			Year 3 [3]	3.3	3.3	2.9	3.7	0.4
	Subtidal	ENR	Baseline	34	30.0	26.0	51.0	13.4
			Year 1	9.6	7.7	7.2	16.0	4.9
			Year 2	16	13.0	13.0	23.0	5.8
			Year 3	3.8	3.7	3.5	4.3	0.4
		ENR+AC	Baseline	100	97	76	150	38
			Year 1	3.8	3.7	3.5	4.2	0.4
			Year 2	14	15.0	9.8	18.0	4.1
			Year 3	4.2	4.3	3.2	5.4	1.1

Notes:
1. Measured in sediment and porewater samples from 0 to 10 centimeters.
2. Total PCB is the sum of total PCB congeners.
3. Scour Year 3 Data are Type 2 (cleared).

Abbreviations:
dw = dry weight
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
ng/L = nanogram(s) per liter
PCB = Polychlorinated biphenyl
µg/kg = microgram(s) per kilogram

Table 3.3-2
Data Summary – Depositional Material

Chemical	Plot	Subplot	Event	Composite
Depositional Material PCBs (Total PCB, µg/kg dw)	Scour	ENR	Year 2	86.7
			Year 3	9.7
		ENR+AC	Year 2	28.8
			Year 3	13.7
Depositional Material Total Percent Fines (%)	Scour	ENR	Year 2	44.2
			Year 3	70.6
		ENR+AC	Year 2	24.9
			Year 3	45.7
Depositional Material Activated Carbon/Black Carbon (%)	Scour	ENR	Year 2	0.75
			Year 3	0.31
		ENR+AC	Year 2	5.8
			Year 3	2.2
Depositional Material Total Organic Carbon (%)	Scour	ENR	Year 2	2.0
			Year 3	2.8
		ENR+AC	Year 2	5.0
			Year 3	5.0

Abbreviations:
dw = dry weight
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
PCB = Polychlorinated biphenyl
µg/kg = microgram(s) per kilogram

Table 3.5-1
Data Summary – Laboratory Bioaccumulation Study

Parameter	Plot	Subplot	Geometric Mean	Median	Minimum	Maximum	Standard Deviation
Polychaete Tissue PCBs (Total PCB, ng/g ww) [1]	Subtidal	ENR	43.0	40.7	31.7	61.3	15.2
		ENR+AC	23.0	24.1	17.7	29.9	6.1
Clam Tissue PCBs (Total PCB, ng/g ww) [1]	Subtidal	ENR	7.2	4.0	4.0	22.9	10.9
		ENR+AC	5.6	5.2	5.0	6.8	1.0
Cf_{ree} PCBs (Total PCB, ng/L) [1, 2]	Subtidal	ENR	10.0	7.5	5.2	26.0	11.4
		ENR+AC	6.2	5.2	4.7	9.9	2.9
Polychaete Survival (%)	Subtidal	ENR	93	95	50	100	11
		ENR+AC	91	94	65	100	9
Clam Survival (%)	Subtidal	ENR	98	100	75	100	6
		ENR+AC	92	100	75	100	12
Polychaete Growth - Tissue Mass (g)	Subtidal	ENR	5.8	5.8	2.9	12.2	2.2
		ENR+AC	5.5	5.6	3.9	9.3	1.6
Clam Growth - Tissue Mass (g)	Subtidal	ENR	26.4	25.7	13.7	43.9	9.0
		ENR+AC	25.4	27.9	11.5	45.8	9.2

Notes:
1. Total PCB is the sum of total PCB congeners.
2. Measured from 0 to 10 centimeters

Abbreviations:
C_{free} = Freely dissolved concentrations
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
g = gram(s)
ng/g = nanogram(s) per gram
ng/L = nanogram(s) per liter
PCB = Polychlorinated biphenyl
ww = wet weight

Table 3.5-2
Summary of Subtidal Plot Bioaccumulation Study Results by Individual ENR and ENR+AC Replicates

Core	Silt Thickness (cm) [4]	C_{free} (Total PCB ng/L) [1]	Clam Tissue (Total PCB ng/g ww) [1, 2]	Polychaete (Total PCB ng/g ww) [1, 2]	Clam Tissue Lipid Content (% by ww)	Polychaete Tissue Lipid Content (% by ww)	Bulk Sediment Total PCBs Congeners [3] (µg/g)	Bulk Sediment Activated Carbon/Black Carbon (%)	Bulk Sediment Total Organic Carbon (%)
LDW-Y3-SU-ENR-A-CORE-BIO	3.7	5.2	3.9	41	0.100	0.700	8.98	0.23	0.53
LDW-Y3-SU-ENR-B-CORE-BIO	5.4	26	23	61	0.123	0.590	159	0.12	0.51
LDW-Y3-SU-ENR-C-CORE-BIO	4.6	7.5	4	32	0.316	0.893	12.7	0.25	0.35
LDW-Y3-SU-ENR+AC-A-CORE-BIO	11.7	9.9	5.2	30	0.203	0.452	42	0.97	1.6
LDW-Y3-SU-ENR+AC-B-CORE-BIO	6.7	5.2	5	18	0.341	0.380	8.96	0.84	1.6
LDW-Y3-SU-ENR+AC-C-CORE-BIO	13.5	4.7	6.8	24	0.303	0.482	21.7	1.7	1.2

Notes:
1. Total PCB is the sum of total PCB congeners.
2. Concentrations of clams and polychaetes were measured on single samples prior to addition of animals to the cores (time zero) and were found to be 0.6 and 1.4 ng/g ww, respectively. All concentrations reported in the above table were more than 5 times these values, and were assumed to be the result of uptake from the ENR and ENR+AC cores; therefore, the values were not adjusted by time zero results (i.e., time zero results were not subtracted from results of animals exposed to the cores).
3. Bulk sediment PCB concentrations from samples collected from the bioaccumulation cores. These concentrations represent the concentrations to which the organisms were exposed during the testing.
4. Silt thickness based on field observations.

Abbreviations:

C_{free} = Freely dissolved concentrations
cm = centimeter(s)
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
ng/g = nanogram(s) per gram
ng/g ww = nanogram(s) per gram wet weight
ng/L = nanogram(s) per liter
PCB = Polychlorinated biphenyl

Table 3.5-3
Summary of Benthic Macroinvertebrate Community Survey Metrics

Metric	Symbol/Unit	Description
Shannon Weiner	H'	Measurement of biodiversity
Abundance	Per Sample	Total count of all individual organisms
Annelid Abundance	Per Sample	Total count of individual Annelid organisms
Taxa Richness	Per Sample	Number of taxa
Pielou's J	J'	Evenness in abundance of each species in sample
Swartz Dominance Index	SDI	Number of taxa accounting for 75% of total abundance in a sample
Relative Abundance	%	Percent abundance of major taxa

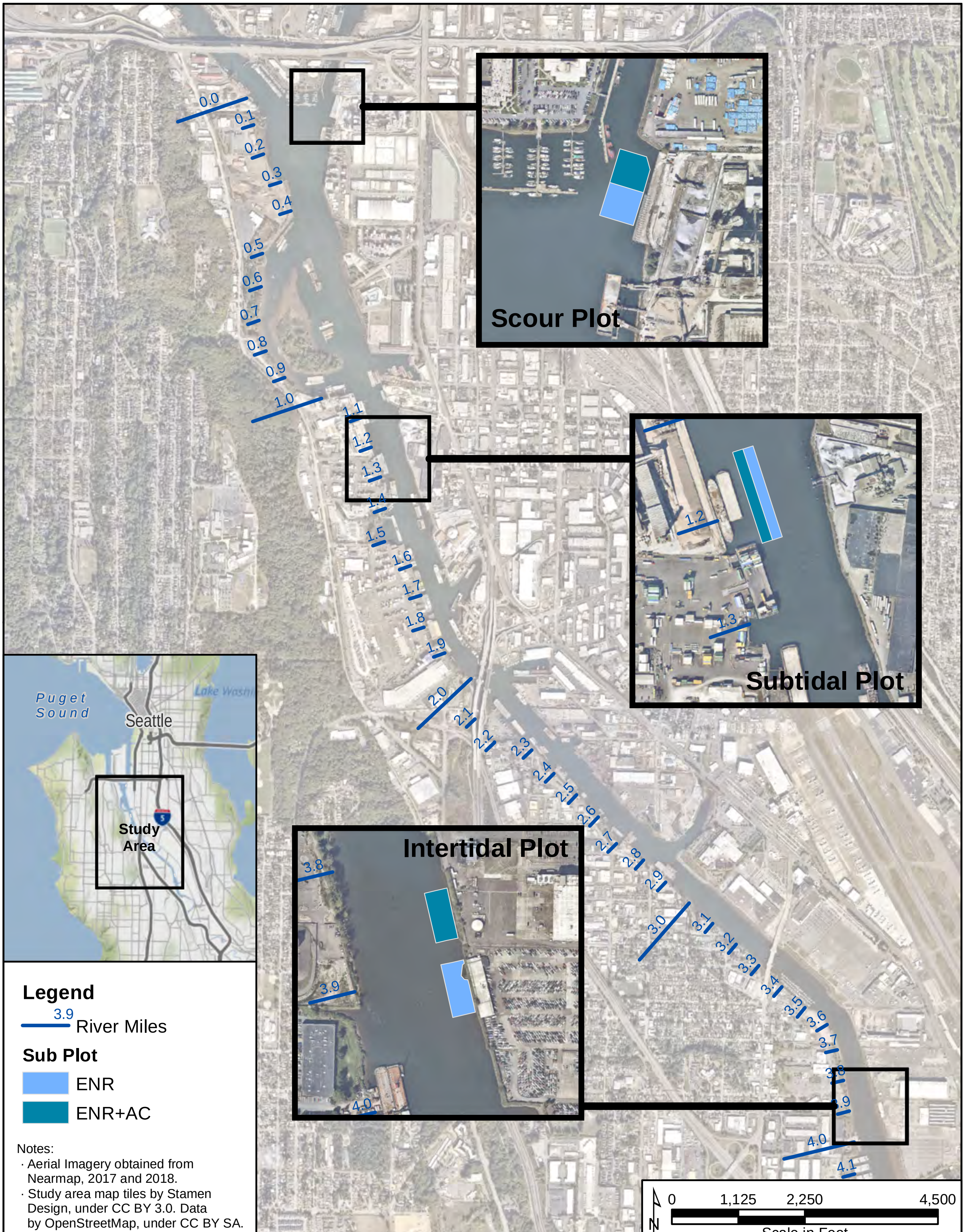
Table 3.5-4
Benthic Macroinvertebrate Metrics Comparison of ENR and ENR+AC by Plot [1, 2]

Plot	Subplot	Diversity (H')	Abundance (per Sample)	Annelid Abundance (per Sample)	Richness	Pielou's J	Swartz Dominance Index
Intertidal	ENR	1.1	79	19	6	0.63	2
	ENR+AC	1.4	85	18	8	0.62	3
	Significant Difference? ($p < 0.05$)	No	No	No	No	No	No
Scour	ENR	2.8	190	120	34	0.80	11
	ENR+AC	2.3	160	140	27	0.71	7
	Significant Difference? ($p < 0.05$)	Yes	No	No	No	No	Yes
Subtidal	ENR	2.3	35	23	12	0.91	7
	ENR+AC	2	110	55	18	0.72	5
	Significant Difference? ($p < 0.05$)	No	No	No	No	Yes	Yes

Notes:
1. Values for each metric represent arithmetic means or geometric means.
2. There were 5 replicate samples per subplot.

Abbreviations:
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

FIGURES



Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 1.1-1 Plot Locations in the Lower Duwamish Waterway

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3/4/2021

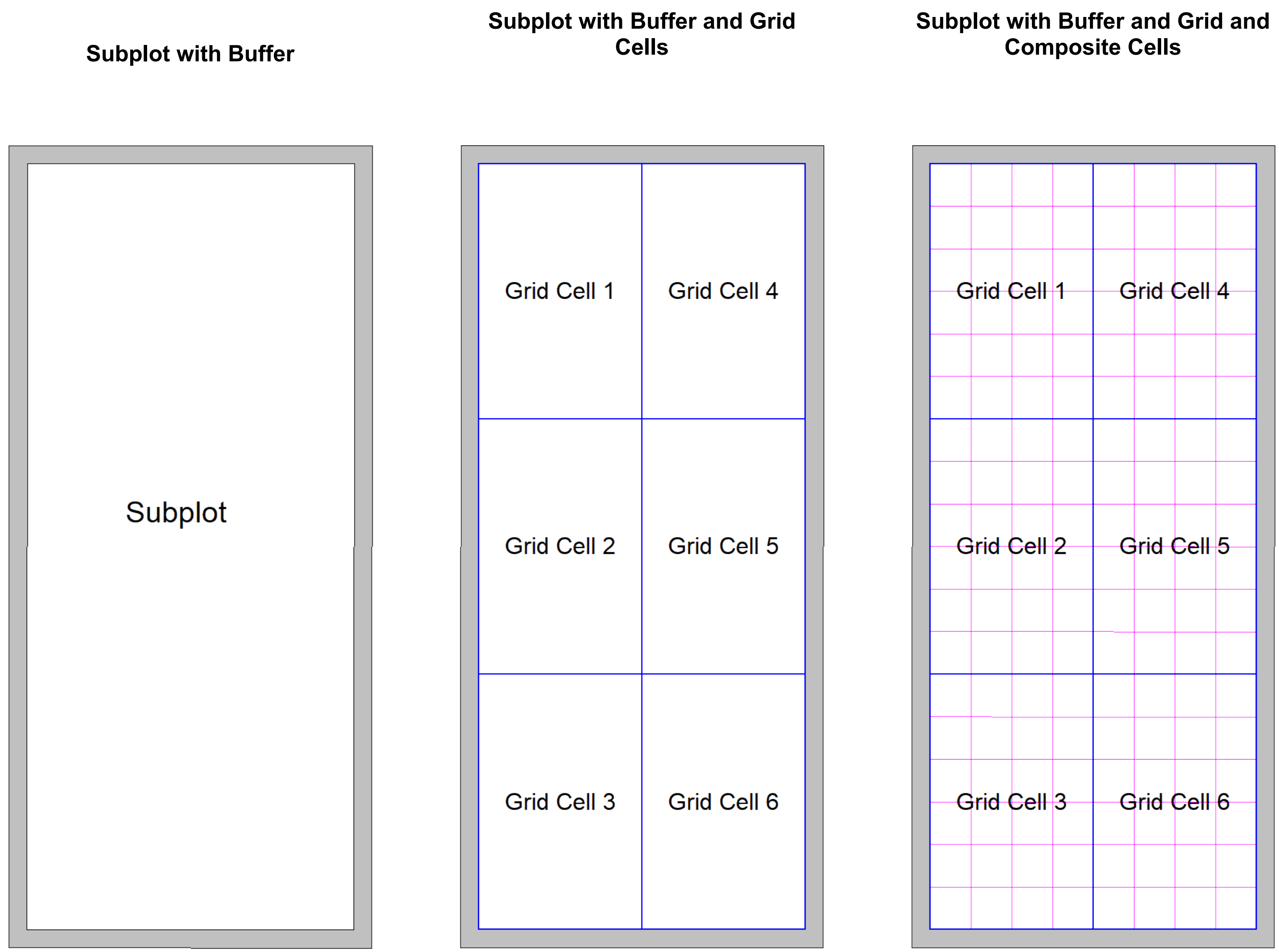

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Figure 2.1-1
General Subplot Layout

2/7/2021

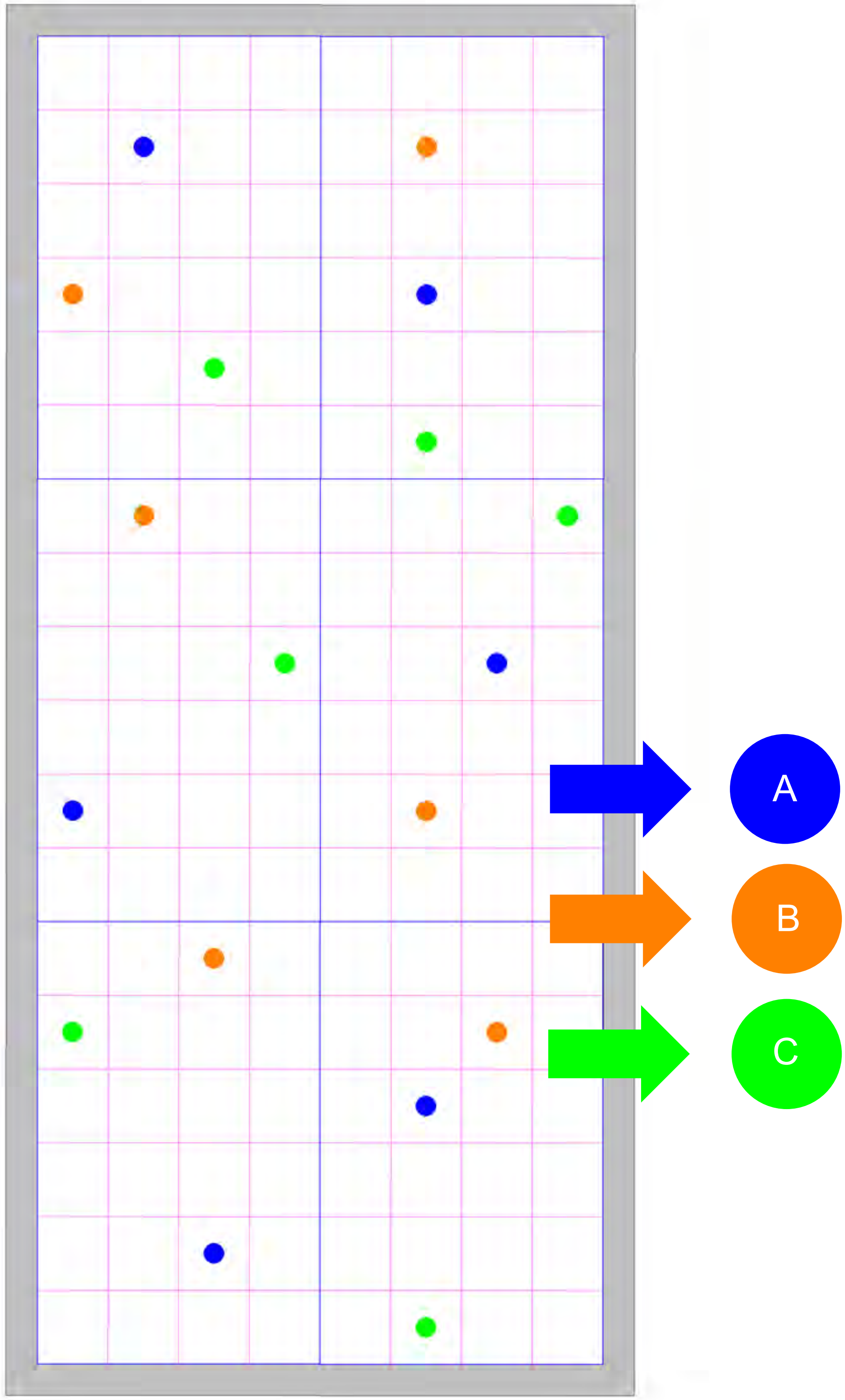

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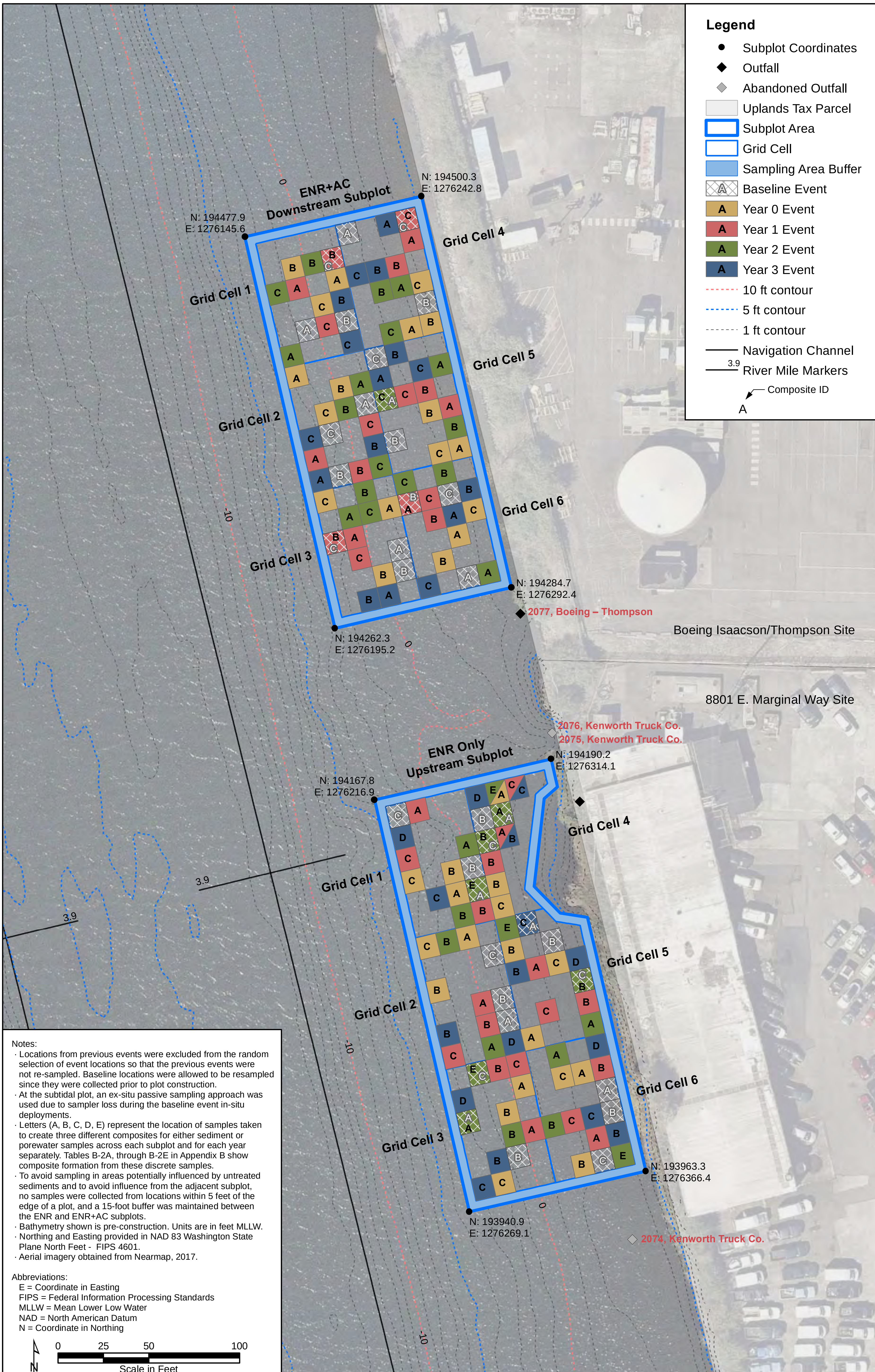
Figure 2.1-2
Sample Compositing Schematic

3/4/2021



Notes:
- Locations from previous events were excluded from the random selection of event locations so that the previous events were not re-sampled. Baseline locations were allowed to be resampled since they were collected prior to plot construction.
- At the subtidal plot, an ex-situ passive sampling approach was used due to sampler loss during the baseline event in-situ deployments.
- Letters (A, B, C, D, E) represent the location of samples taken to create three different composites for either sediment or porewater samples across each subplot and for each year separately. Tables B-2A, through B-2E in Appendix B show composite formation from these discrete samples.
- To avoid sampling in areas potentially influenced by untreated sediments and to avoid influence from the adjacent subplot, no samples were collected from locations within 5 feet of the edge of a plot, and a 15-foot buffer was maintained between the ENR and ENR+AC subplots.
- Bathymetry shown is pre-construction. Units are in feet MLLW.
- Northing and Easting provided in NAD 83 Washington State Plane North Feet - FIPS 4601.
- Aerial imagery obtained from Nearmap, 2017.

Abbreviations:
E = Coordinate in Easting
FIPS = Federal Information Processing Standards
MLLW = Mean Lower Low Water
NAD = North American Datum
N = Coordinate in Northing

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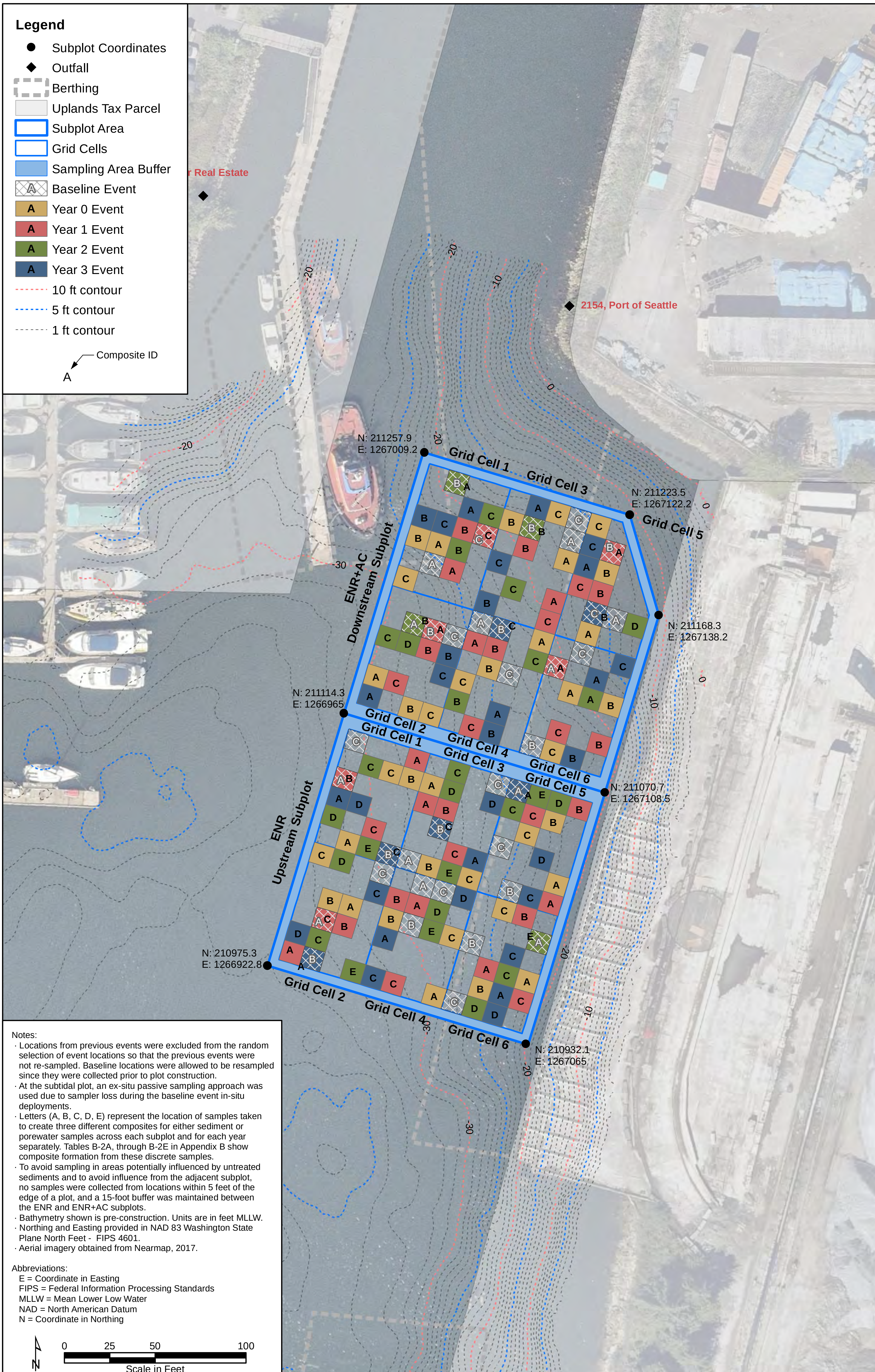
Figure 2.1-3
Intertidal Plot
Discrete Sample Locations
for All Monitoring Events



Notes:
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0 25 50 100
Scale in Feet

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Figure 2.1-4
Scour Plot
Discrete Sample Locations
for All Monitoring Events

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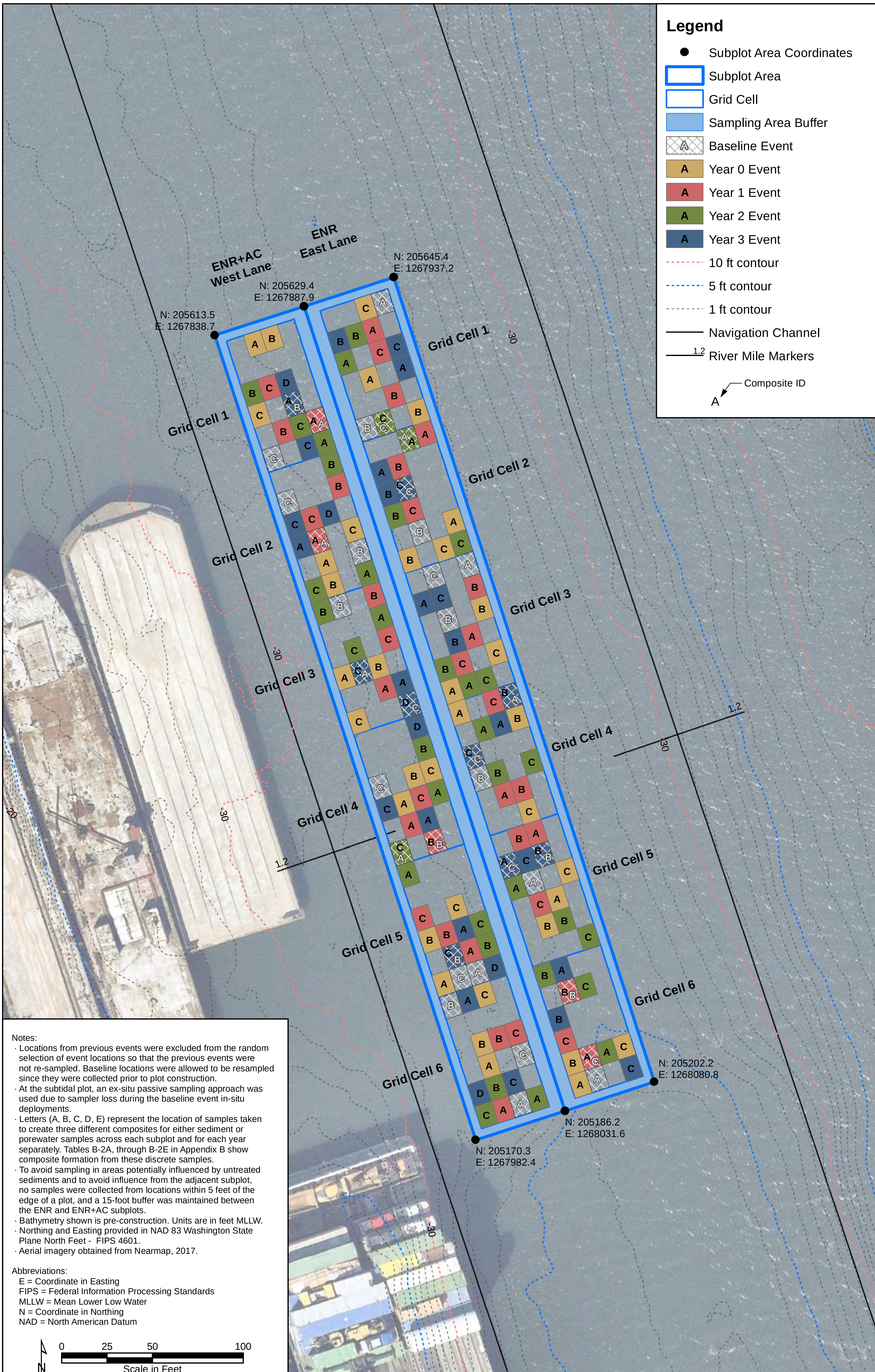
3/8/2021



Notes:
- Locations from previous events were excluded from the random selection of event locations so that the previous events were not re-sampled. Baseline locations were allowed to be resampled since they were collected prior to plot construction.
- At the subtidal plot, an ex-situ passive sampling approach was used due to sampler loss during the baseline event in-situ deployments.
- Letters (A, B, C, D, E) represent the location of samples taken to create three different composites for either sediment or porewater samples across each subplot and for each year separately. Tables B-2A, through B-2E in Appendix B show composite formation from these discrete samples.
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Figure 2.1-5
Subtidal Plot
Discrete Sample Locations
for All Monitoring Events

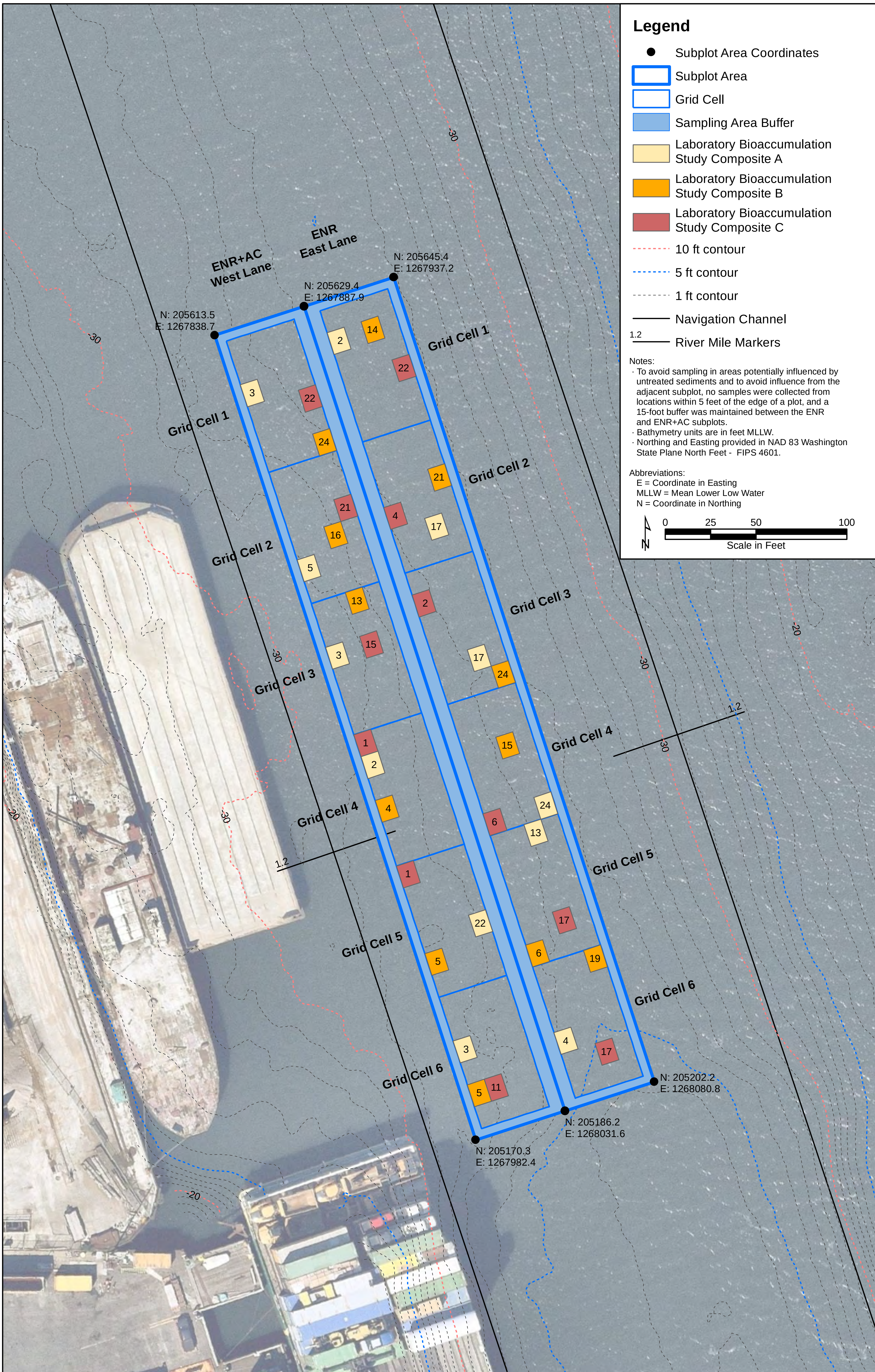

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Figure 2.1-6
Subtidal Plot Laboratory Bioaccumulation Study Sample Locations

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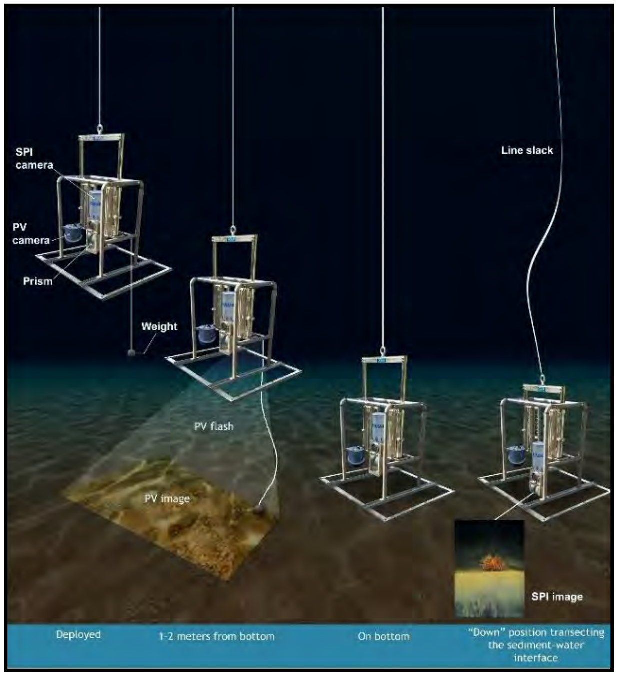
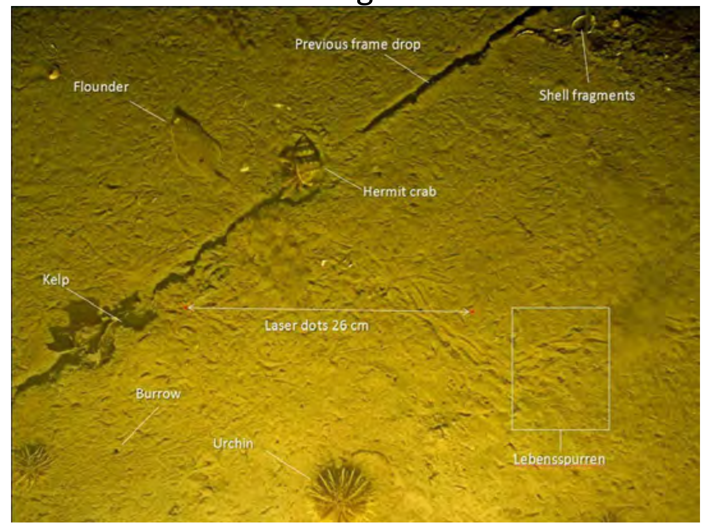
3/8/2021

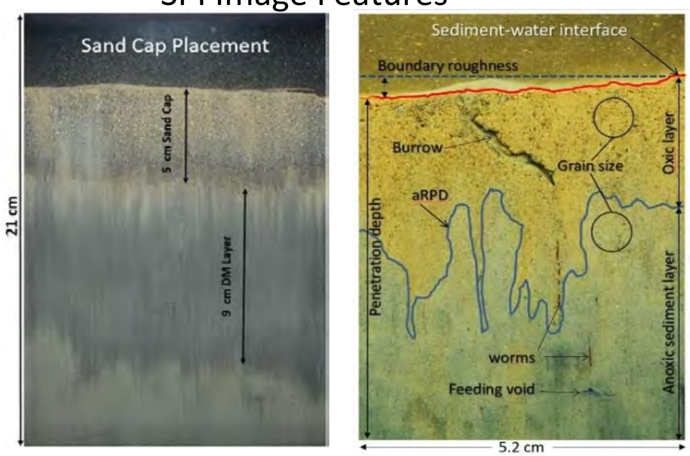
SPI/PV Camera Deployment



Plan View Image Features



SPI Image Features



Infaunal Successional Stage Paradigm

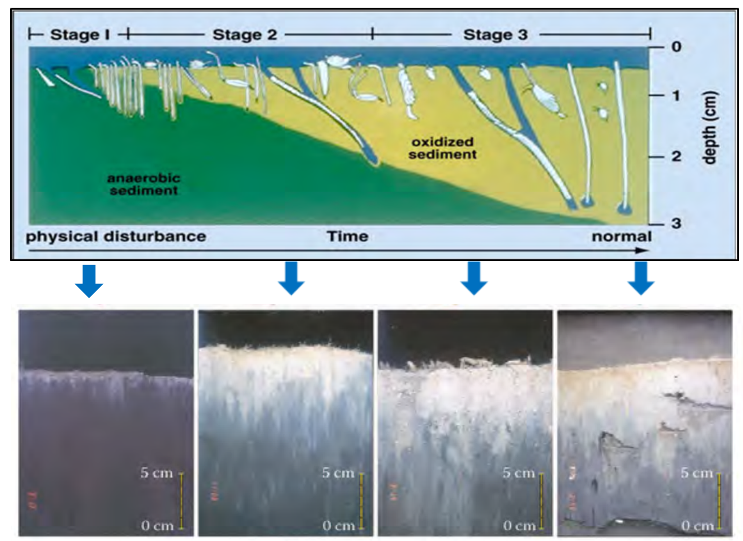


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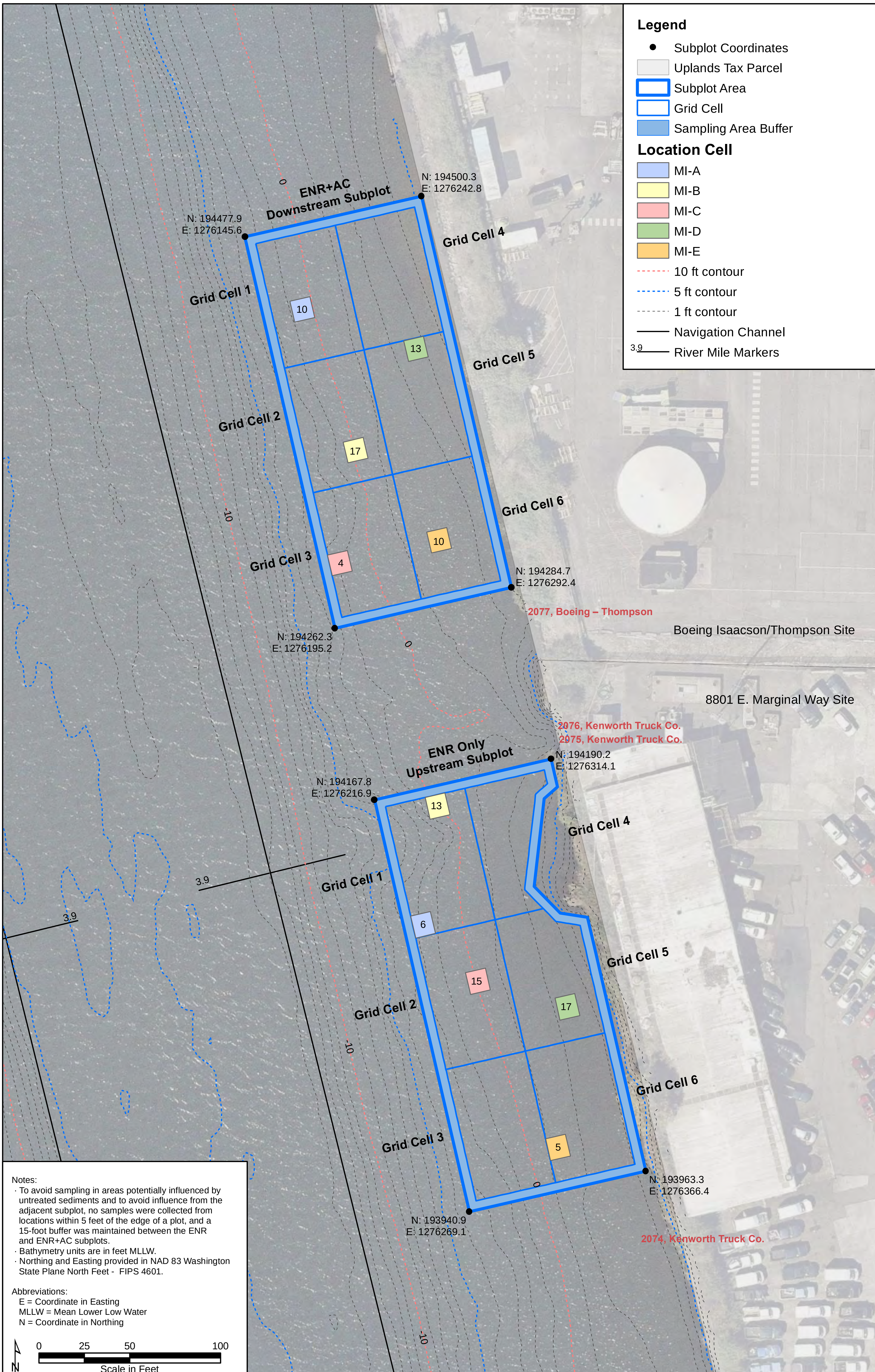
Figure 2.2-1
SPI-PV Image
Sampling and Analysis Approach



Notes:
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- Bathymetry units are in feet MLLW.
- Northing and Easting provided in NAD 83 Washington State Plane North Feet - FIPS 4601.

Abbreviations:
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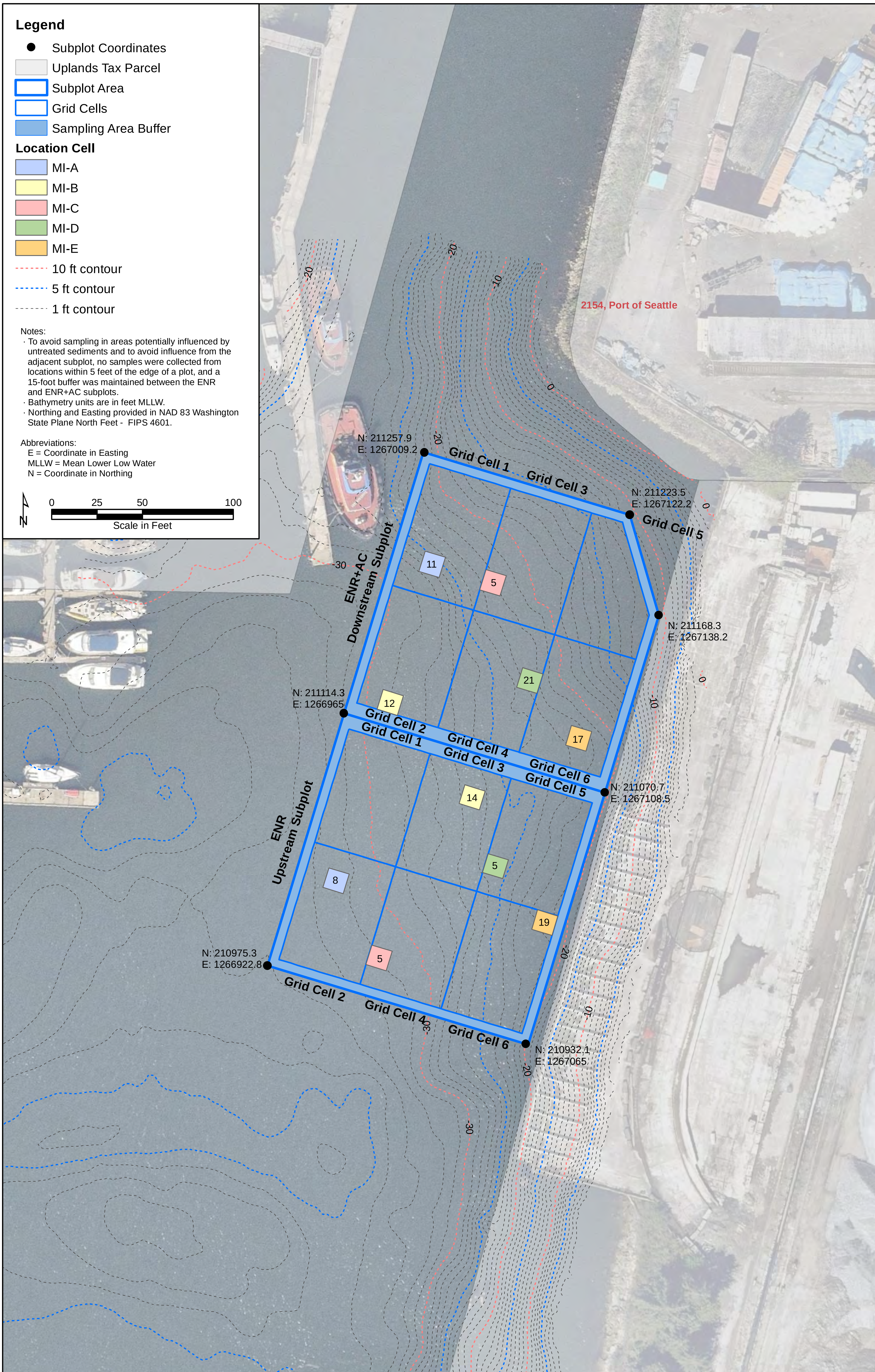
N = Coordinate in Northing

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 2.5-1
Intertidal Plot
Year 3 Macroinvertebrate Census
Sampling Locations

I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 2.5-1 Intertidal Plot with Year 3 Macroinvertebrate Census Sampling Locations.mxd
3/8/2021

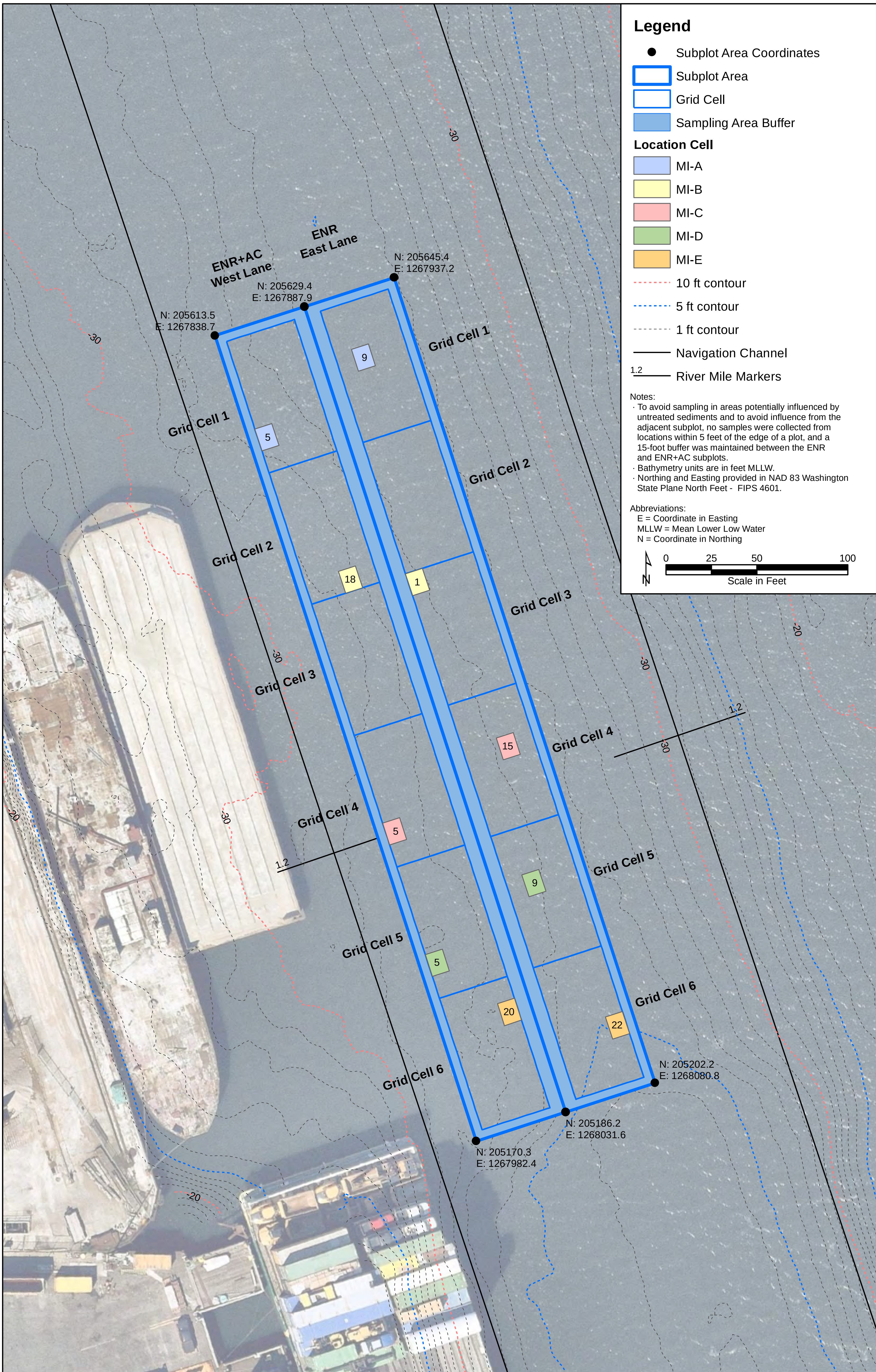


Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

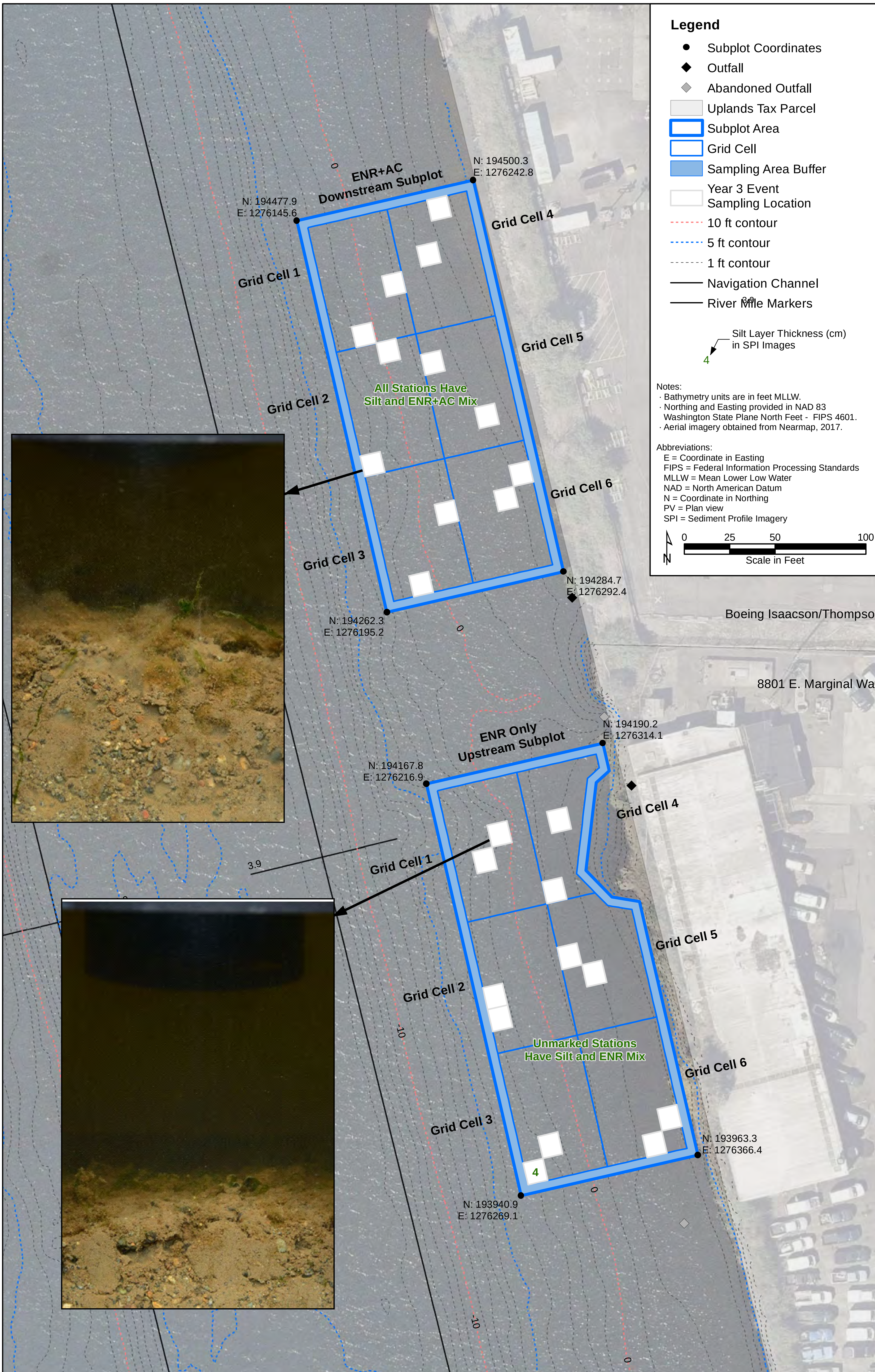
Figure 2.5-2
Scour Plot
Year 3 Macroinvertebrate Census
Sampling Locations

I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 2.5-2 Scour Plot with Year 3 Macroinvertebrate Census Sampling Locations.mxd
3/8/2021



Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** Lower Duwamish Waterway	Figure 2.5-3 Subtidal Plot Year 3 Macroinvertebrate Census Sampling Locations

I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 2.5-3 Subtidal Plot with Year 3 Macroinvertebrate Census Sampling Locations.mxd
3/8/2021

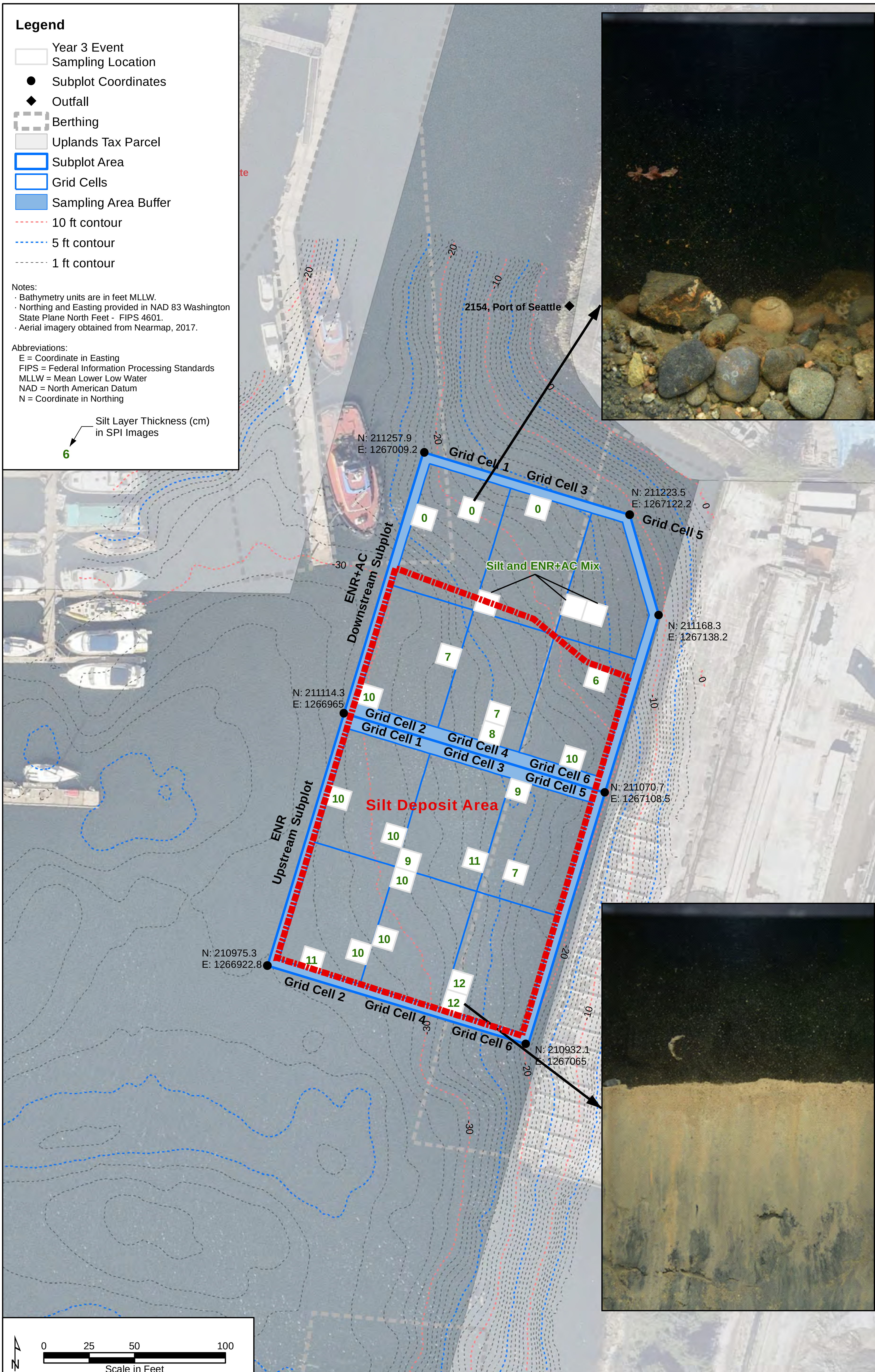


Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Draft
Year 3 Monitoring Report
Lower Duwamish Waterway

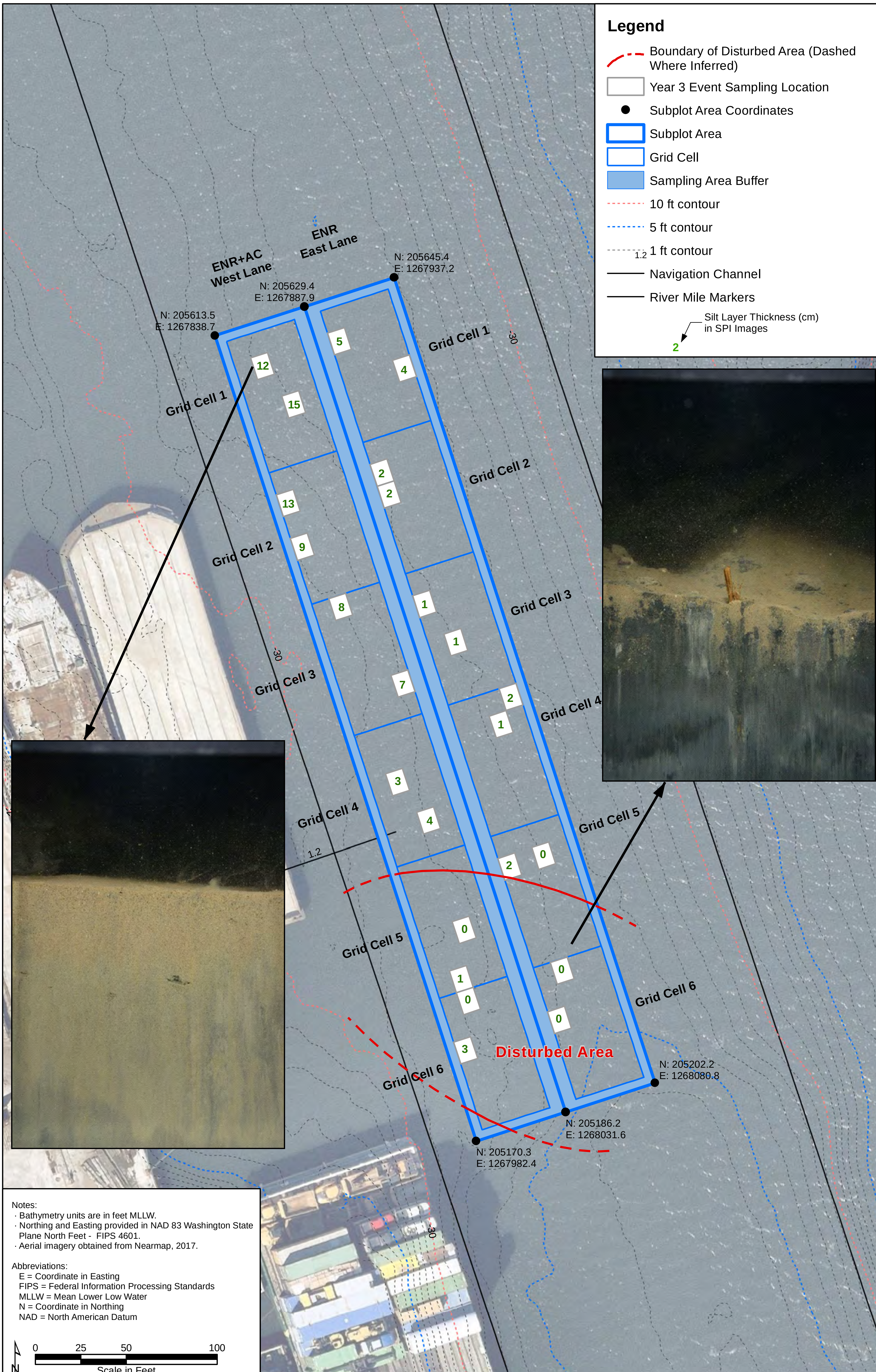
Figure 3.1-1
ENR/AC Pilot Study, Intertidal Plot
Year 3 SPI/PV Sampling Locations

I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 3.1-1a ENR AC Pilot Study, Intertidal Plot Year 3 SPIPV Sampling Locations.mxd
6/17/2021



Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Draft** **Year 3 Monitoring Report** Lower Duwamish Waterway	Figure 3.1-2 ENR/AC Pilot Study, Scour Plot Year 3 SPI/PV Sampling Locations

I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 3.1-1b ENR AC Pilot Study, Scour Plot Year 3 SPIPV Sampling Locations.mxd
6/16/2021

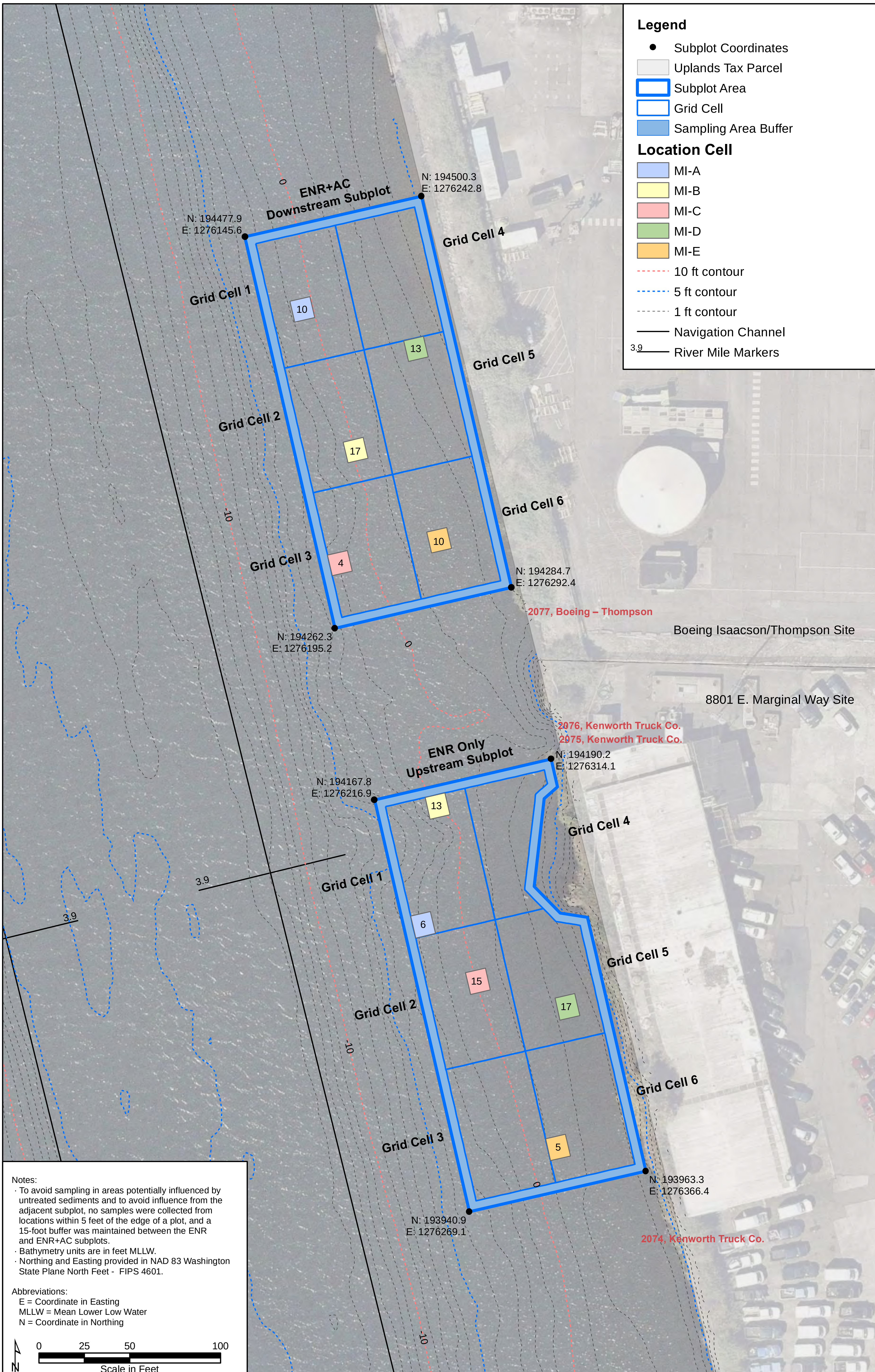


Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Draft
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.1-3
ENR/AC Pilot Study, Subtidal Plot
Year 3 SPI/PV Sampling Locations

I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 3.1-1c ENR AC Pilot Study, Subtidal Plot Year 3 SPIPV Sampling Locations.mxd
6/23/2021

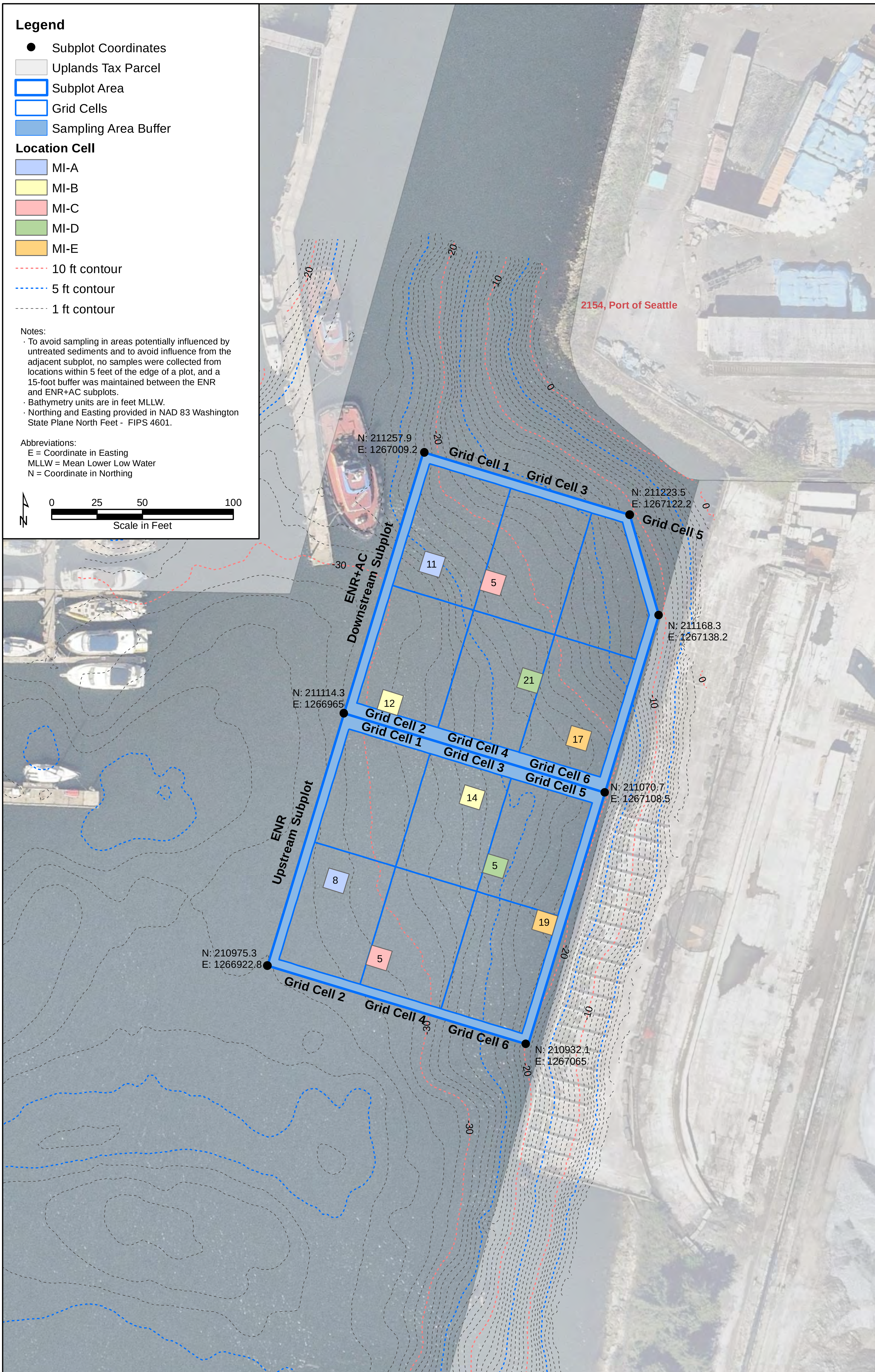


Notes:
- To avoid sampling in areas potentially influenced by untreated sediments and to avoid influence from the adjacent subplot, no samples were collected from locations within 5 feet of the edge of a plot, and a 15-foot buffer was maintained between the ENR and ENR+AC subplots.
- Bathymetry units are in feet MLLW.
- Northing and Easting provided in NAD 83 Washington State Plane North Feet - FIPS 4601.

Abbreviations:
E = Coordinate in Easting
MLLW = Mean Lower Low Water
N = Coordinate in Northing

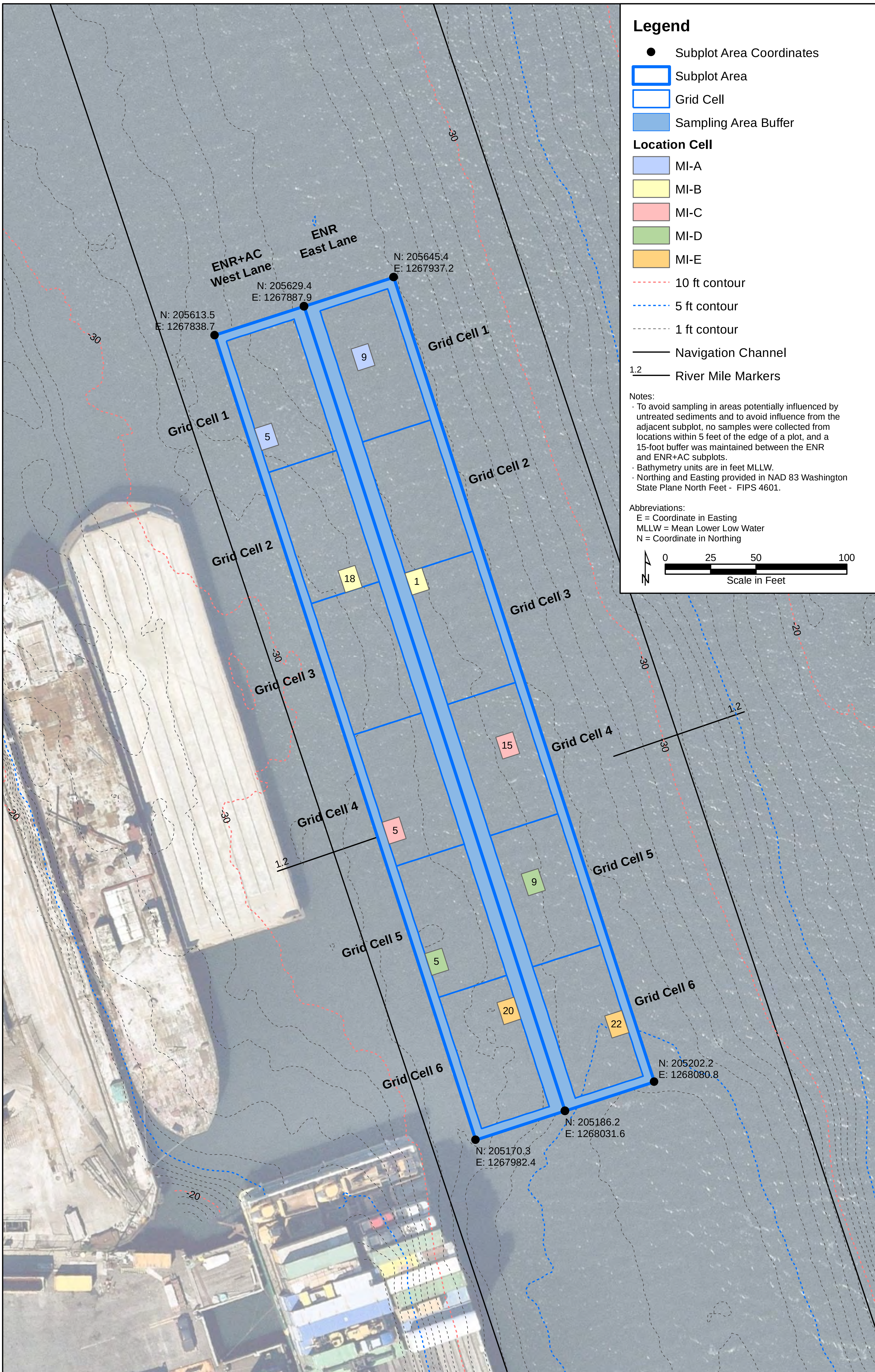
Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** Lower Duwamish Waterway	Figure 2.5-1 Intertidal Plot Year 3 Macroinvertebrate Census Sampling Locations

I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 2.5-1 Intertidal Plot with Year 3 Macroinvertebrate Census Sampling Locations.mxd
3/8/2021



Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** Lower Duwamish Waterway	Figure 2.5-2 Scour Plot Year 3 Macroinvertebrate Census Sampling Locations

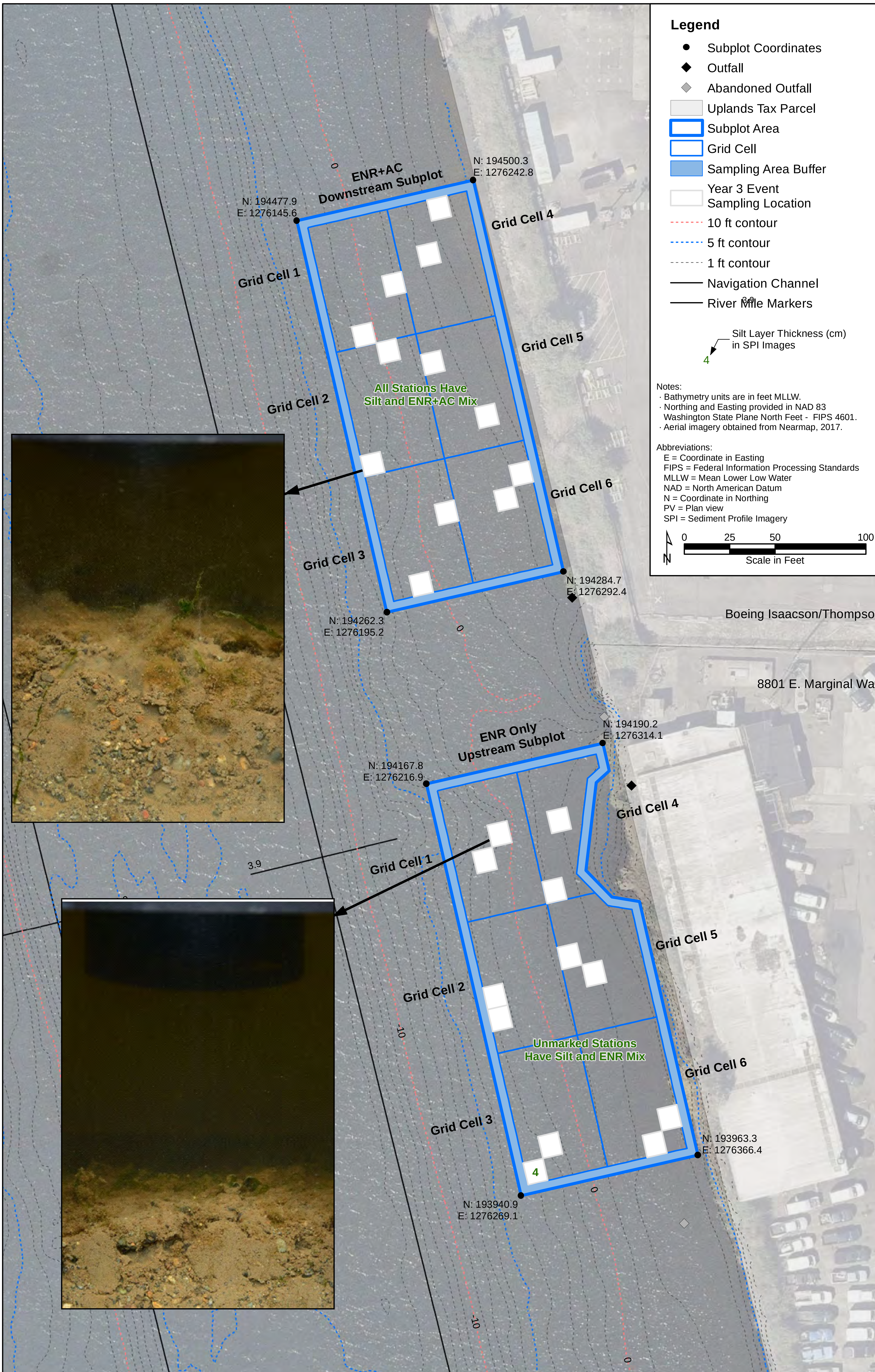
I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 2.5-2 Scour Plot with Year 3 Macroinvertebrate Census Sampling Locations.mxd
3/8/2021



ENR/AC Pilot Study Year 3 Monitoring Report Lower Duwamish Waterway	Figure 2.5-3 Subtidal Plot Year 3 Macroinvertebrate Census Sampling Locations

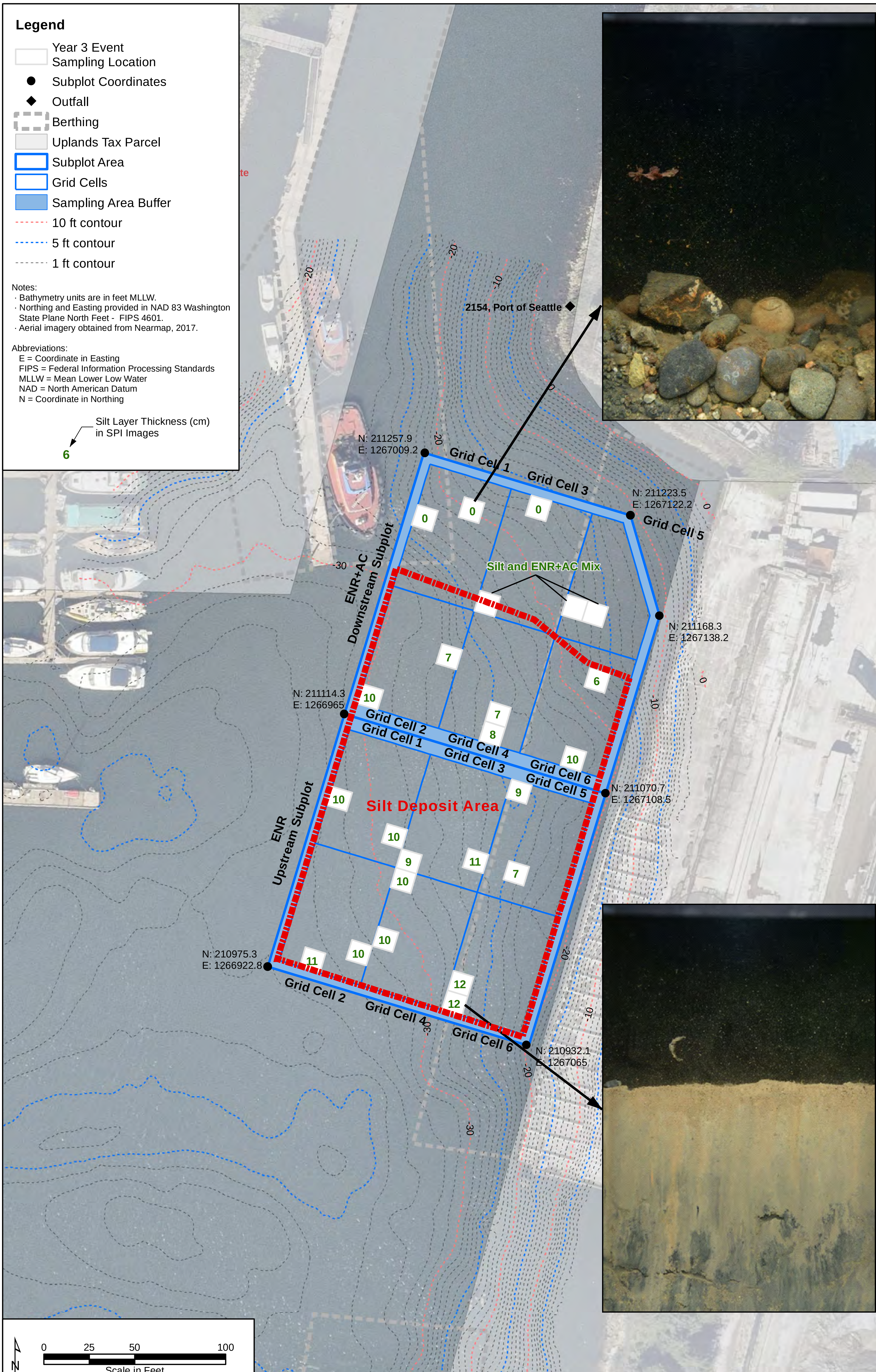
Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 2.5-3 Subtidal Plot with Year 3 Macroinvertebrate Census Sampling Locations.mxd
3/8/2021



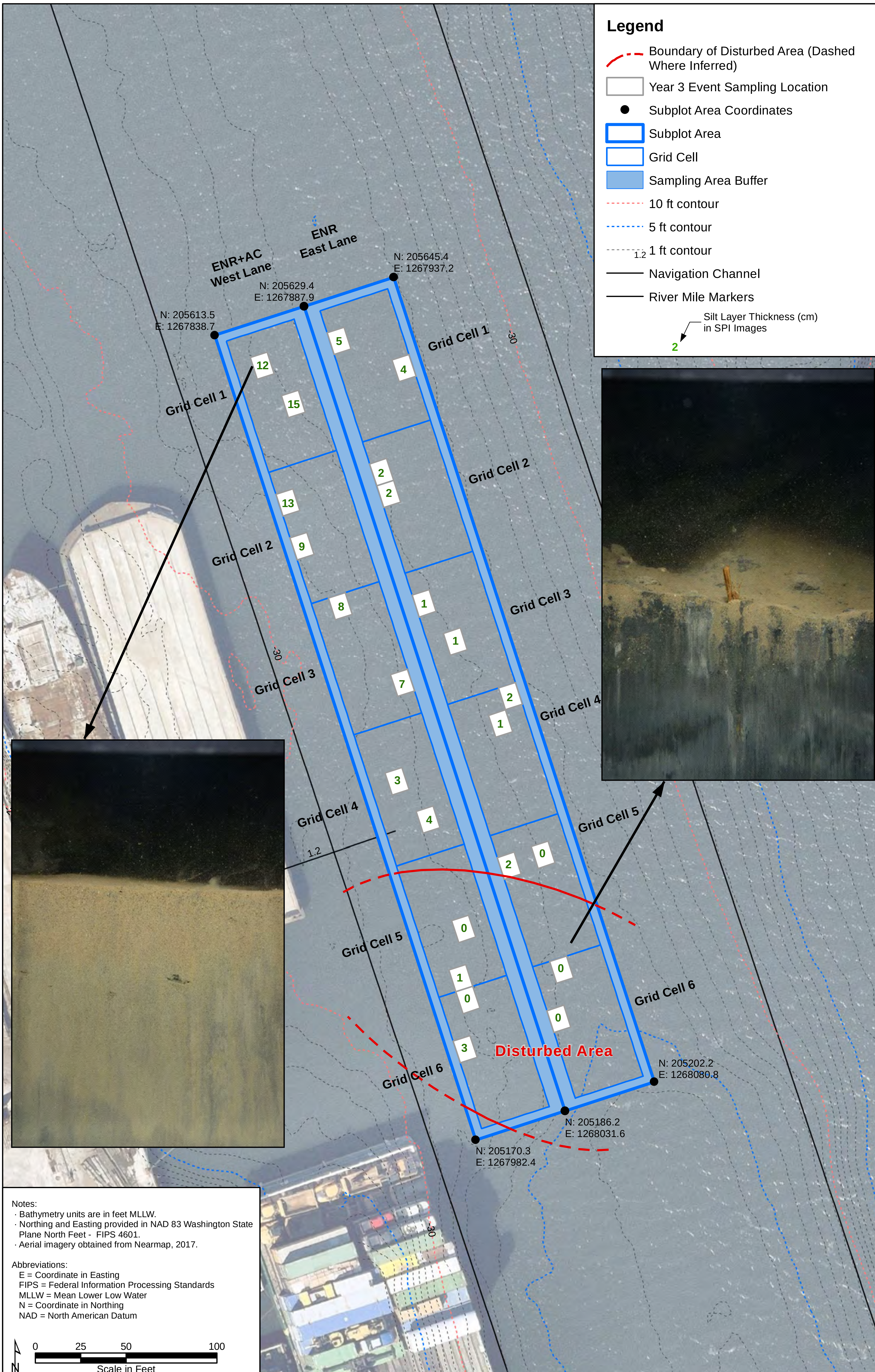
Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Draft** **Year 3 Monitoring Report** Lower Duwamish Waterway	Figure 3.1-1 ENR/AC Pilot Study, Intertidal Plot Year 3 SPI/PV Sampling Locations

I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 3.1-1a ENR AC Pilot Study, Intertidal Plot Year 3 SPIPV Sampling Locations.mxd
6/17/2021



Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Draft** **Year 3 Monitoring Report** Lower Duwamish Waterway	Figure 3.1-2 ENR/AC Pilot Study, Scour Plot Year 3 SPI/PV Sampling Locations

I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 3.1-1b ENR AC Pilot Study, Scour Plot Year 3 SPIPV Sampling Locations.mxd
6/16/2021

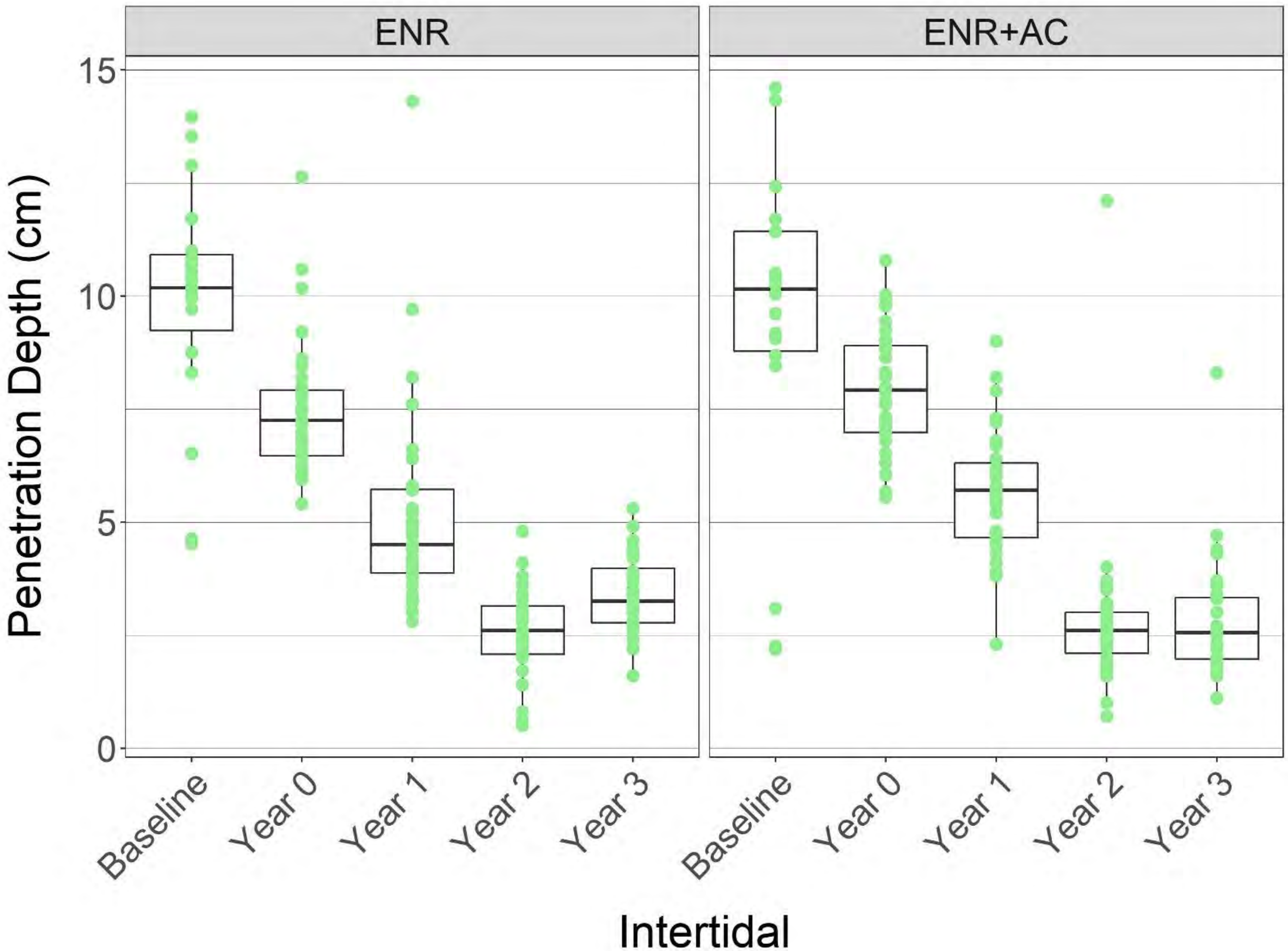


Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Draft
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.1-3
ENR/AC Pilot Study, Subtidal Plot
Year 3 SPI/PV Sampling Locations

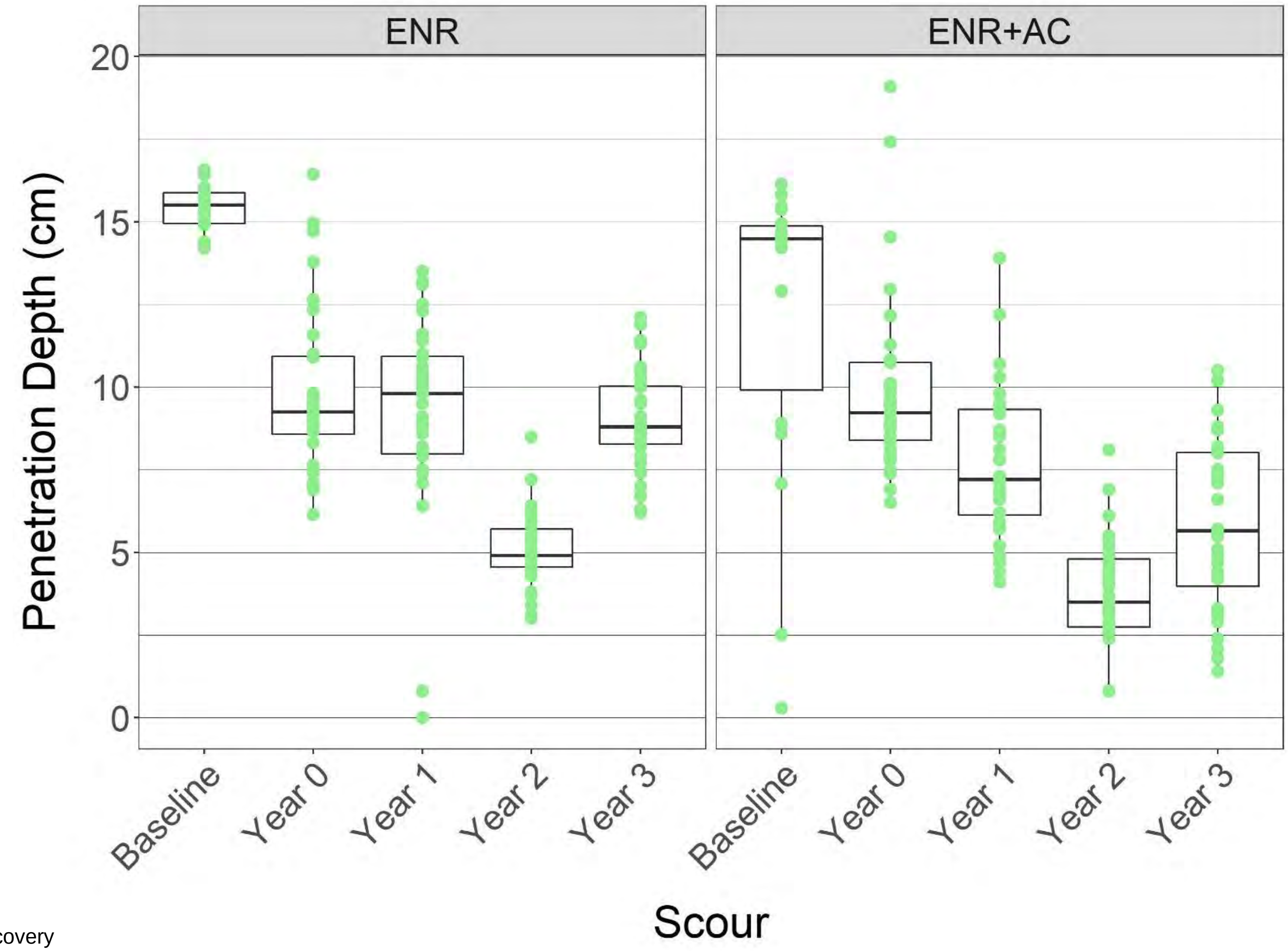
I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 3.1-1c ENR AC Pilot Study, Subtidal Plot Year 3 SPIPV Sampling Locations.mxd
6/23/2021



Boxes show first quartile, median, and third quartile. Dots show data points.

Abbreviations:
cm = centimeter(s)
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.1-4 Intertidal Plot SPI Penetration Depths - Baseline through Year 3

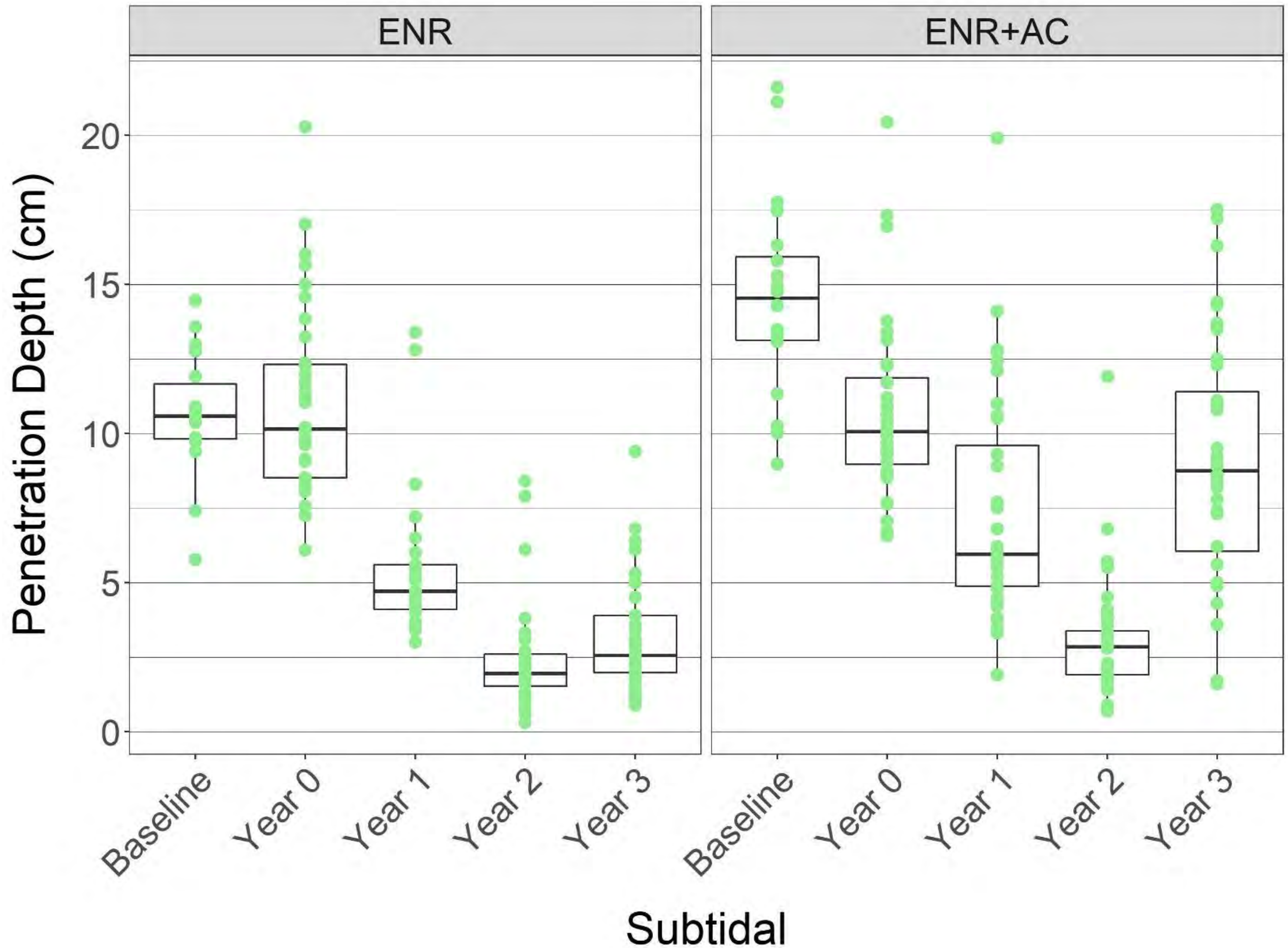


Abbreviations:
cm = centimeter(s)
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
SPI = Sediment profile imaging

Boxes show first quartile, median, and third quartile. Dots show data points.

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.1-5 Scour Plot SPI Penetration Depths - Baseline through Year 3

7/9/2021



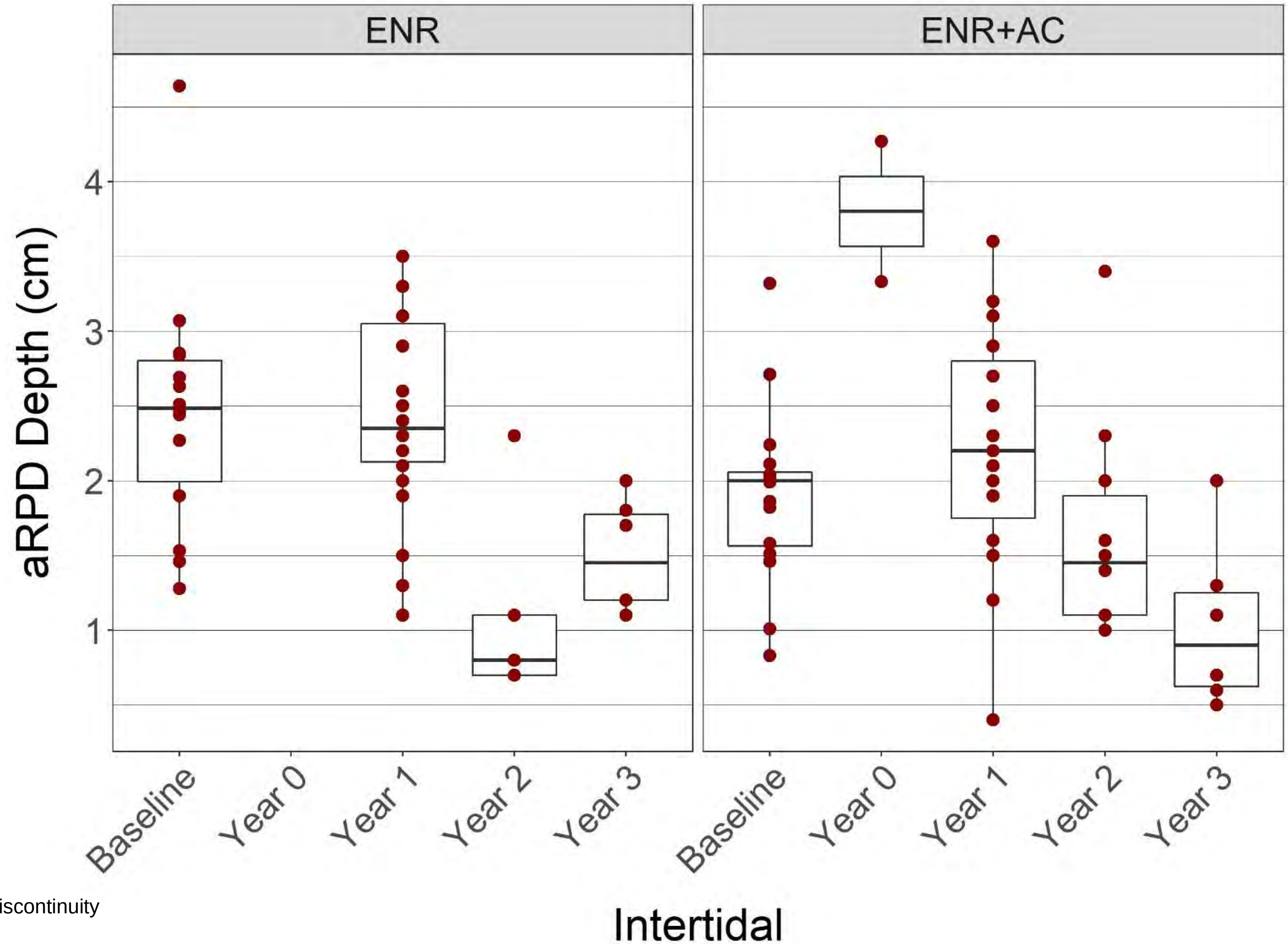
Boxes show first quartile, median, and third quartile. Dots show data points.

Abbreviations:
cm = centimeter(s)
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

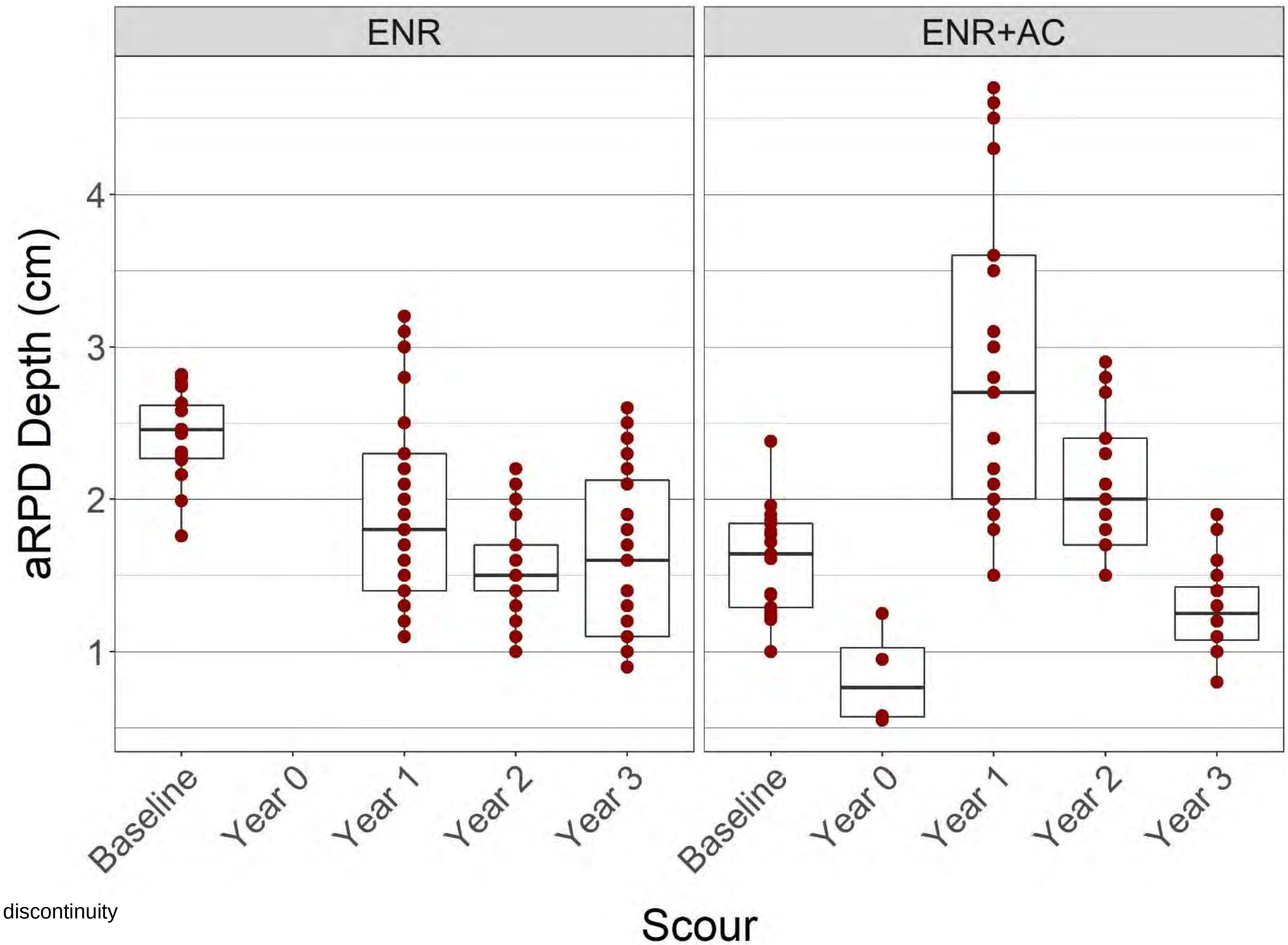
Figure 3.1-6
Subtidal Plot SPI Penetration Depths - Baseline through Year 3



Boxes show first quartile, median, and third quartile. Dots show data points.

Abbreviations:
- aRPD = apparent redox-potential discontinuity
- cm = centimeter(s)
- ENR = Enhanced natural recovery
- ENR+AC = Enhanced natural recovery amended with activated carbon

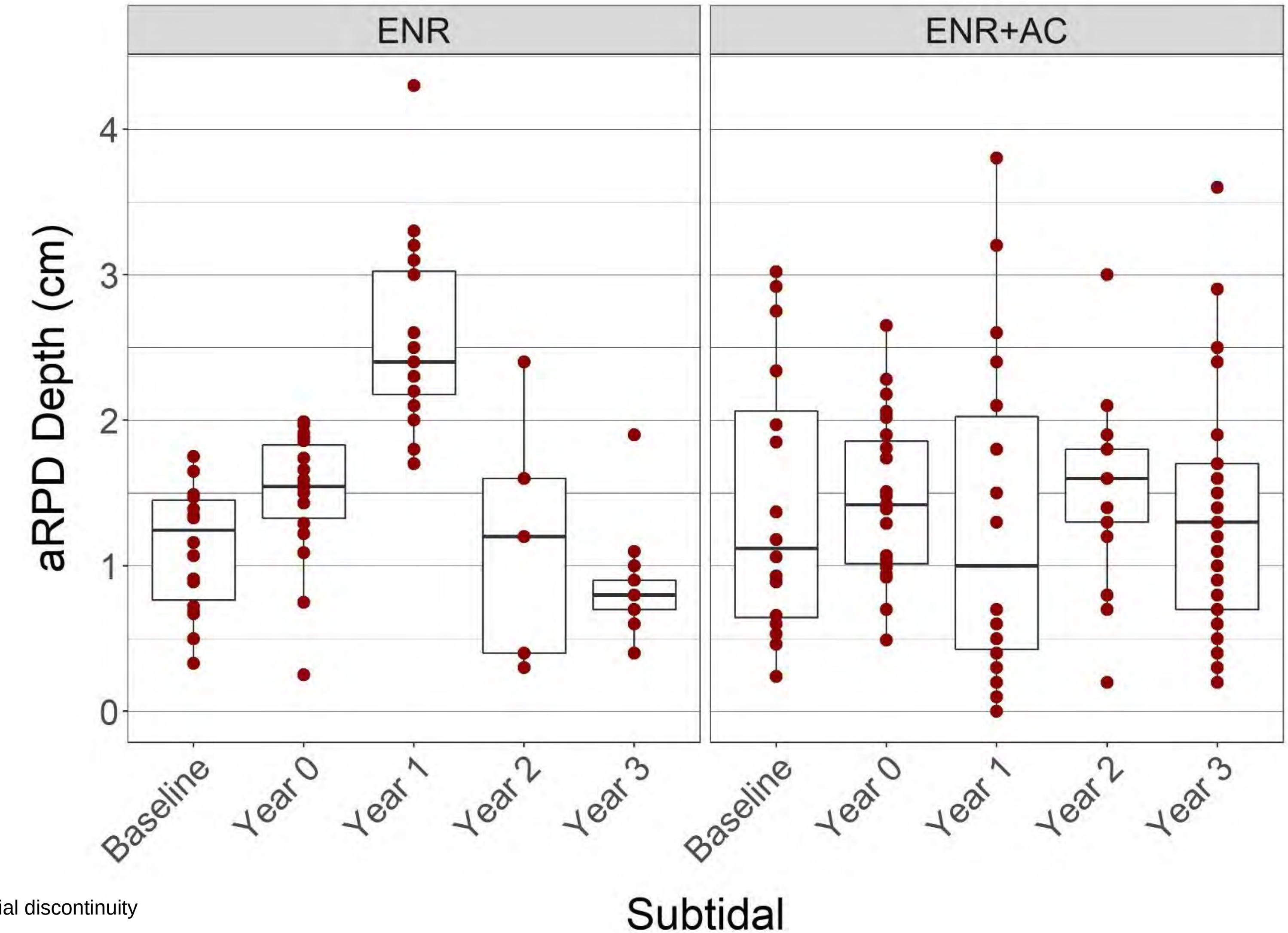
Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.1-7 Intertidal Plot aRPD Depths - Baseline through Year 3



Boxes show first quartile, median, and third quartile. Dots show data points.

Abbreviations:
aRPD = apparent redox-potential discontinuity
cm = centimeter(s)
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.1-8 Scour Plot aRPD Depths - Baseline through Year 3

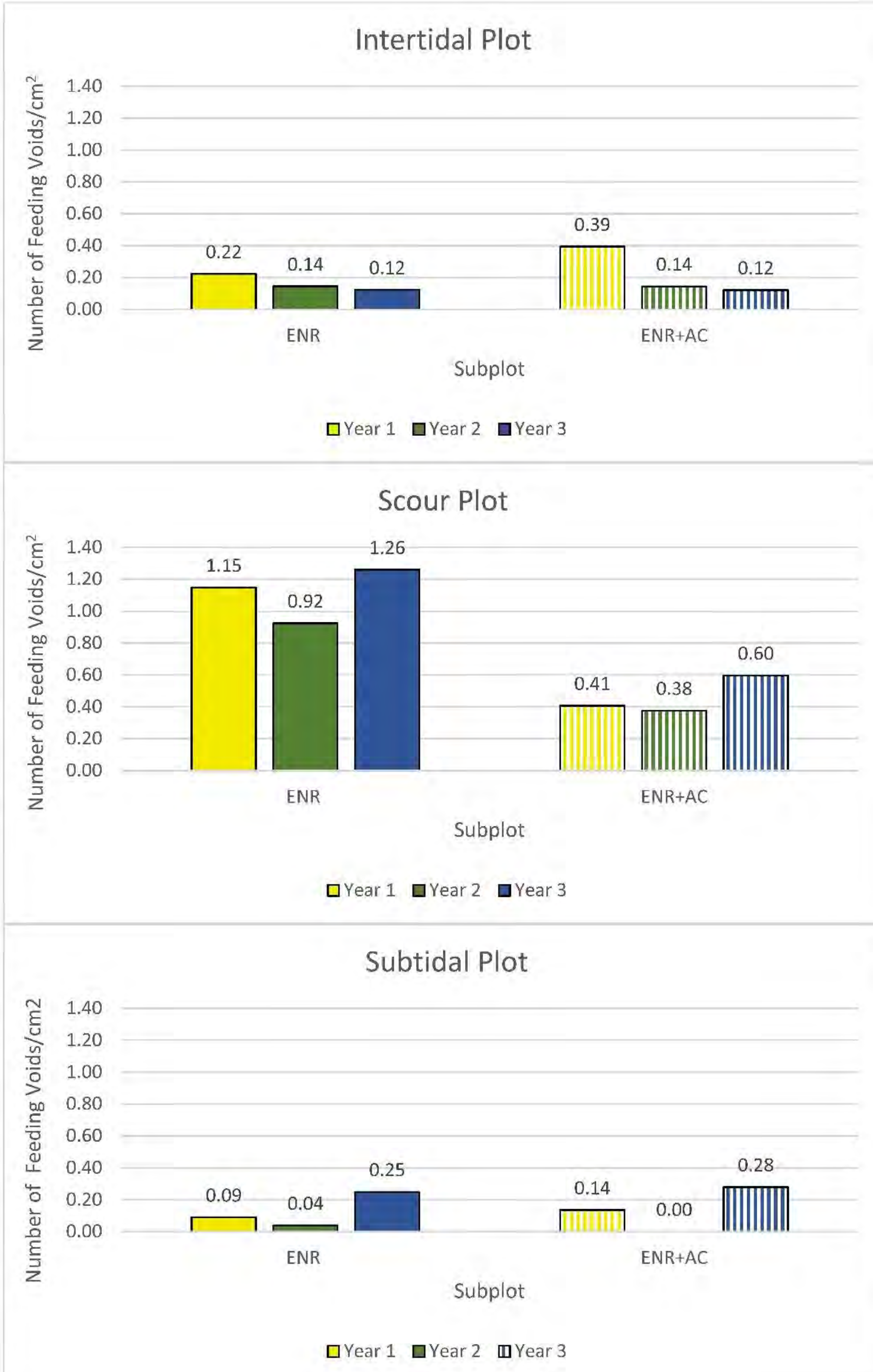


Boxes show first quartile, median, and third quartile. Dots show data points.

Abbreviations:

aRPD = apparent redox-potential discontinuity
cm = centimeter(s)
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study Year 3 Monitoring Report Lower Duwamish Waterway**	Figure 3.1-9 Subtidal Plot aRPD Depths - Baseline through Year 3

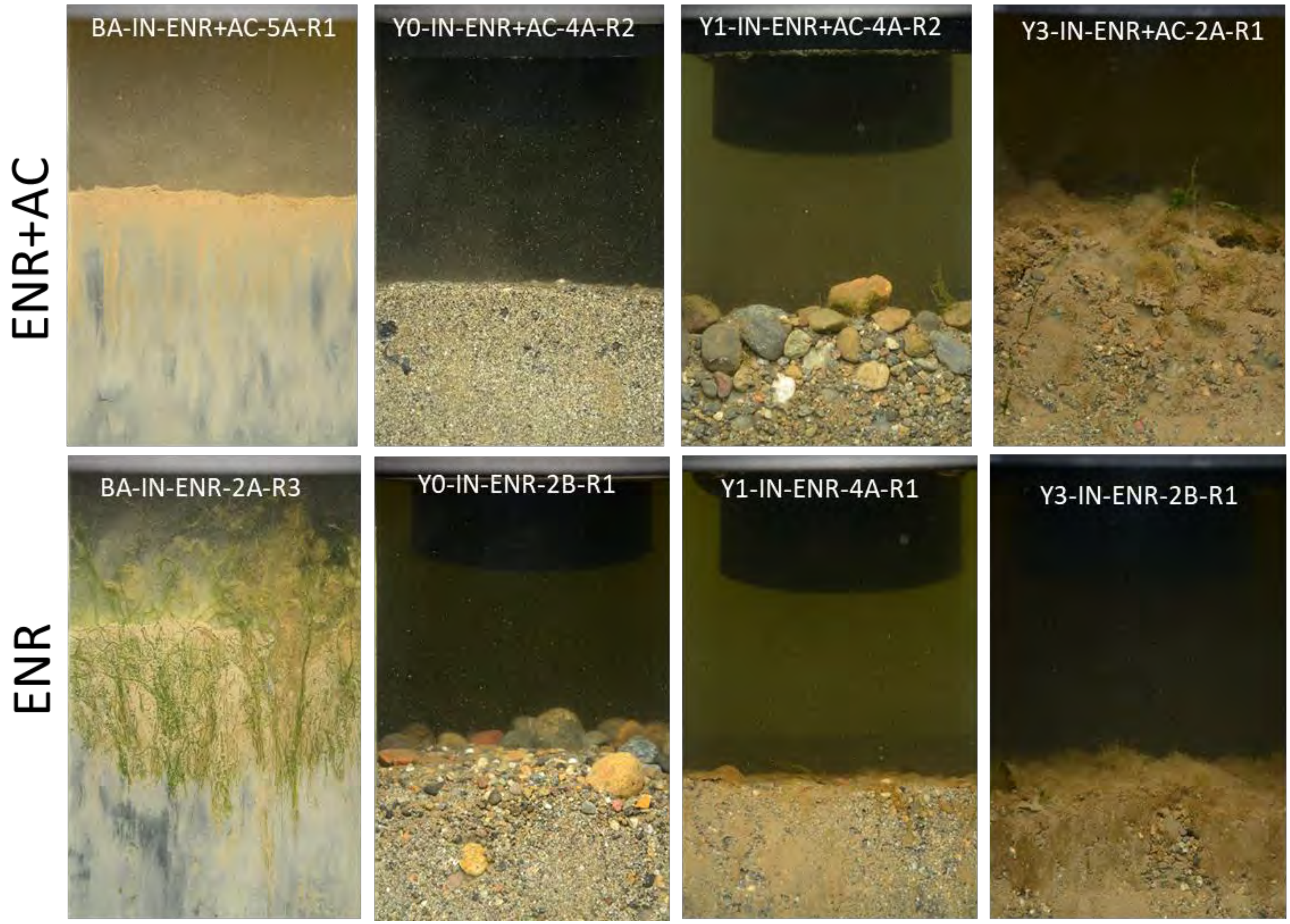


Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

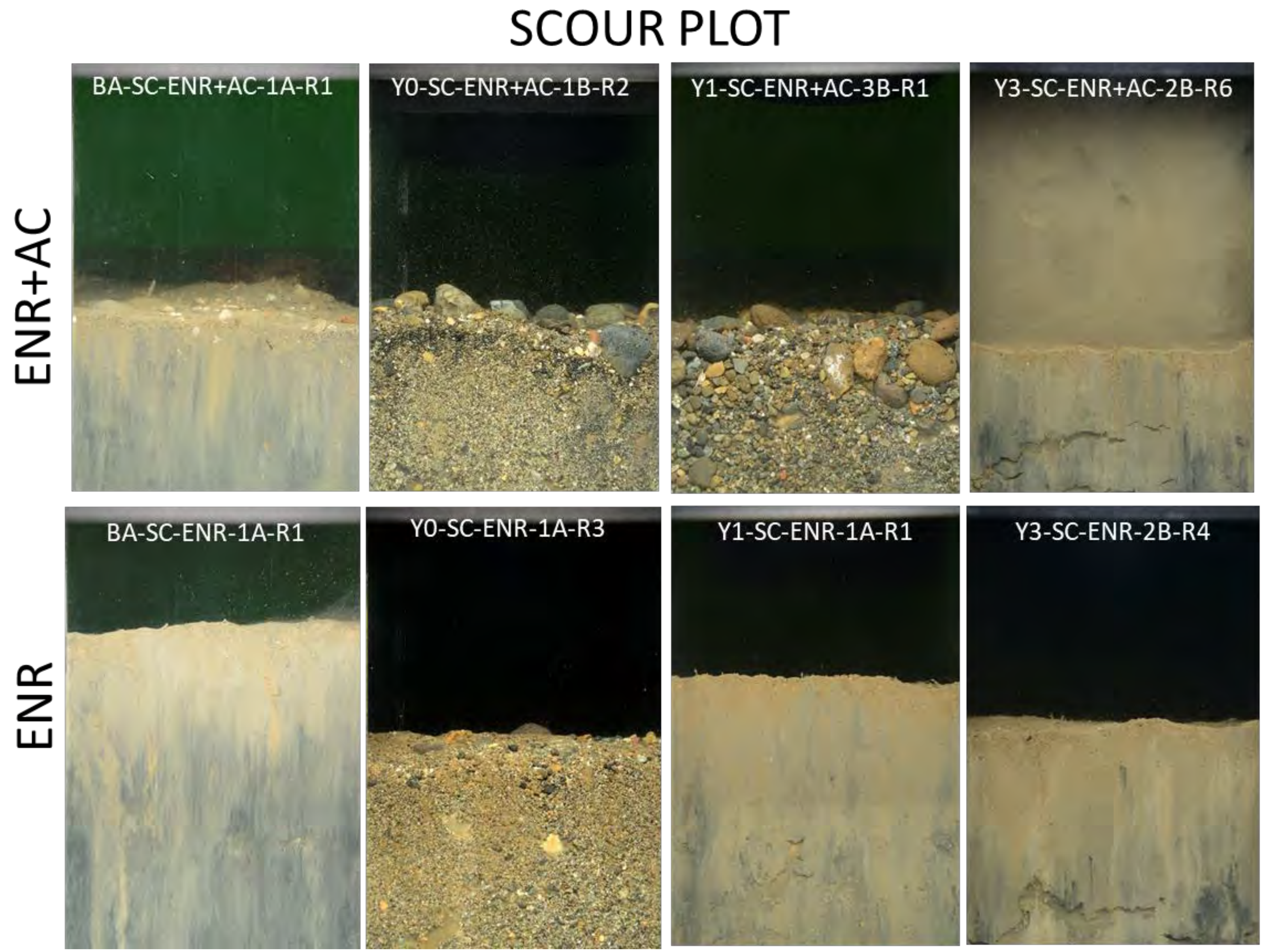
ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.1-10
The Number of Feeding Voids per cm² in Each Subplot for Years 1 through 3

INTERTIDAL PLOT



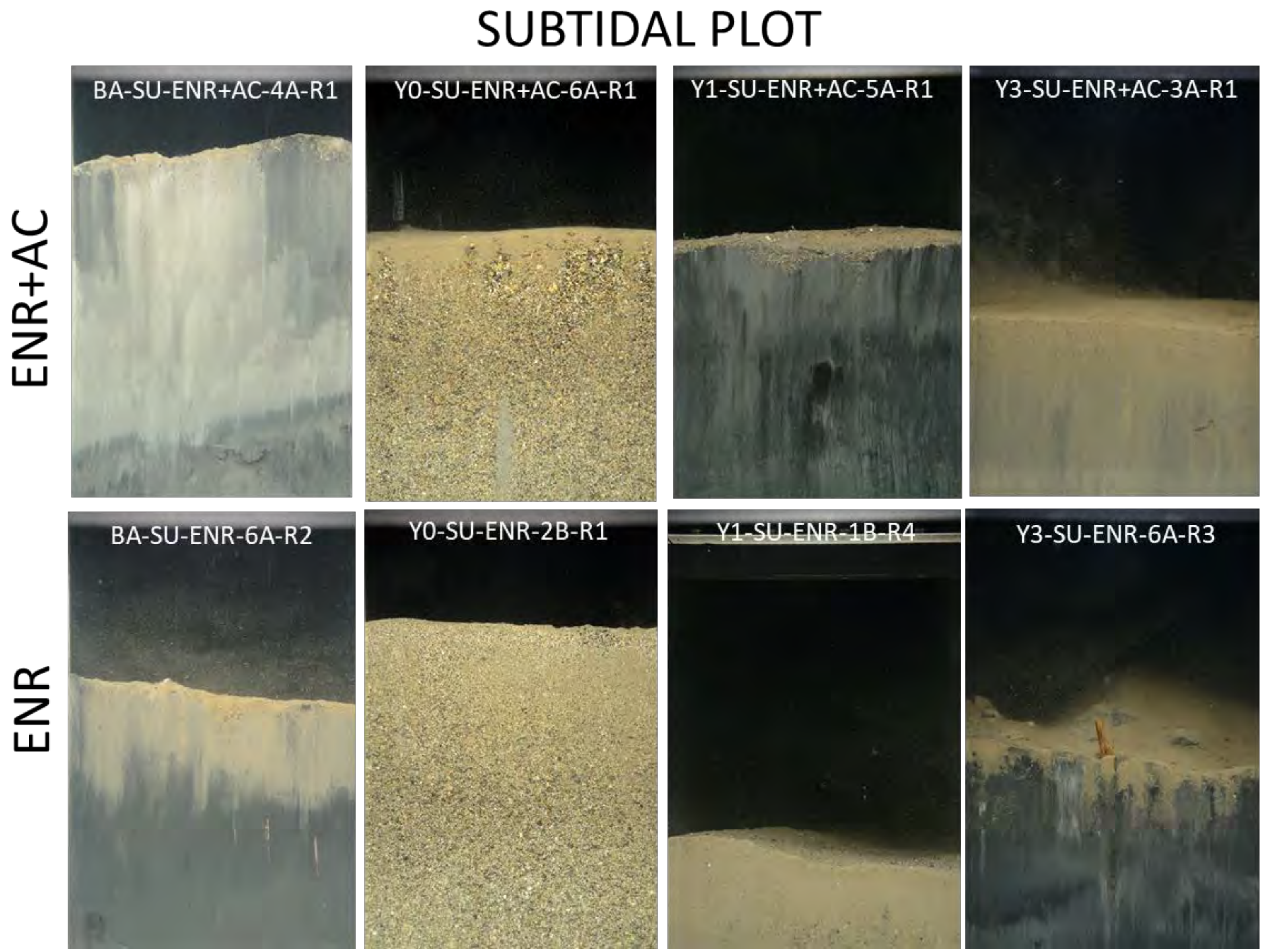
Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.1-11 Representative Intertidal Plot SPI Images from the Baseline and Years 0, 1, and 3 Surveys. Scale: width of images = 14.4 cm



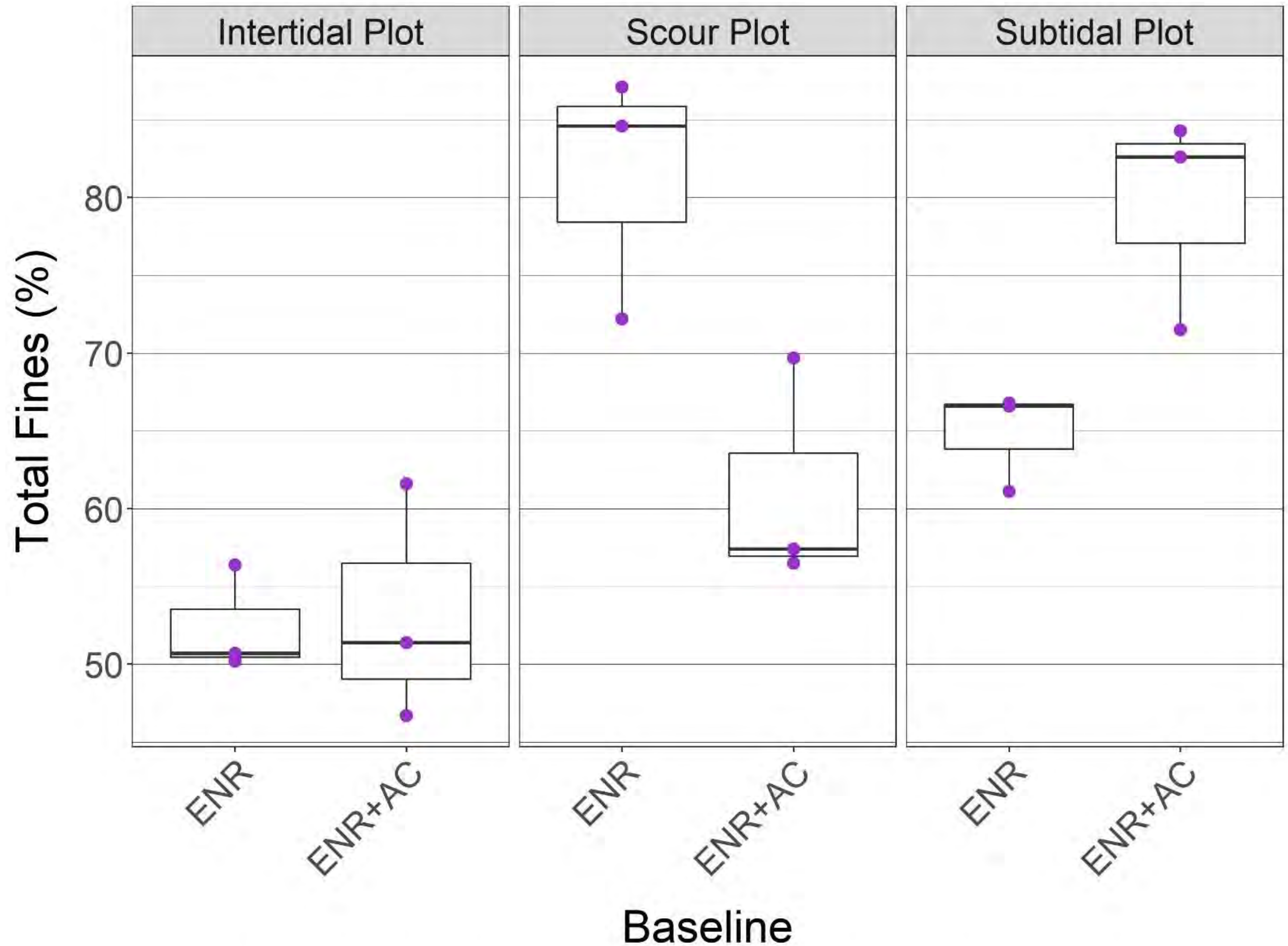
Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.1-12
Representative Scour Plot SPI Images from the Baseline and Years 0, 1, and 3 Surveys.
Scale: width of images = 14.4 cm

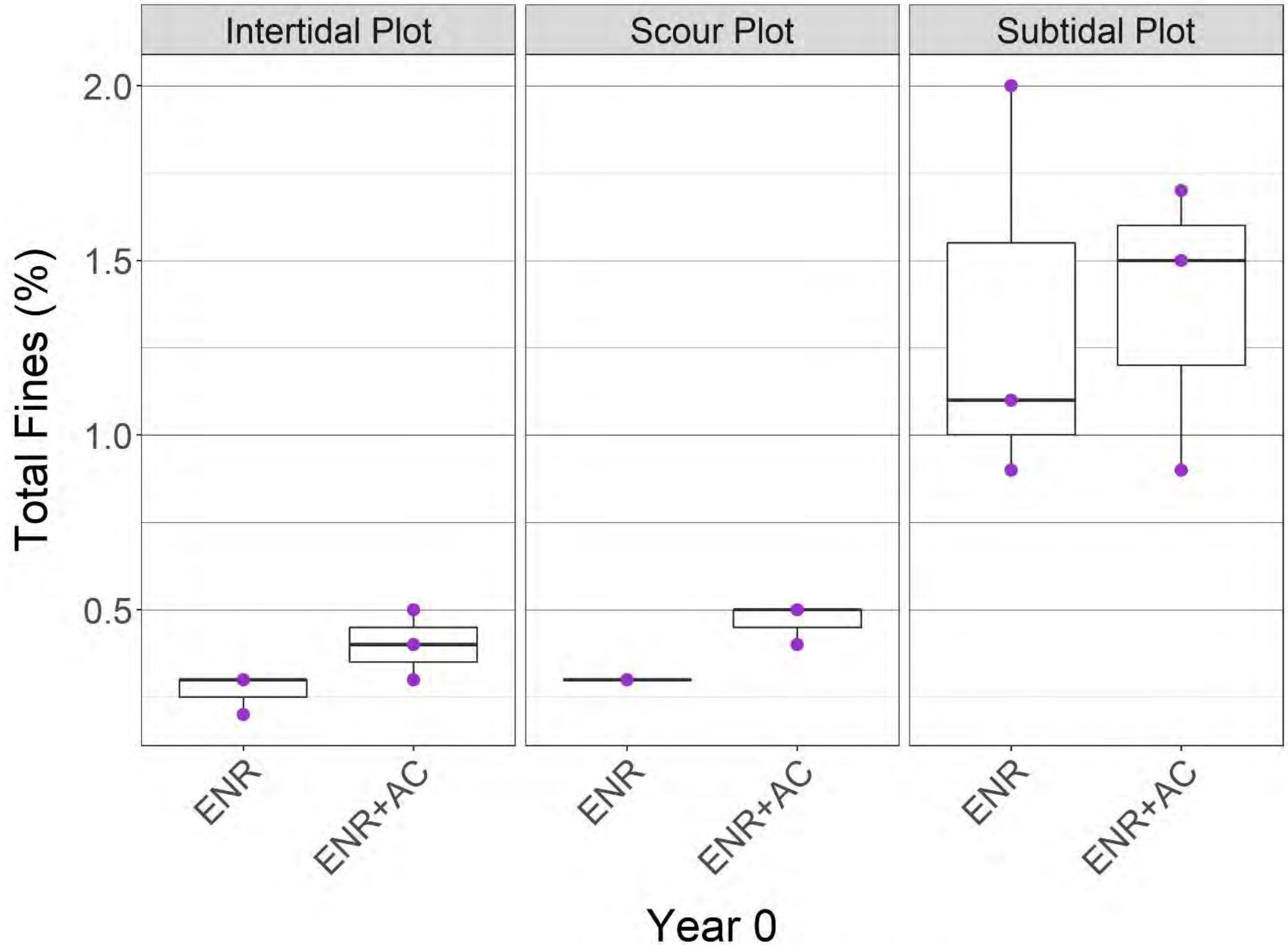


Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.1-13 Representative Subtidal Plot SPI Images from the Baseline and Year 0, 1, and 3 Surveys. Scale: width of images = 14.4 cm



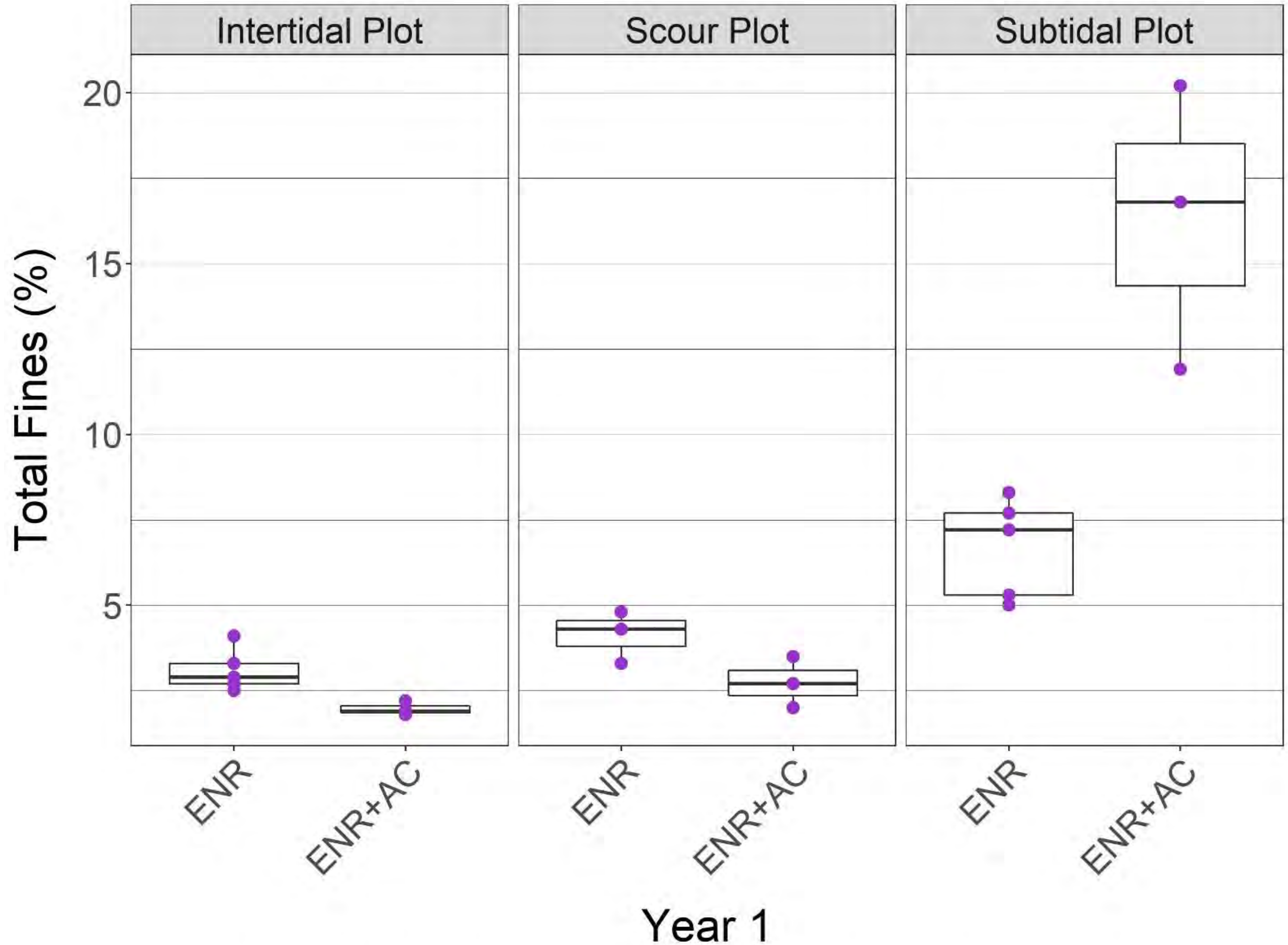
Boxes show first quartile, median, and third quartile. Dots show data points.

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.2-1 Baseline Total Fines - All Plots

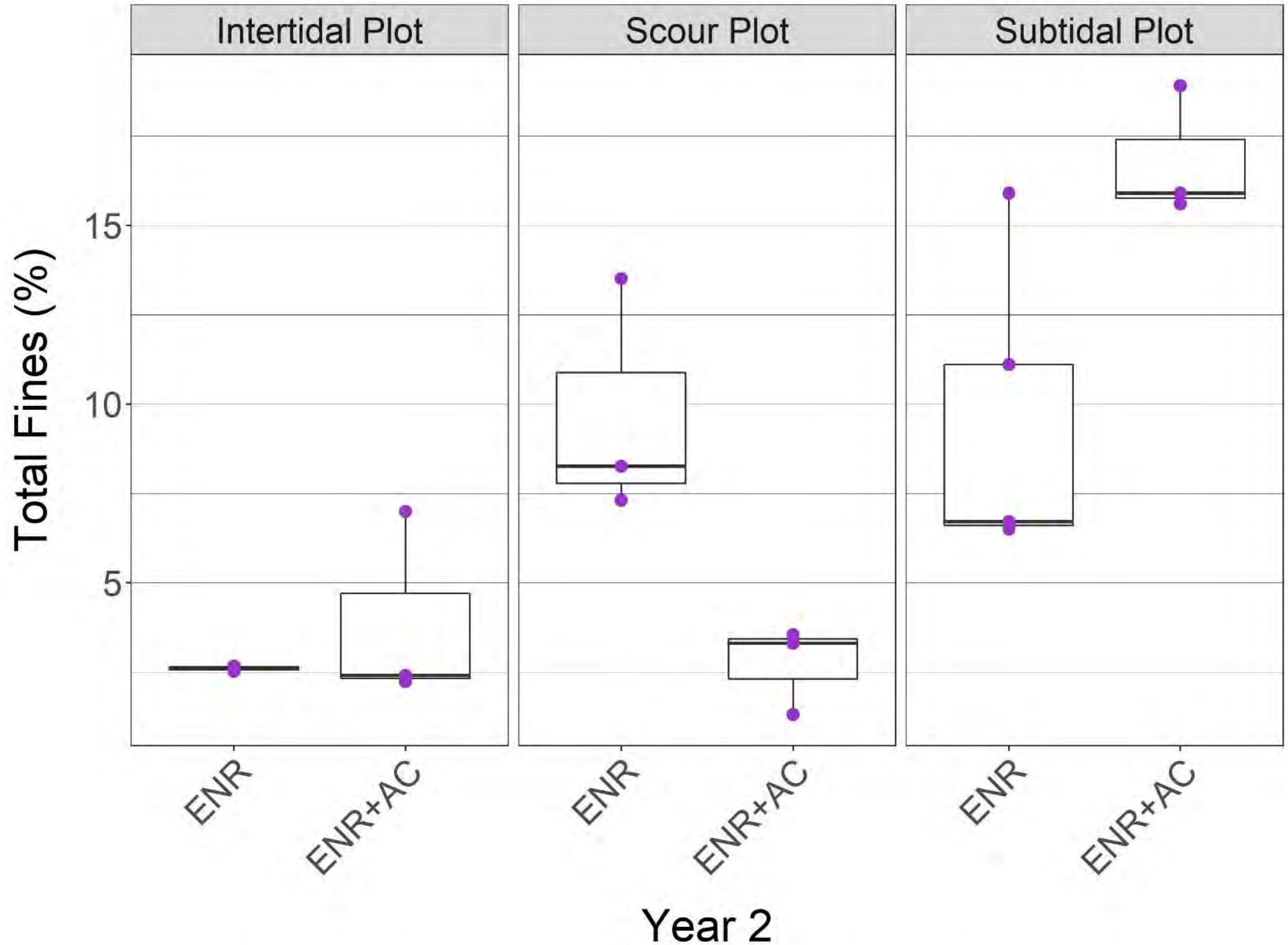


Boxes show first quartile, median, and third quartile. Dots show data points.

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.2-2 Year 0 Total Fines - All Plots

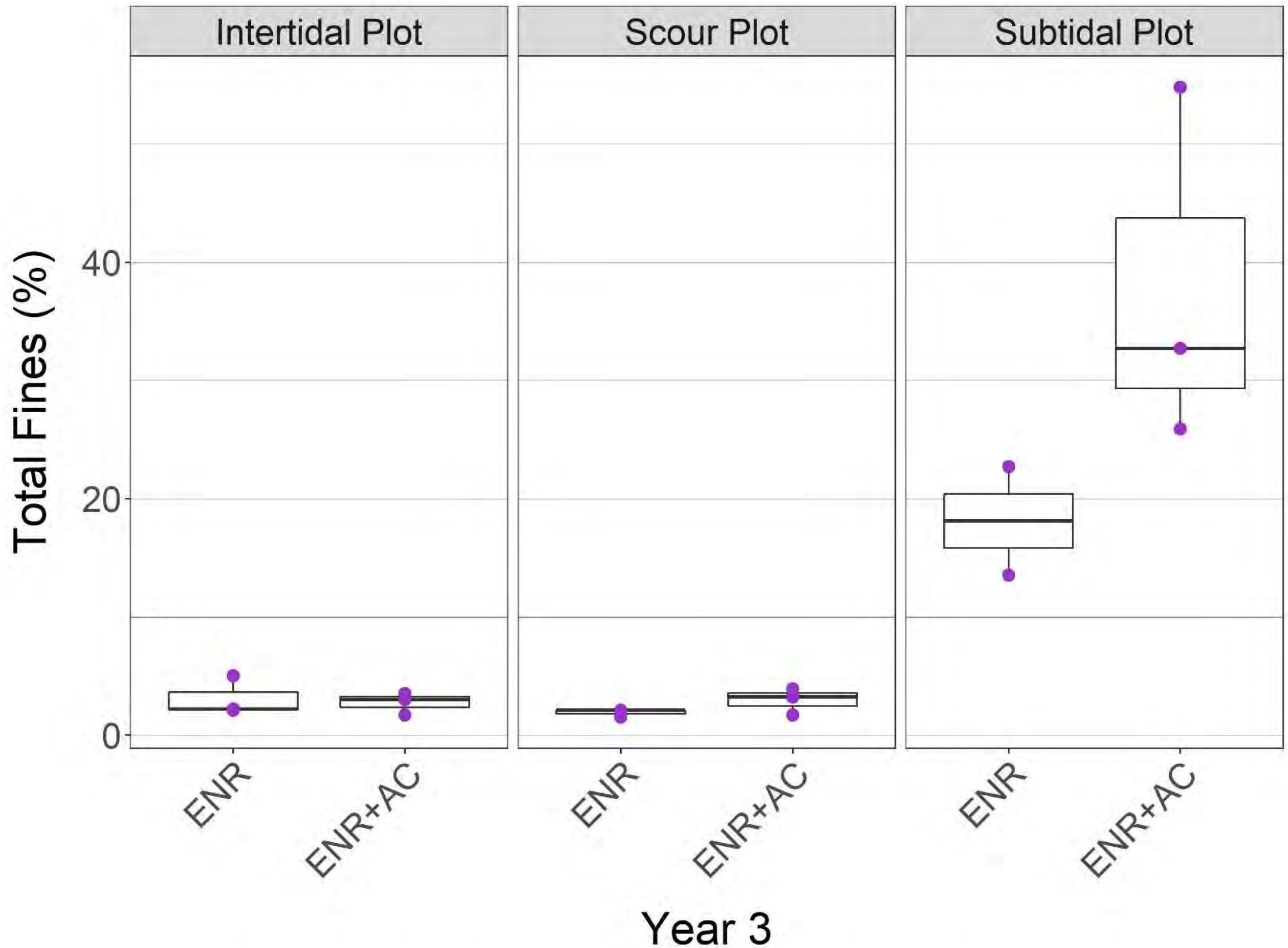


Boxes show first quartile, median, and third quartile. Dots show data points.



Boxes show first quartile, median, and third quartile. Dots show data points.

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.2-4 Year 2 Total Fines - All Plots

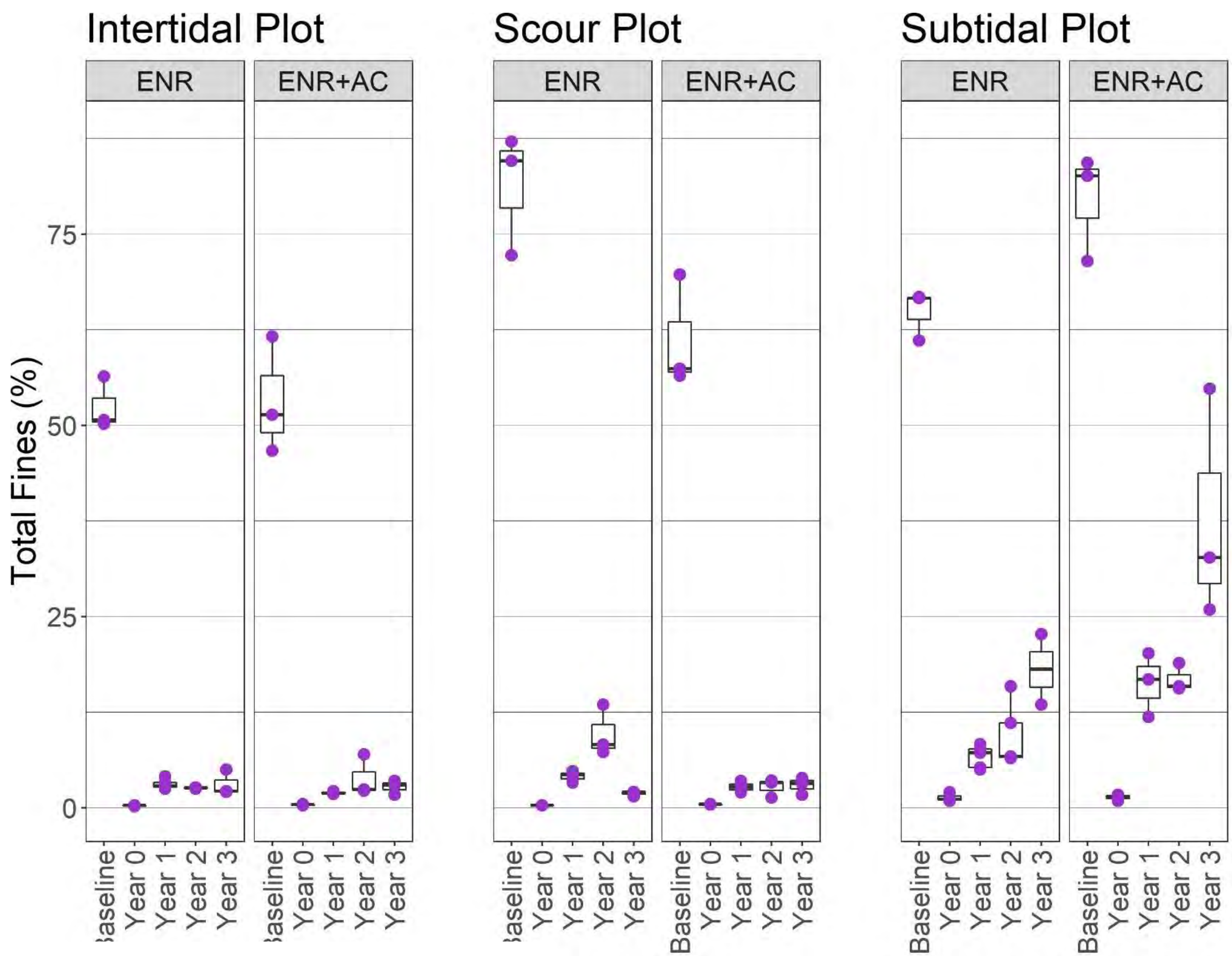


Notes:
1. Boxes show first quartile, median, and third quartile. Dots show data points.
2. Scour plot Year 3 results are from Type 2 samples.

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

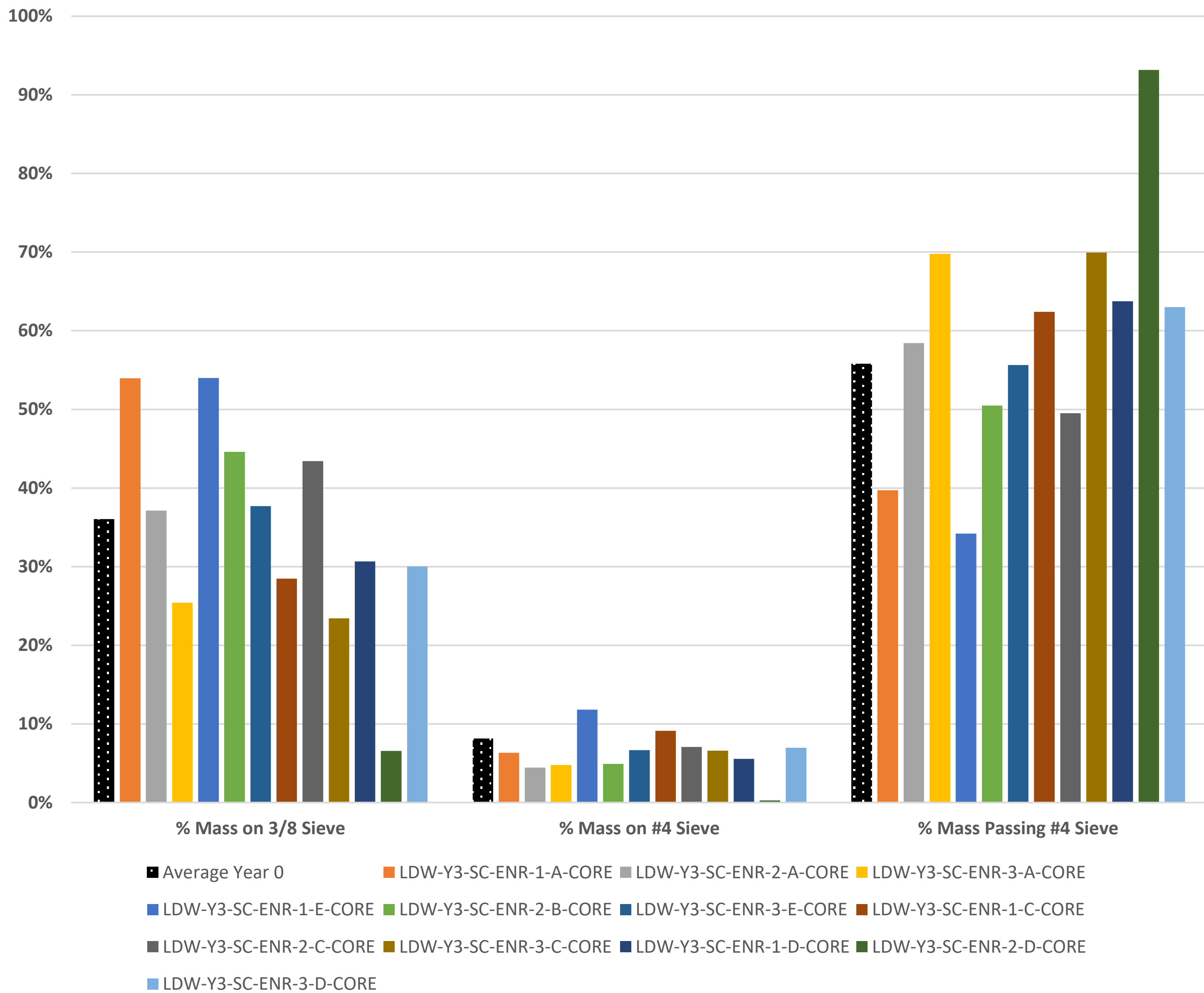
ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.2-5
Year 3 Total Fines - All Plots



Notes:
1. Boxes show first quartile, median, and third quartile. Dots show data points.
2. Scour plot Year 3 results are from Type 2 samples.

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.2-6 Total Fines - All Plots, All Years



Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.2-7
Percent Mass of Material on 3/8 inch and #4 Sieves, and Passing #4 Sieve for Samples Located in Scoured Area of Scour Plot

7/9/2021

Legend

- 2.5 Silt Sample Location and Thickness (cm)

Average Silt Thickness (cm)

- 0–1
- 1–2.5
- 2.5–5
- 5–7.5
- 7.5–10
- 10–27

Other Features

- Outfall
- Abandoned Outfall
- 3.9 River Mile Markers
- Navigation Channel
- Subplot Area
- Grid Cell
- Sampling Area Buffer
- Cell Removed From Analysis
- Uplands Tax Parcel

Notes:
- Silt thickness was interpolated using IDW with a power of 2.
- The thickness of the silt layer deposited on top of the treatment layer (ENR or ENR+AC) was measured by field personnel when retrieving the SPME sampler at each location. The low and high values of the silt layer thickness at each location were averaged to represent an average silt layer thickness at each location. These values were then averaged to obtain an average silt layer thickness for each subplot, which are indicated in Table 3.2-3.
- Some grid cells have fewer than 5 silt thickness measurements because sediment samples and silt thickness measurements were not collected when SPMEs were not recoverable.
- To avoid sampling in areas potentially influenced by untreated sediments and to avoid influence from the adjacent subplot, no samples were collected from locations within 5 feet of the edge of a plot, and a 15-foot buffer will be maintained between the ENR and ENR+AC subplots.
- Aerial imagery obtained from Nearmap, 2017.

Abbreviations:
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
FIPS = Federal Information Processing Standards
IDW = Inverse distance weighted
SPME = Solid-phase microextraction

0 32.5 65 130
Scale in Feet

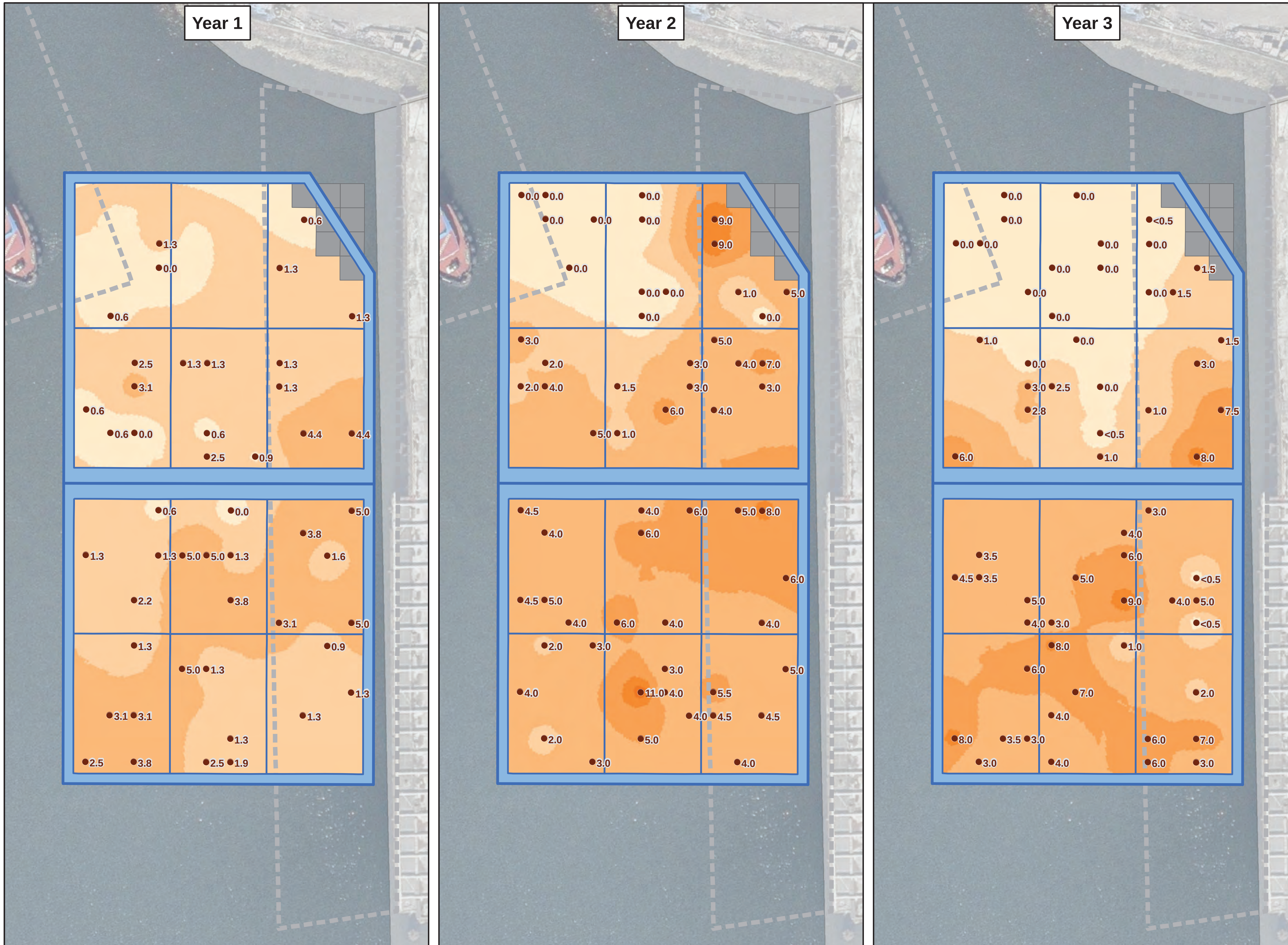
N

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.2-8
Intertidal Plot Silt Deposition Thickness Using IDW and Sample Measurements Years 1–3

I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 3.2-7 Intertidal Plot Silt Deposition Thickness Using IDW and Sample Measurements Years 1-3.mxd
3/20/2021



Legend

●2.5 Silt Sample Location and Thickness (cm)

Average Silt Thickness (cm)

- 0–1
- 1–2.5
- 2.5–5
- 5–7.5
- 7.5–10
- 10–27

Other Features

- Subplot Area
- Grid Cells
- Sampling Area Buffer
- Cell Removed From Analysis
- Berthing
- Uplands Tax Parcel

Notes:

- Silt thickness was interpolated using IDW with a power of 2.
- The thickness of the silt layer deposited on top of the treatment layer (ENR or ENR+AC) was measured by field personnel when retrieving the SPME sampler at each location. The low and high values of the silt layer thickness at each location were averaged to represent an average silt layer thickness at each location. These values were then averaged to obtain an average silt layer thickness for each subplot, which are indicated in Table 3.2-3.
- Some grid cells have fewer than 5 silt thickness measurements because sediment samples and silt thickness measurements were not collected when SPMEs were not recoverable.
- To avoid sampling in areas potentially influenced by untreated sediments and to avoid influence from the adjacent subplot, no samples were collected from locations within 5 feet of the edge of a plot, and a 15-foot buffer will be maintained between the ENR and ENR+AC subplots.
- Aerial imagery obtained from Nearmap, 2017.

Abbreviations:

ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
FIPS = Federal Information Processing Standards
IDW = Inverse distance weighted
SPME = Solid-phase microextraction

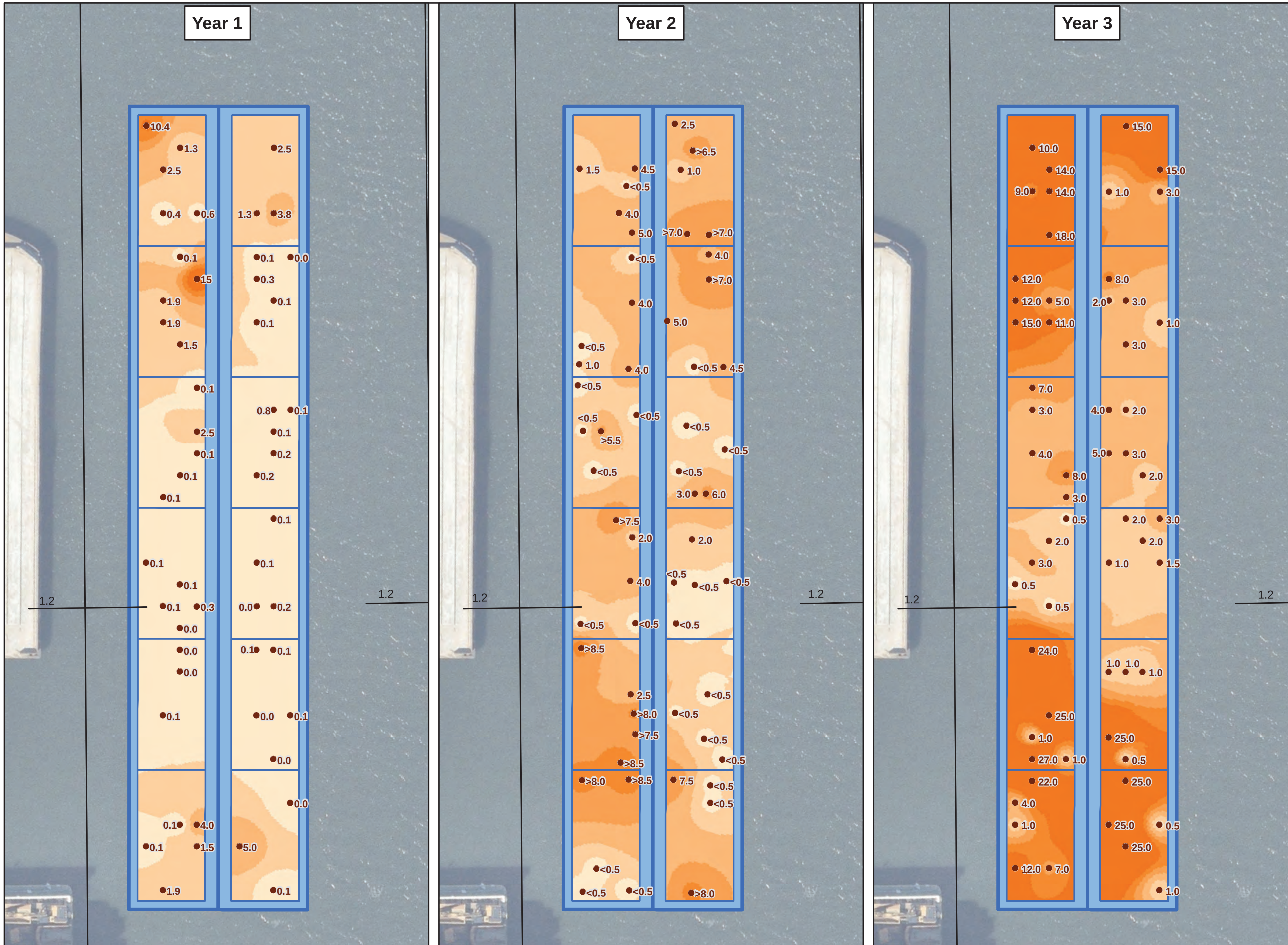
0 25 50 100
Scale in Feet

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.2-9
Scour Plot Silt Deposition Thickness Using IDW and Sample Measurements Years 1–3

I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 3.2-8 Scour Plot Silt Deposition Thickness Using IDW and Sample Measurements Years 1-3.mxd
3/20/2021



Legend

● 2.5 Silt Sample Location and Thickness (cm)

Average Silt Thickness (cm)

- 0–1
- 1–2.5
- 2.5–5
- 5–7.5
- 7.5–10
- 10–27

Other Features

- 1.2 River Mile Markers
- Navigation Channel
- Subplot Area
- Grid Cell
- Sampling Area Buffer

Notes:
- Silt thickness was interpolated using IDW with a power of 2.
- The thickness of the silt layer deposited on top of the treatment layer (ENR or ENR+AC) was measured by field personnel when retrieving the SPME sampler at each location. The low and high values of the silt layer thickness at each location were averaged to represent an average silt layer thickness at each location. These values were then averaged to obtain an average silt layer thickness for each subplot, which are indicated in Table 3.2-3.
- Some grid cells have fewer than 5 silt thickness measurements because sediment samples and silt thickness measurements were not collected when SPMEs were not recoverable.
- To avoid sampling in areas potentially influenced by untreated sediments and to avoid influence from the adjacent subplot, no samples were collected from locations within 5 feet of the edge of a plot, and a 15-foot buffer will be maintained between the ENR and ENR+AC subplots.
- Aerial imagery obtained from Nearmap, 2017.

Abbreviations:
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
FIPS = Federal Information Processing Standards
IDW = Inverse distance weighted
SPME = Solid-phase microextraction

0 30 60 120
Scale in Feet

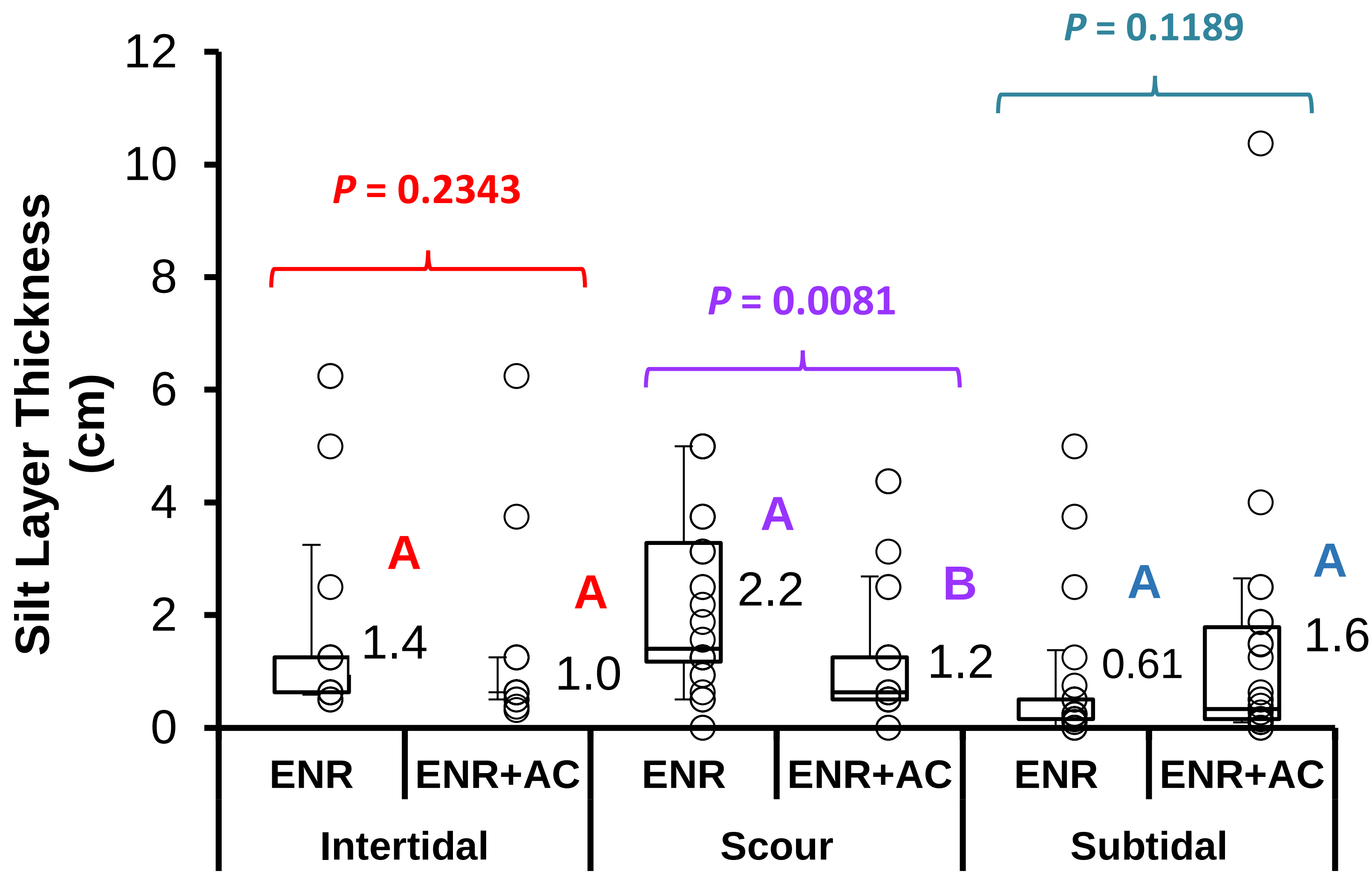
N

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.2-10
Subtidal Plot Silt Deposition Thickness Using IDW and Sample Measurements Years 1–3

I:\GIS\Projects\Wood-KC-ENR\MXD\Project Monitoring and Data Reports\Year 3 Figures\Monitoring Report\Figure 3.2-9 Subtidal Plot Silt Deposition Thickness Using IDW and Sample Measurements Years 1-3.mxd
3/20/2021



Notes:
Results within each plot are compared statistically (t test) such that if results for ENR and ENR+AC for a plot are labeled with the same colored letter, the results are not statistically different.

Abbreviations:
cm = centimeter(s)
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

Lower Duwamish Waterway Group
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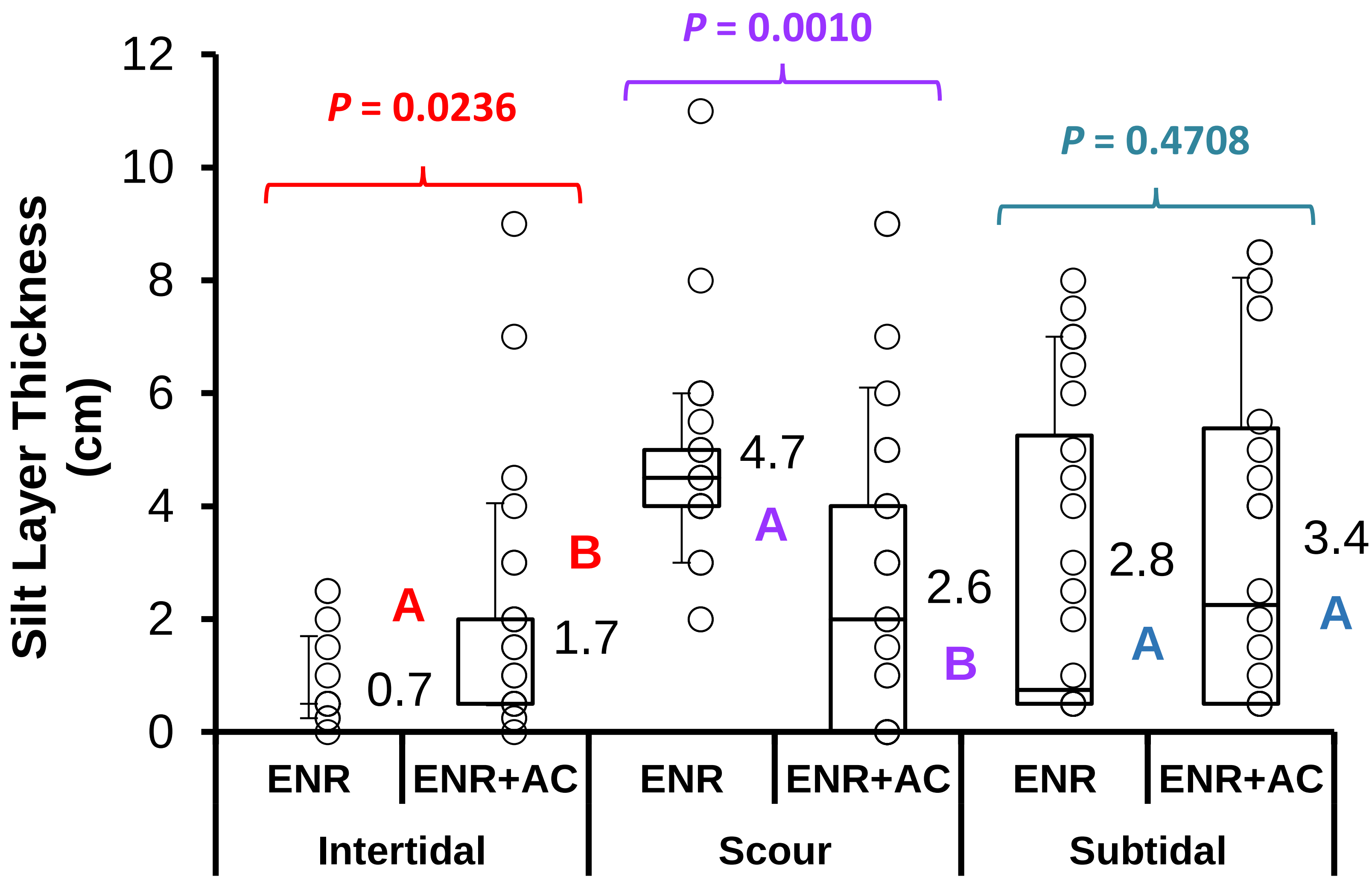
ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.2-11
Year 1 Silt Layer Thickness



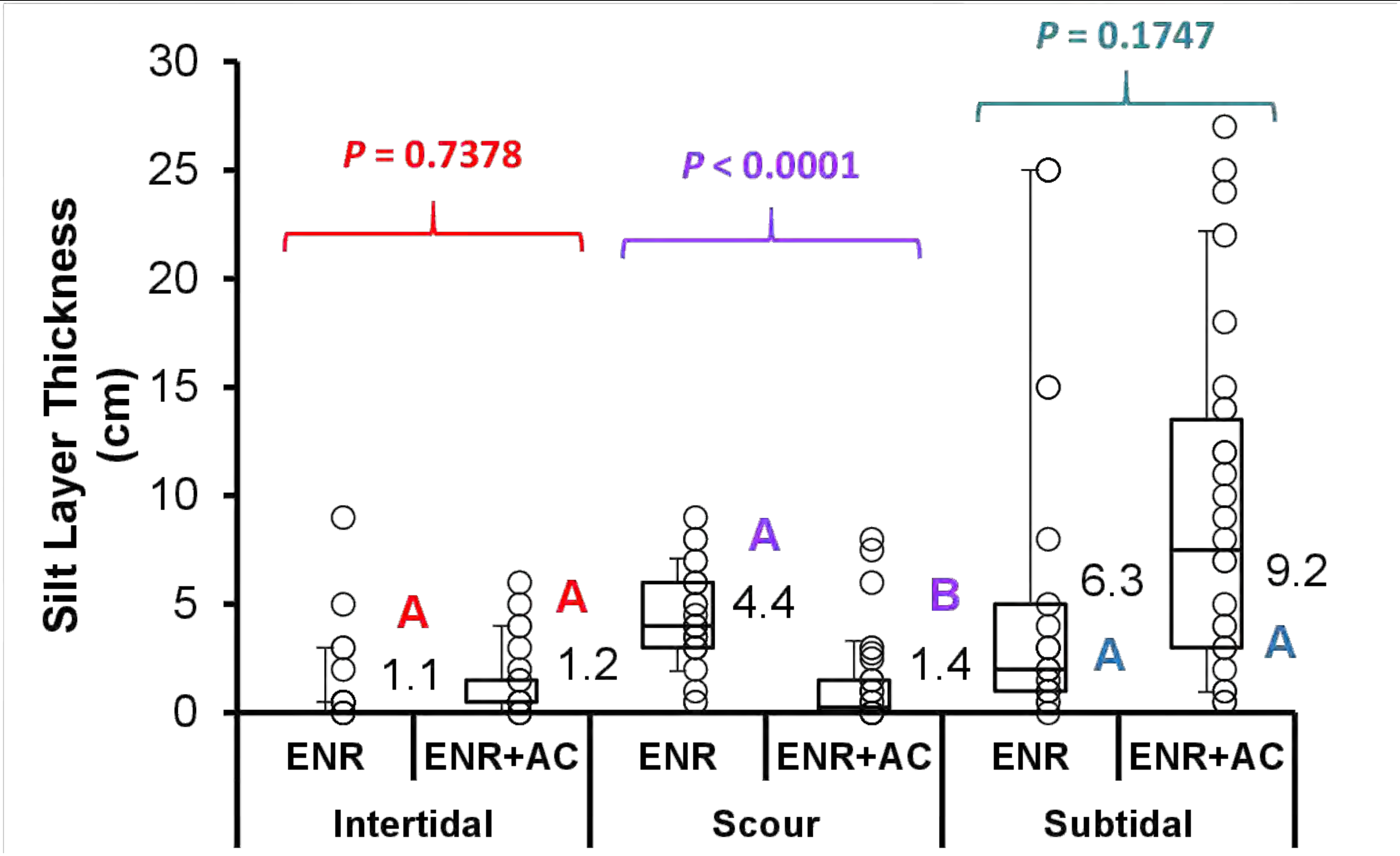
Notes:
Results within each plot are compared statistically (t test) such that if results for ENR and ENR+AC for a plot are labeled with the same colored letter, the results are not statistically different.

Abbreviations:
cm = centimeter(s)
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.2-12
Year 2 Silt Layer Thickness



Notes:

Results within each plot are compared statistically (t test) such that if results for ENR and ENR+AC for a plot are labeled with the same colored letter, the results are not statistically different.

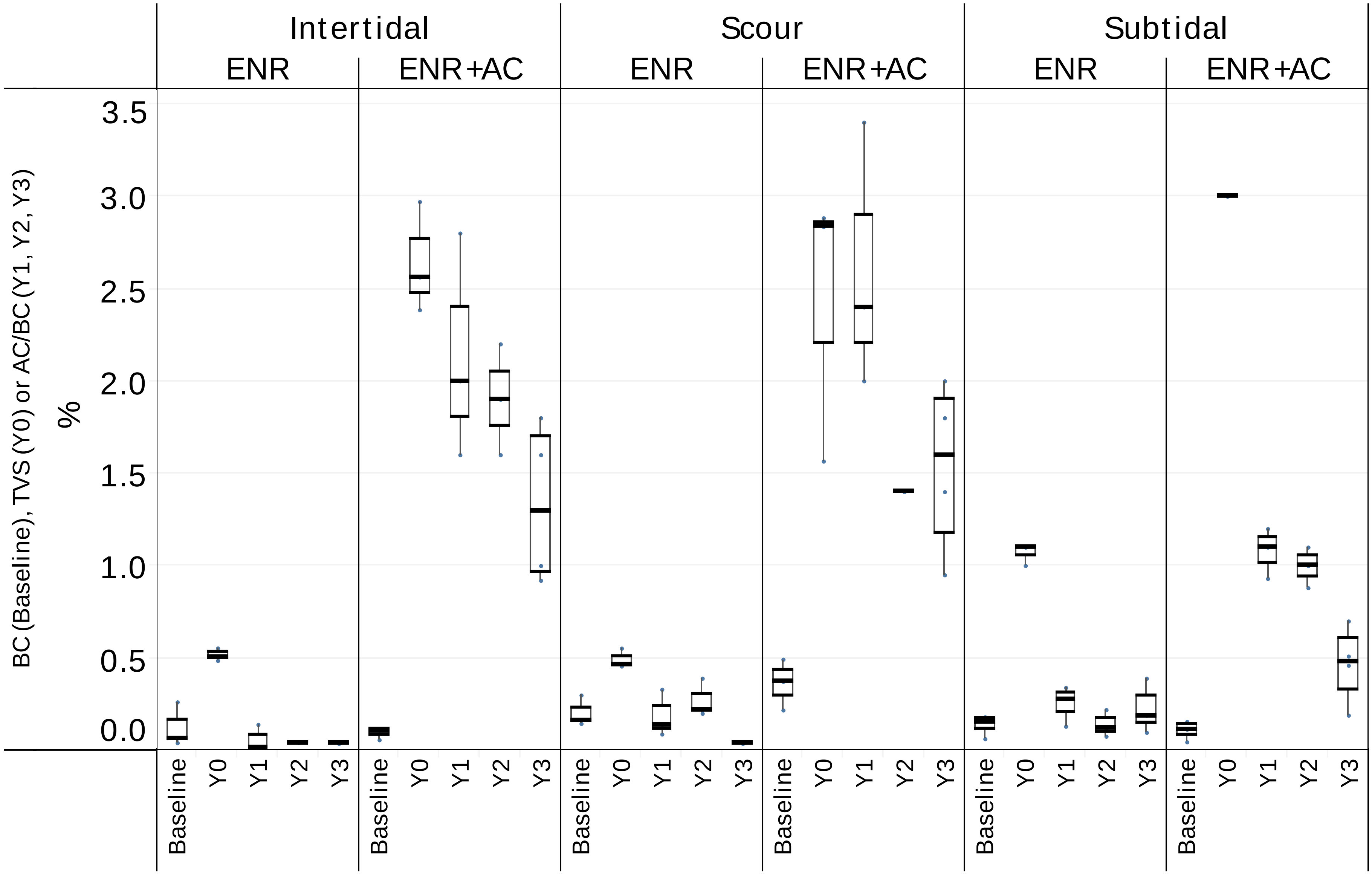
Abbreviations:

cm = centimeter(s)
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.2-13
Year 3 Silt Layer Thickness



Notes: 1. Boxes show first quartile, median, and third quartile. Dots show data points. 2. Scour plot Year 3 results are from Type 2 samples.

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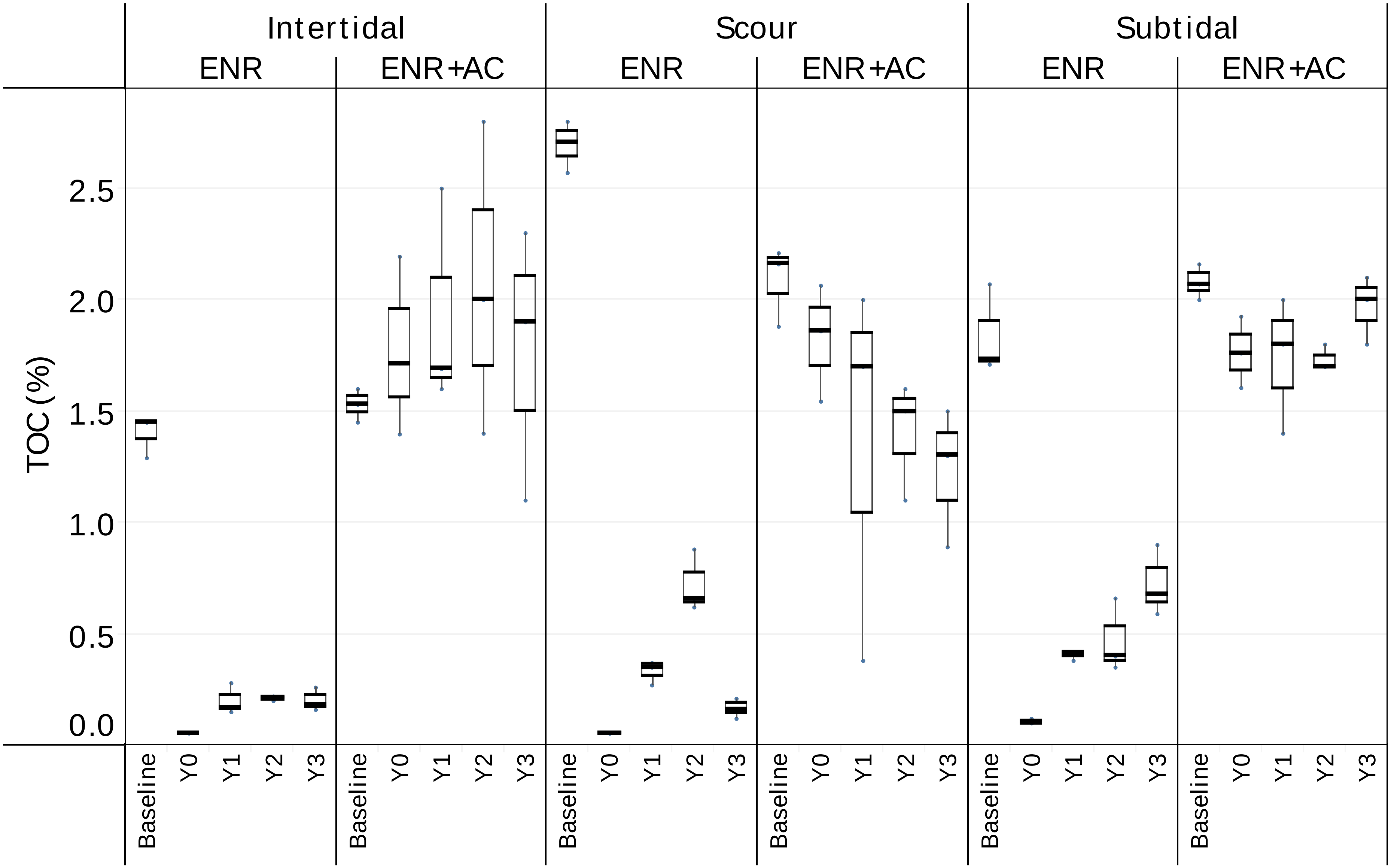
ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.2-14
Black Carbon (Baseline), Total Volatile Solids (Year 0), and Activated Carbon/Black Carbon (Years 1, 2, and 3) Results



Notes: 1. Boxes show first quartile, median, and third quartile. Dots show data points. 2. Scour plot Year 3 results are from Type 2 samples.

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.2-15 Total Organic Carbon Results

Notes:
- Bathymetry units are in feet MLLW.
- Northing and Easting provided in NAD 83 Washington State Plane North Feet - FIPS 4601.
- Aerial imagery obtained from Nearmap, 2017.

Abbreviations:
E = Coordinate in Easting
FIPS = Federal Information Processing Standards
in = Inches
MLLW = Mean Lower Low Water
N = Coordinate in Northing
NAD = North American Datum

0 25 50 100
Scale in Feet

Lower Duwamish Waterway Group
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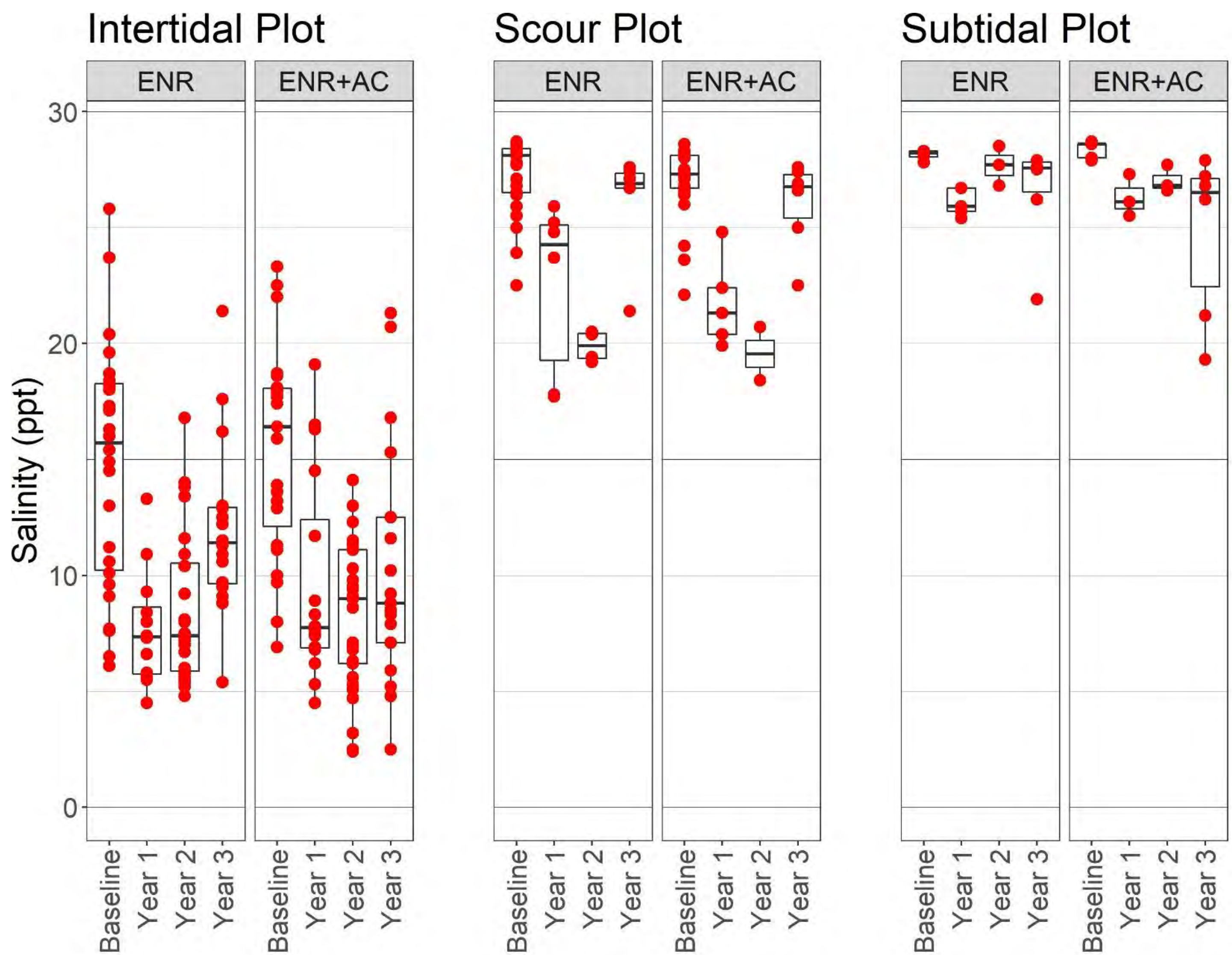
ENR/AC Draft
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.2-16
ENR/AC Pilot Study, Subtidal Plot
Year 3 ENR/ENR+AC Layer Thickness



Abbreviations:
ppt = parts per thousand

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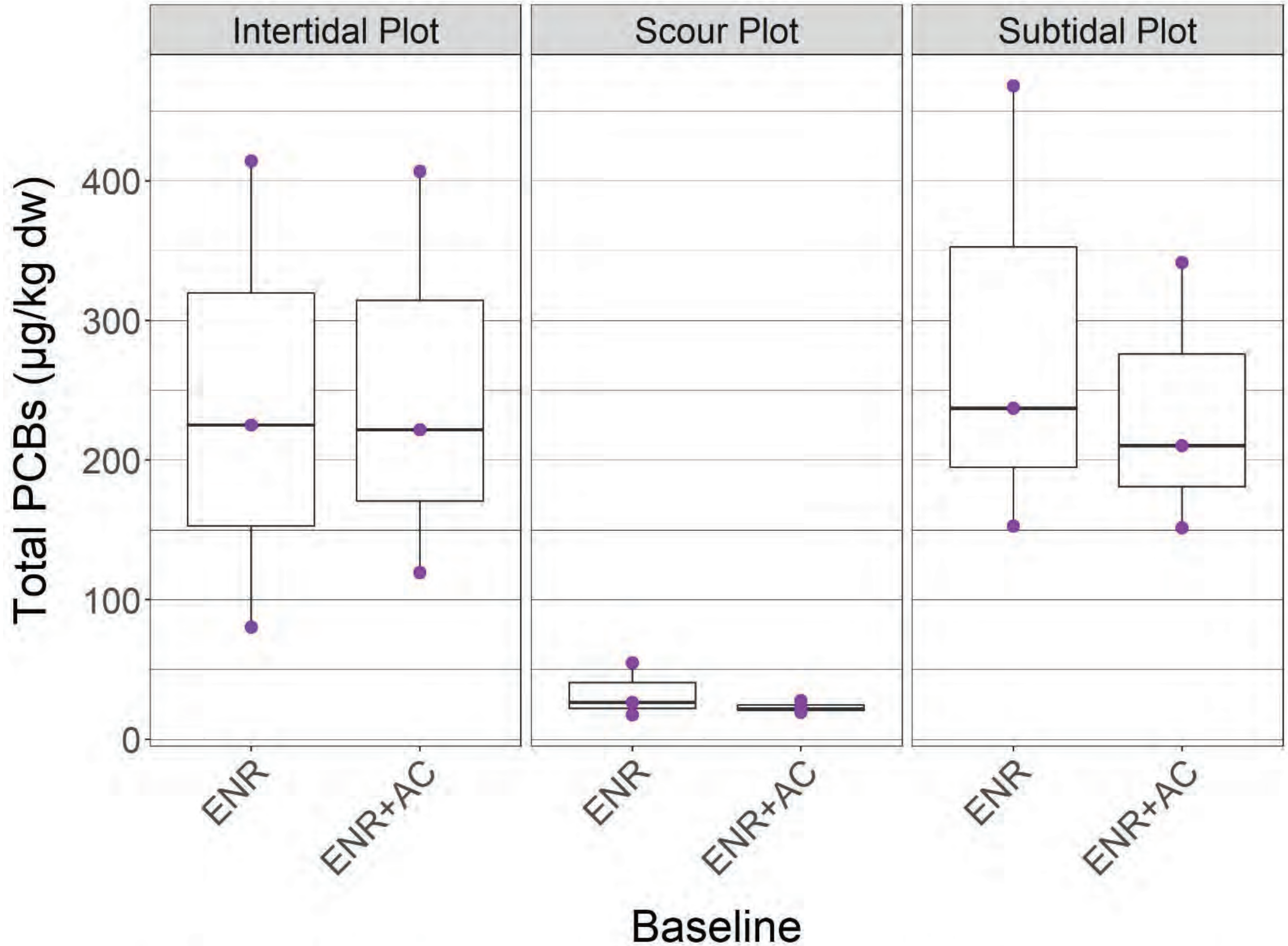
ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.2-17
Salinity - All Plots, All Years



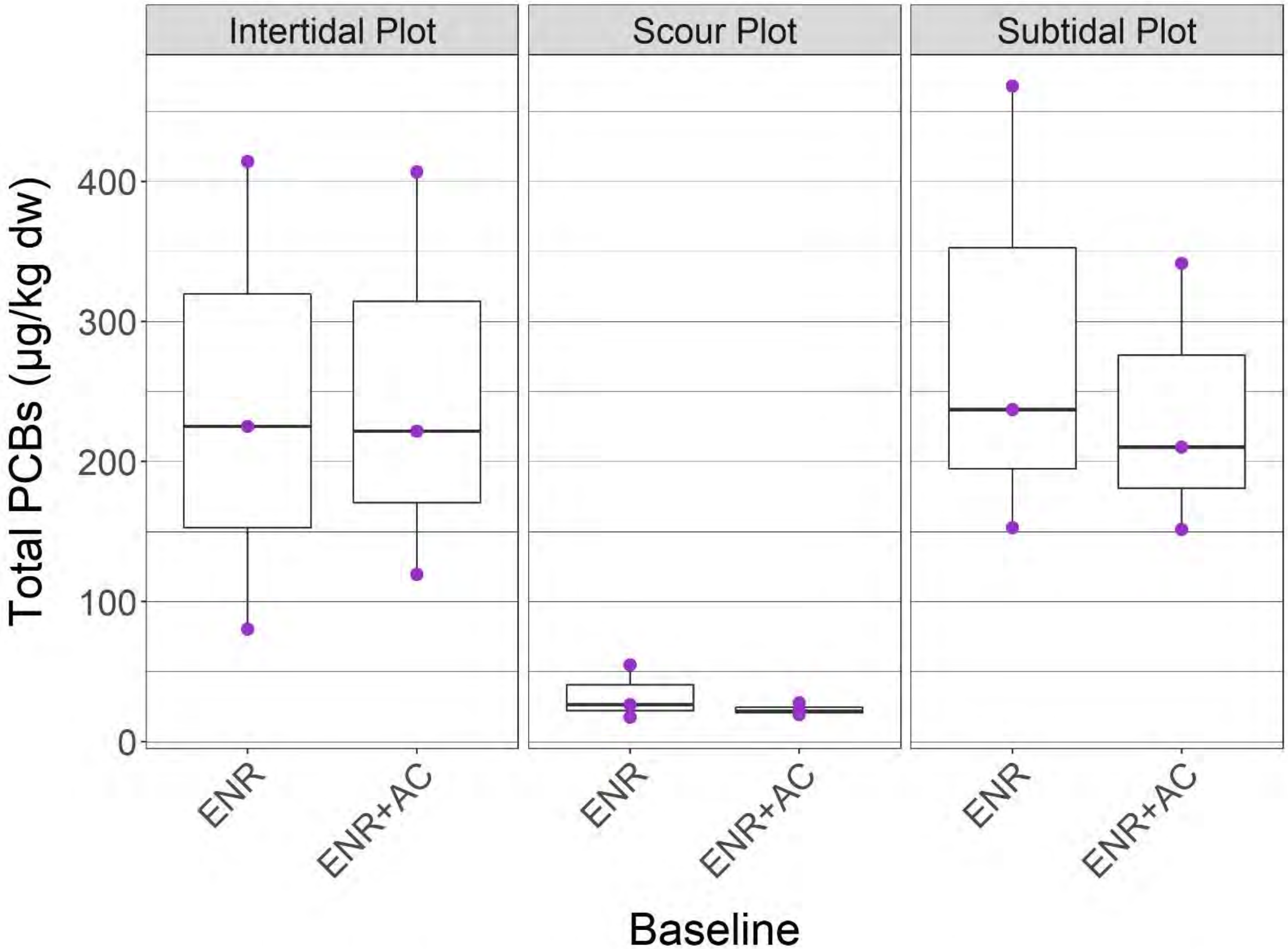
Boxes show first quartile, geometric mean, and third quartile. Dots show data points

Abbreviations:
dw = dry weight
PCB = polychlorinated biphenyl
µg/kg = microgram(s) per kilogram

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

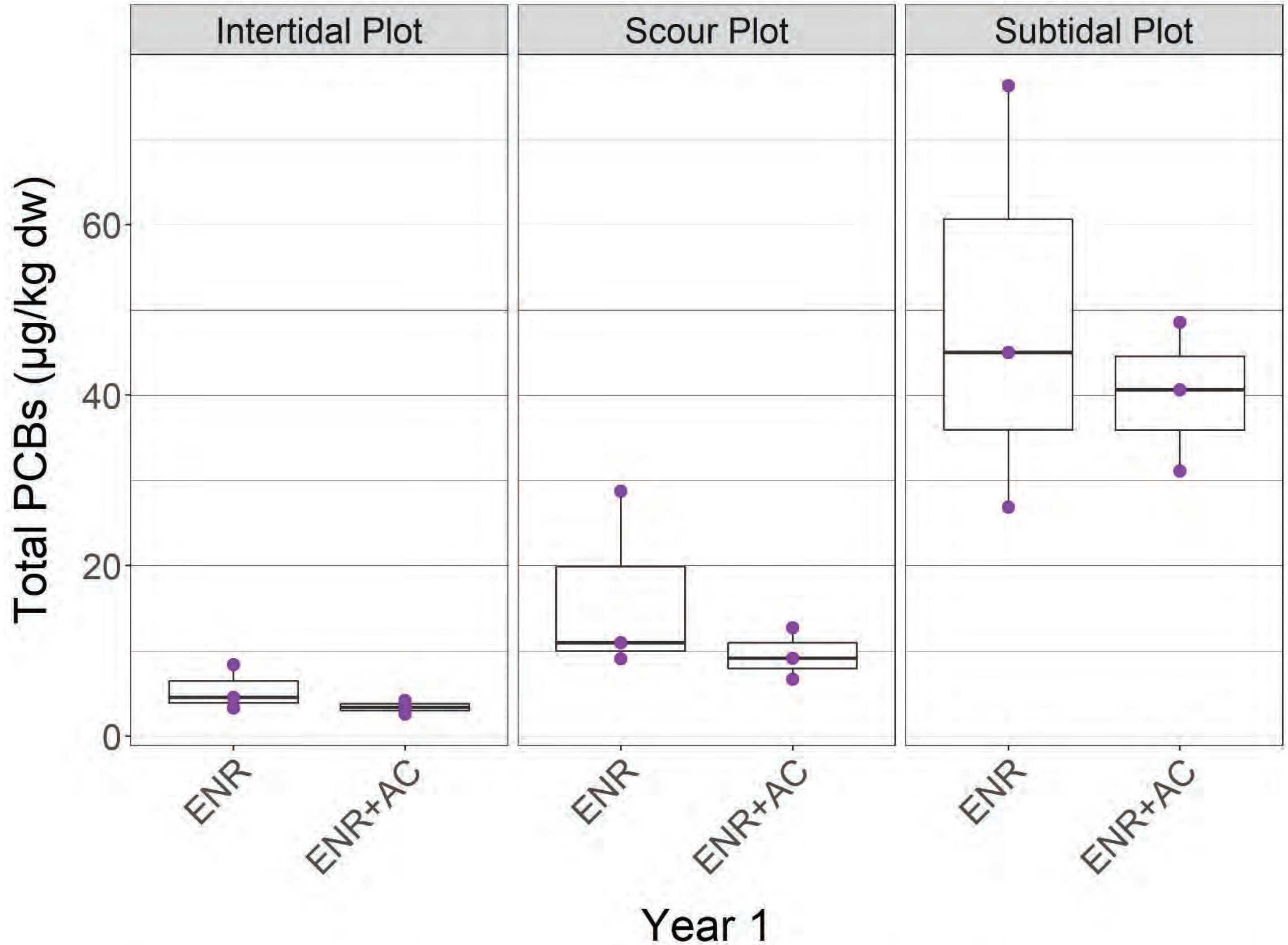
Figure 3.3-1
Baseline Bulk Sediment Total PCB Concentrations - All Plots



Boxes show first quartile, geometric mean, and third quartile. Dots show data points

Abbreviations:
dw = dry weight
PCB = polychlorinated biphenyl
µg/kg = microgram(s) per kilogram

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.3-1 Baseline Bulk Sediment Total PCB Concentrations - All Plots



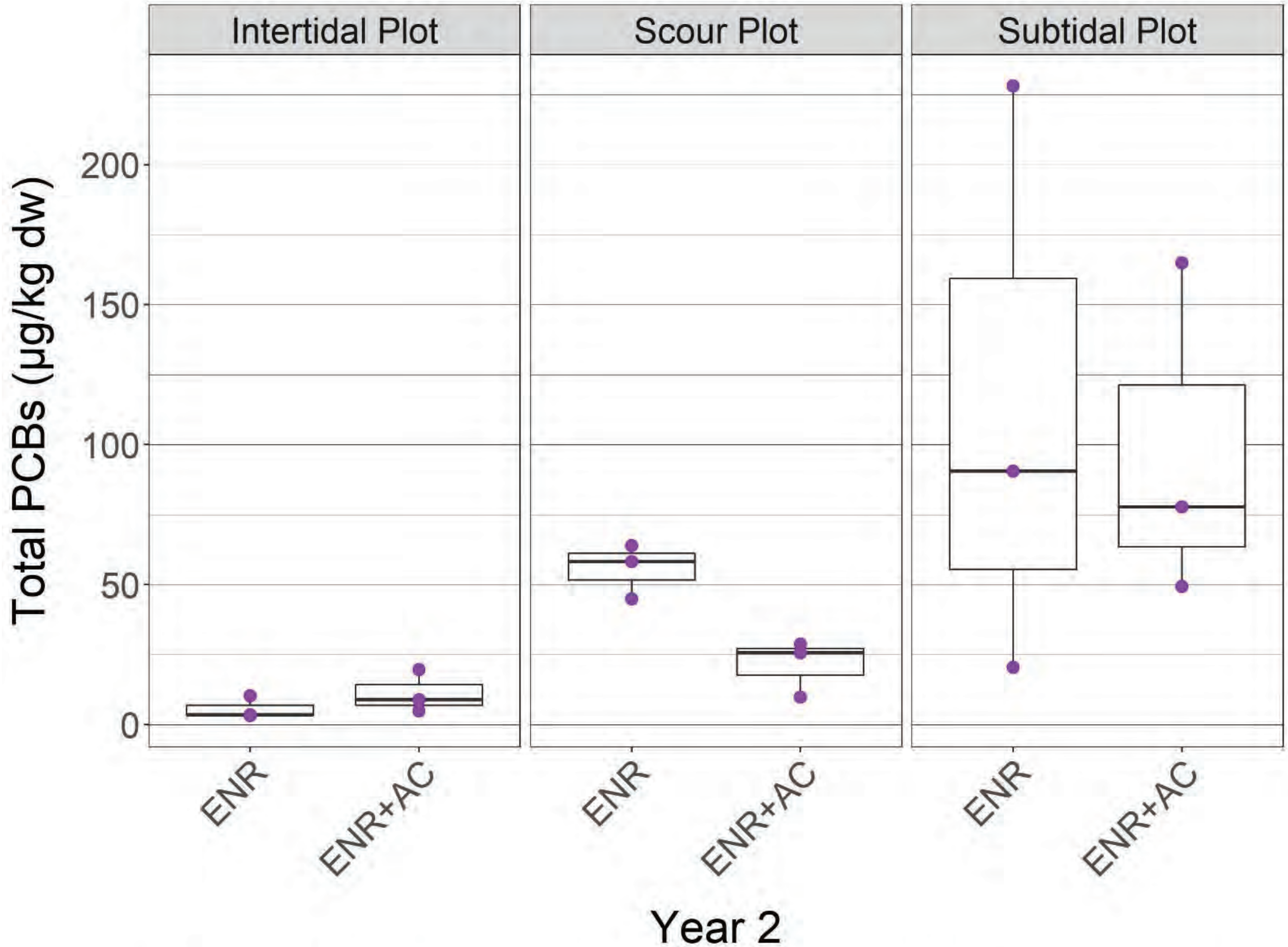
Boxes show first quartile, geometric mean, and third quartile. Dots show data points.

Abbreviations:
dw = dry weight
PCB = polychlorinated biphenyl
µg/kg = microgram(s) per kilogram

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.3-2
Year 1 Bulk Sediment Total PCB Concentrations - All Plots



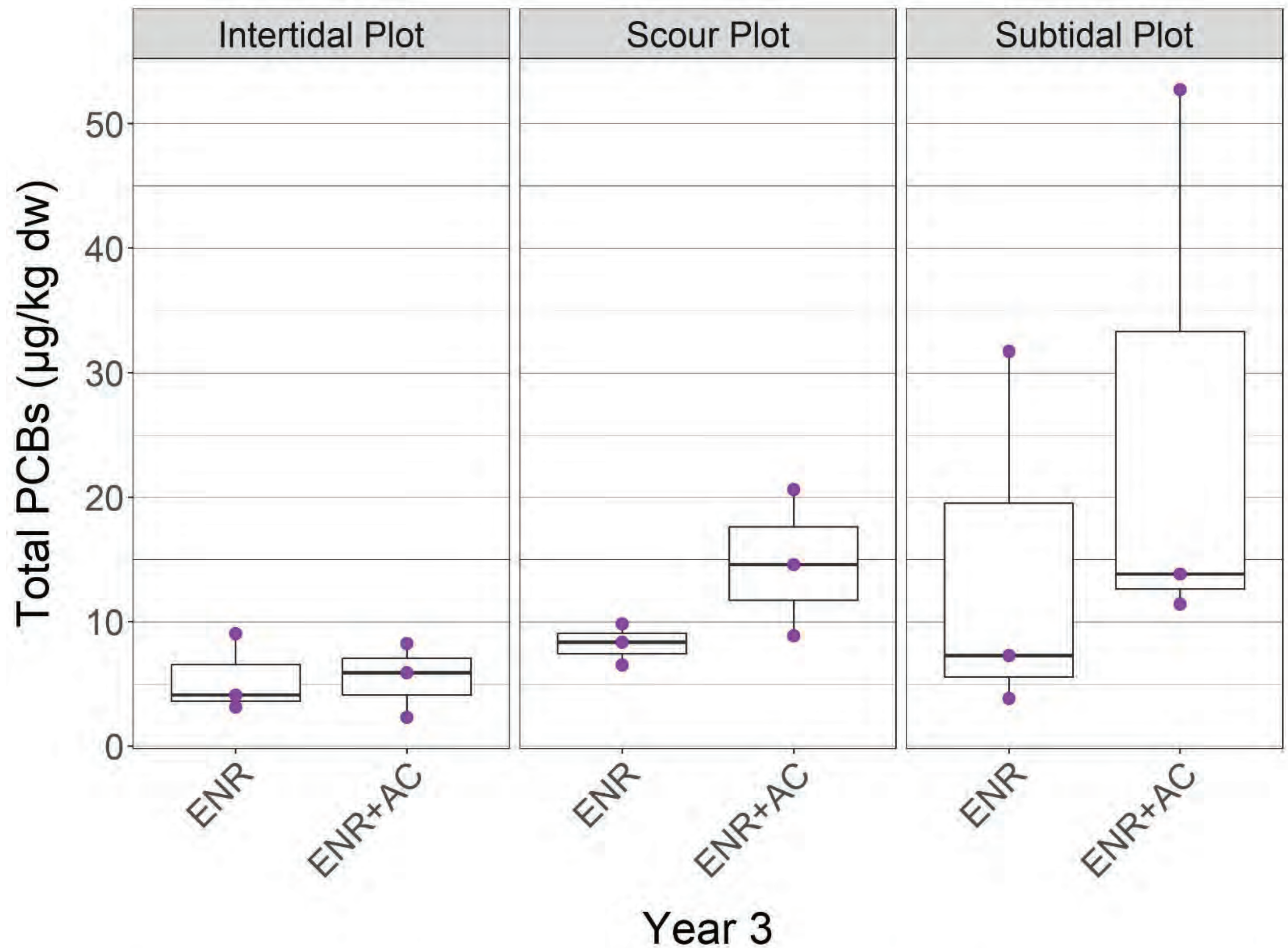
Boxes show first quartile, geometric mean, and third quartile. Dots show data points

Abbreviations:
dw = dry weight
PCB = polychlorinated biphenyl
µg/kg = microgram(s) per kilogram

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

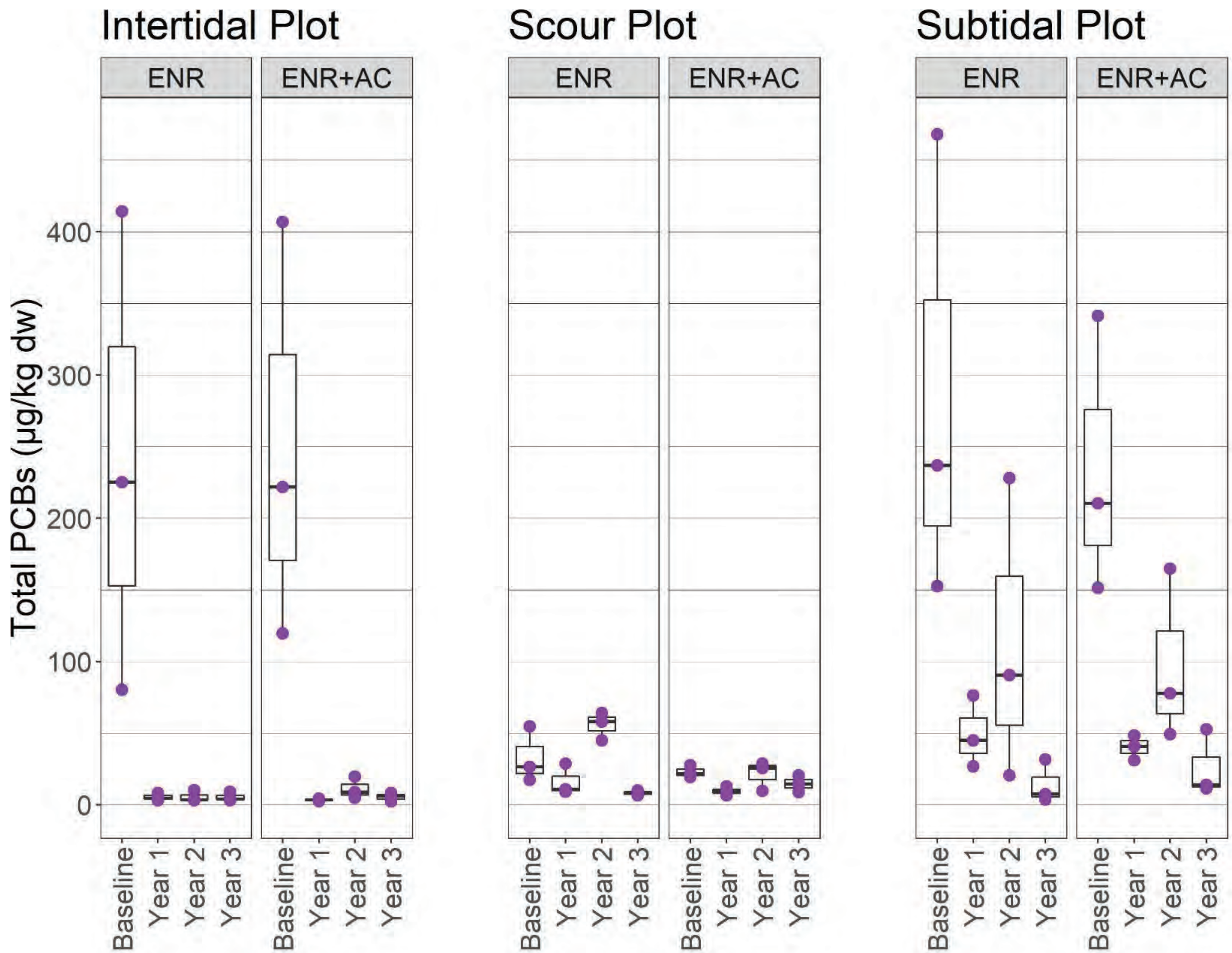
Figure 3.3-3
Year 2 Bulk Sediment Total PCB Concentrations - All Plots



Abbreviations:
dw = dry weight
PCB = polychlorinated biphenyl
µg/kg = microgram(s) per kilogram

Notes:
1. Boxes show first quartile, median, and third quartile. Dots show data points.
2. Scour plot Year 3 results are from Type 2 samples.

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.3-4 Year 3 Bulk Sediment Total PCB Concentrations - All Plots



Abbreviations:
dw = dry weight
PCB = polychlorinated biphenyl
µg/kg = microgram(s) per kilogram

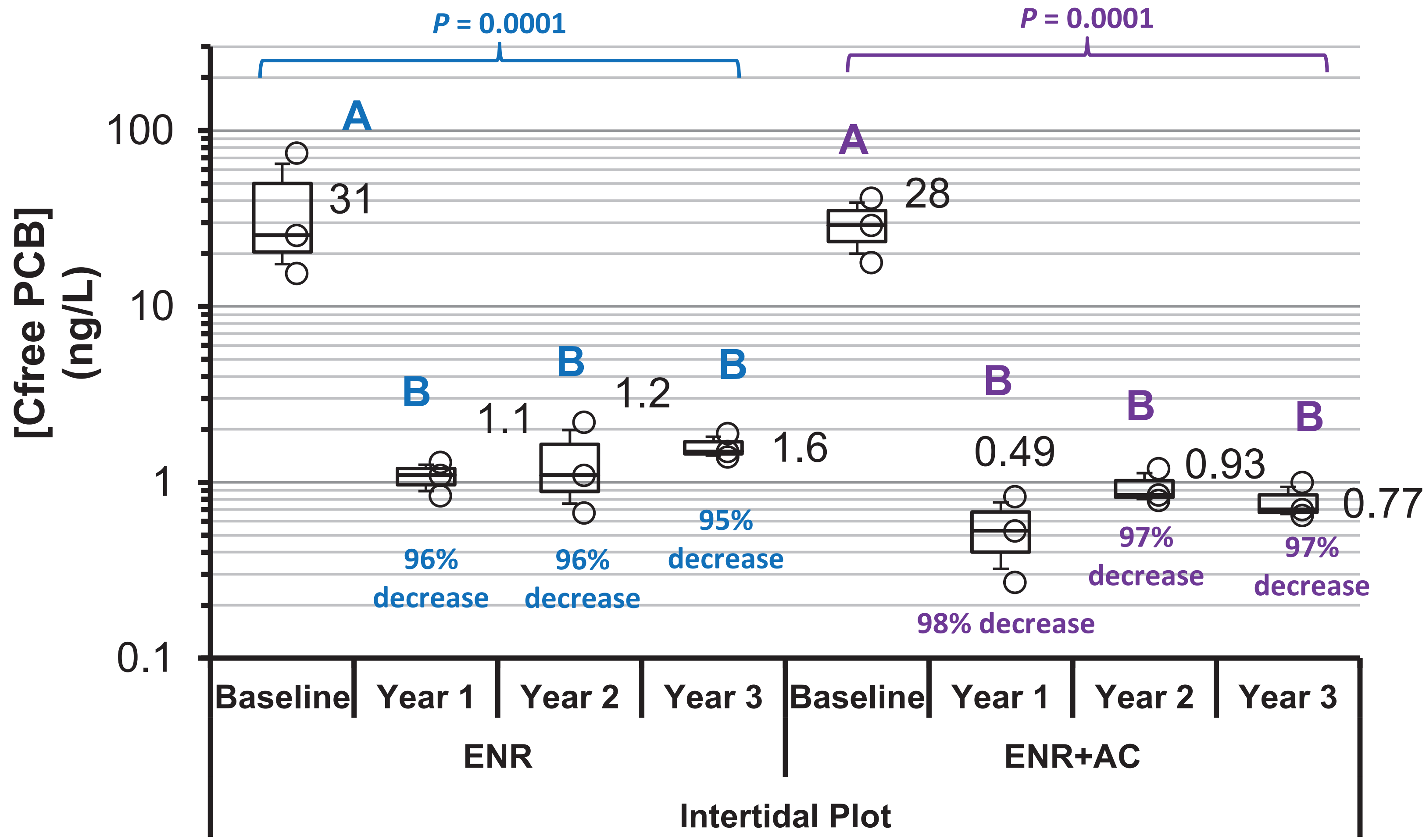
Notes:
1. Boxes show first quartile, median, and third quartile. Dots show data points.
2. Scour plot Year 3 results are from Type 2 samples.

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.3-5
Bulk Sediment Total PCB Concentrations - All Years All Plots

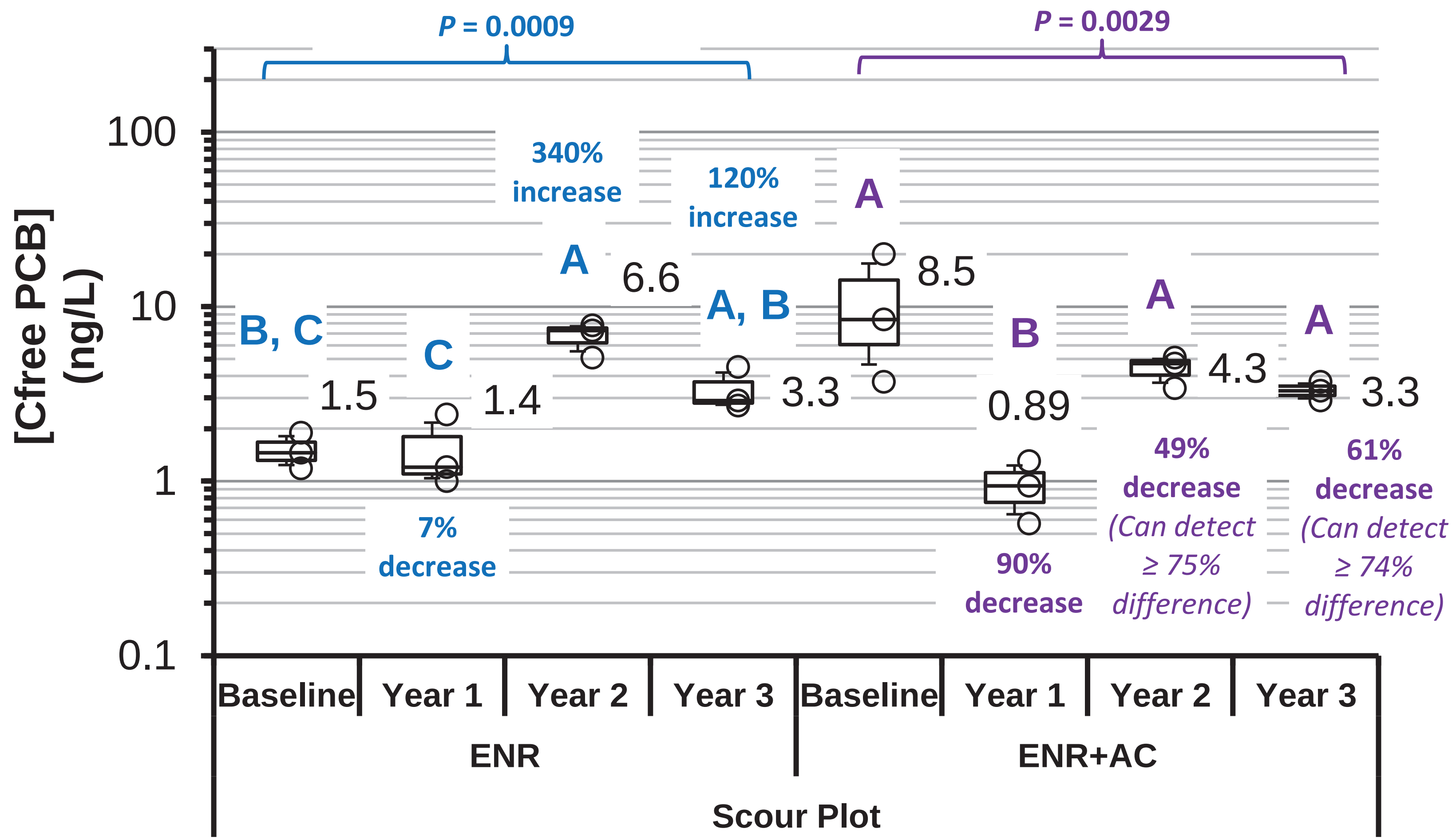
3/19/2021



Notes:
Results within each subplot are compared statistically (ANOVA followed by Tukey's Honestly Significant Difference post-hoc comparison) such that if results for two time periods are labeled with the same colored letter, the results are not statistically different.

Abbreviations:
C_{free} = freely dissolved concentrations
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
ng/L = nanogram(s) per liter
PCB = polychlorinated biphenyl

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	ENR/AC Pilot Study Year 3 Monitoring Report Lower Duwamish Waterway	Figure 3.4-1 Comparison of Total C_{free} PCBs within the Intertidal Subplots for Baseline, Year 1, Year 2, and Year 3



Notes:

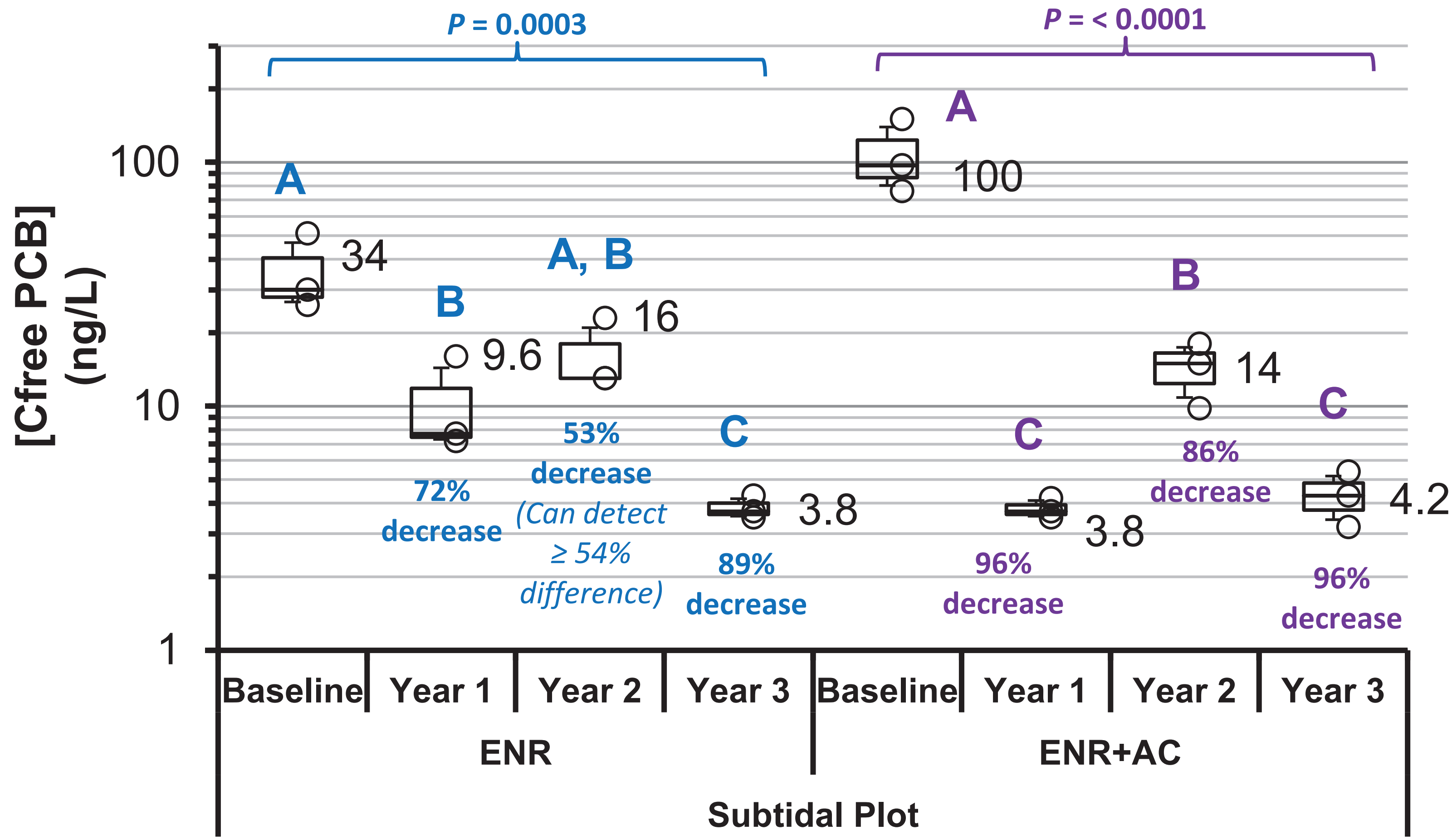
1. Results within each subplot are compared statistically (ANOVA followed by Tukey's Honestly Significant Difference post-hoc comparison) such that if results for two time periods are labeled with the same colored letter, the results are not statistically different.

2. Scour plot Year 3 results are from Type 2 SPMEs

Abbreviations:

C_{free} = freely dissolved concentrations
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
ng/L = nanogram(s) per liter
PCB = polychlorinated biphenyl

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	ENR/AC Pilot Study Year 3 Monitoring Report Lower Duwamish Waterway	Figure 3.4-2 Comparison of Total C_{free} PCBs within the Scour Subplots for Baseline, Year 1, Year 2, and Year 3

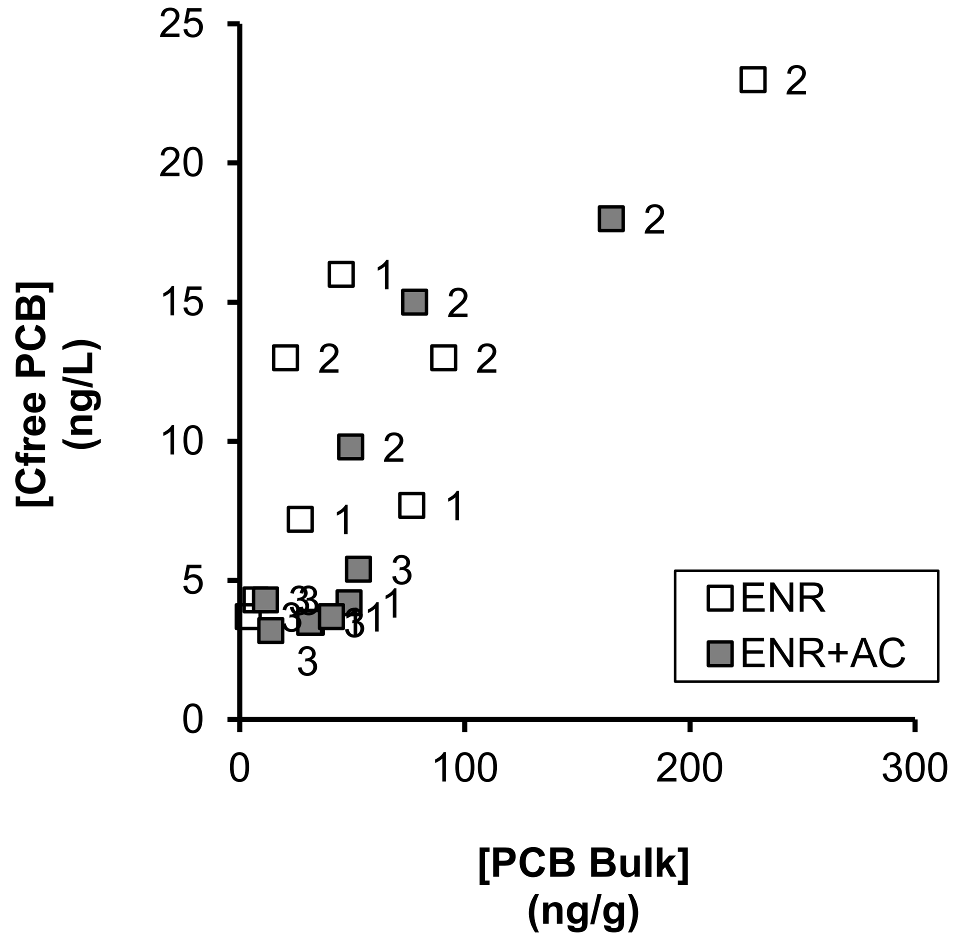


Notes:
Results within each subplot are compared statistically (ANOVA followed by Tukey's Honestly Significant Difference post-hoc comparison) such that if results for two time periods are labeled with the same colored letter, the results are not statistically different.

Abbreviations:
C_{free} = freely dissolved concentrations
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
ng/L = nanogram(s) per liter
PCB = polychlorinated biphenyl

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	ENR/AC Pilot Study Year 3 Monitoring Report Lower Duwamish Waterway	Figure 3.4-3 Comparison of Total C_{free} PCBs within the Subtidal Subplots for Baseline, Year 1, Year 2, and Year 3

3/7/2021



Notes:
Numerical labels adjacent to each symbol indicate the post-amendment monitoring event (i.e., Year 1, 2, or 3).

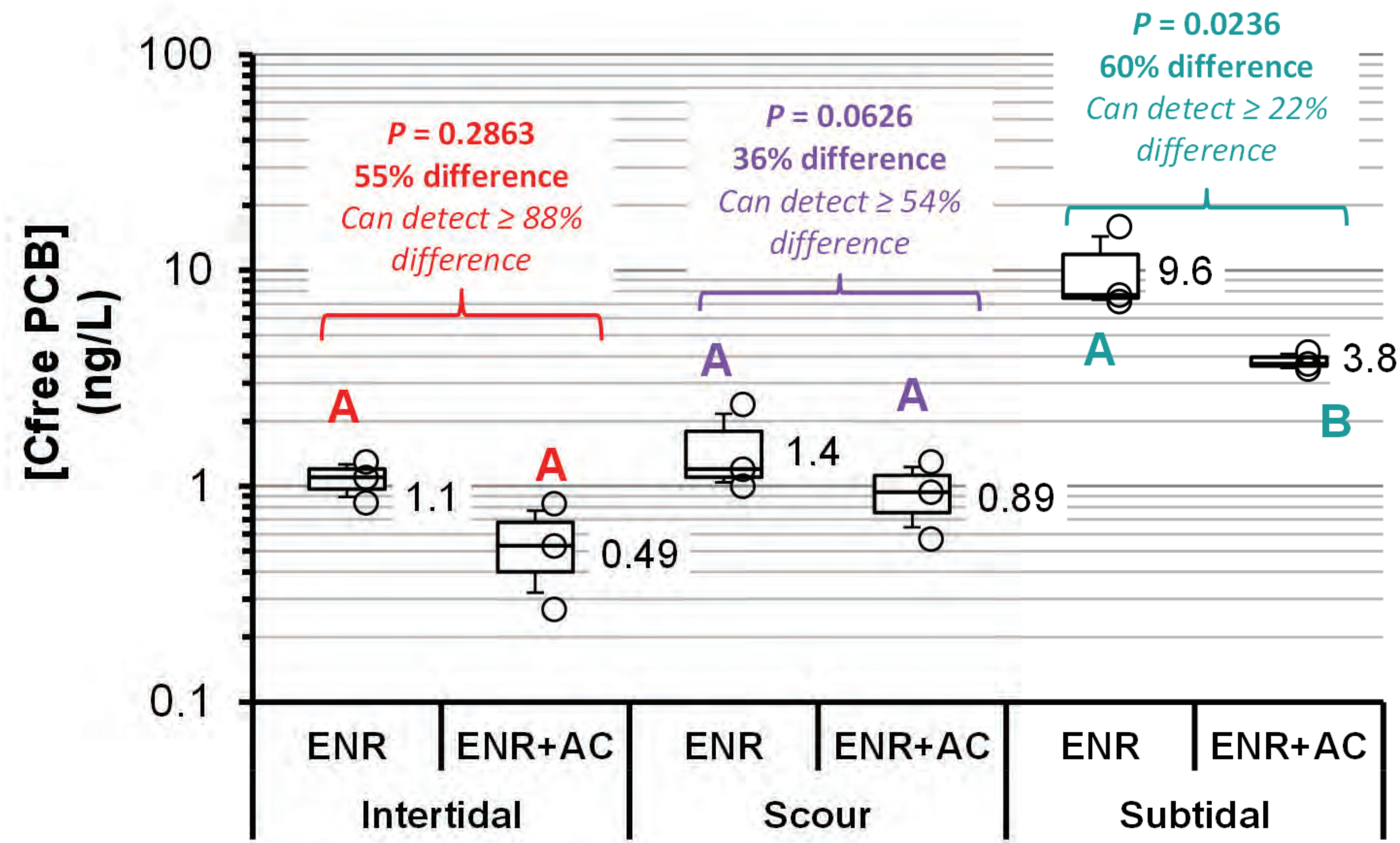
Abbreviations:
C_{free} = freely dissolved concentrations
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
ng/L = nanogram(s) per liter
PCB = polychlorinated biphenyl

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.4-4
Subtidal Plot: Comparison of Total PCB C_{free} and Bulk PCB for Year 1, Year 2, and Year 3

3/7/2021



Notes:

1. Results within each plot are compared statistically (t test) such that if results for ENR and ENR+AC for a plot are labeled with the same colored letter, the results are not statistically different.

2. Scour plot Year 3 results are from Type 2 SPMEs.

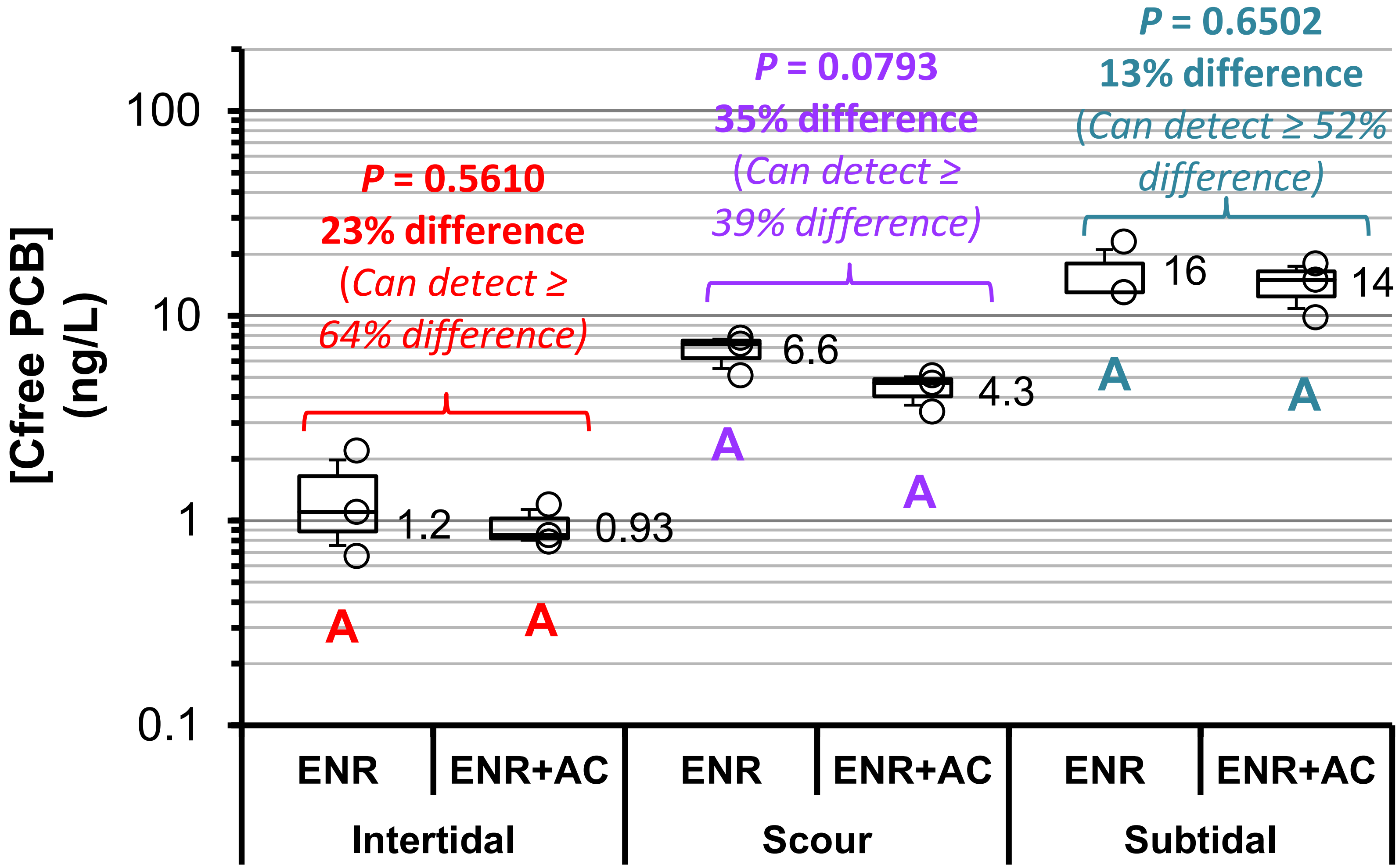
Abbreviations:

C_{free} = freely dissolved concentrations
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
ng/L = nanogram(s) per liter
PCB = polychlorinated biphenyl

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.4-5
Year 1 Comparison of ENR and ENR+AC Total C_{free} PCBs



Notes:

Results within each plot are compared statistically (t test) such that if results for ENR and ENR+AC for a plot are labeled with the same colored letter, the results are not statistically different.

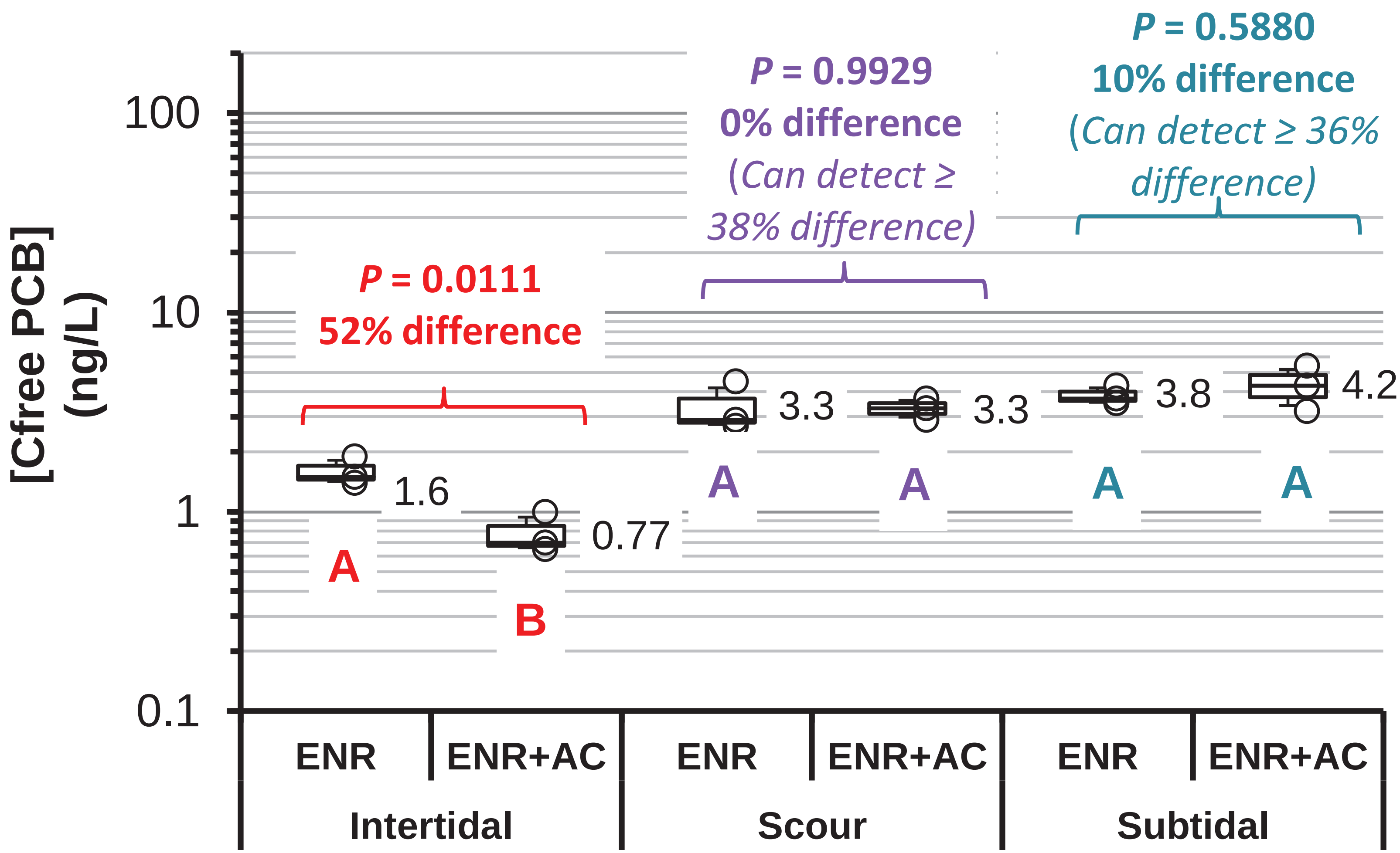
Abbreviations:

C_{free} = freely dissolved concentrations
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
ng/L = nanogram(s) per liter
PCB = polychlorinated biphenyl

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.4-6
Year 2 Comparison of ENR and ENR+AC Total C_{free} PCBs



Notes:

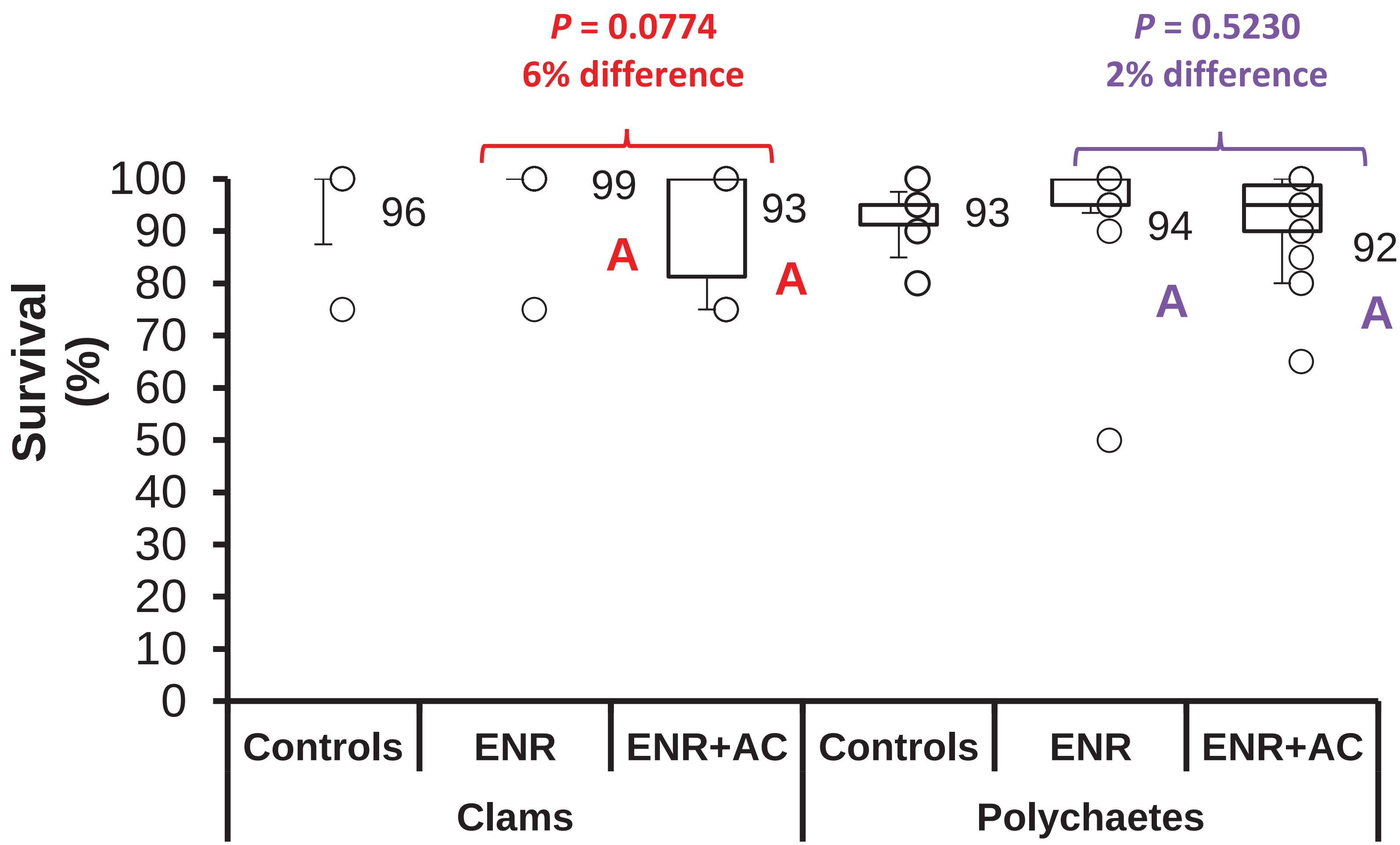
1. Results within each plot are compared statistically (t test) such that if results for ENR and ENR+AC for a plot are labeled with the same colored letter, the results are not statistically different.

2. Scour plot Year 3 results are from Type 2 SPMEs.

Abbreviations:

C_{free} = freely dissolved concentrations
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
ng/L = nanogram(s) per liter
PCB = polychlorinated biphenyl

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	ENR/AC Pilot Study Year 3 Monitoring Report Lower Duwamish Waterway	Figure 3.4-7 Year 3 Comparison of ENR and ENR+AC Total C_{free} PCBs



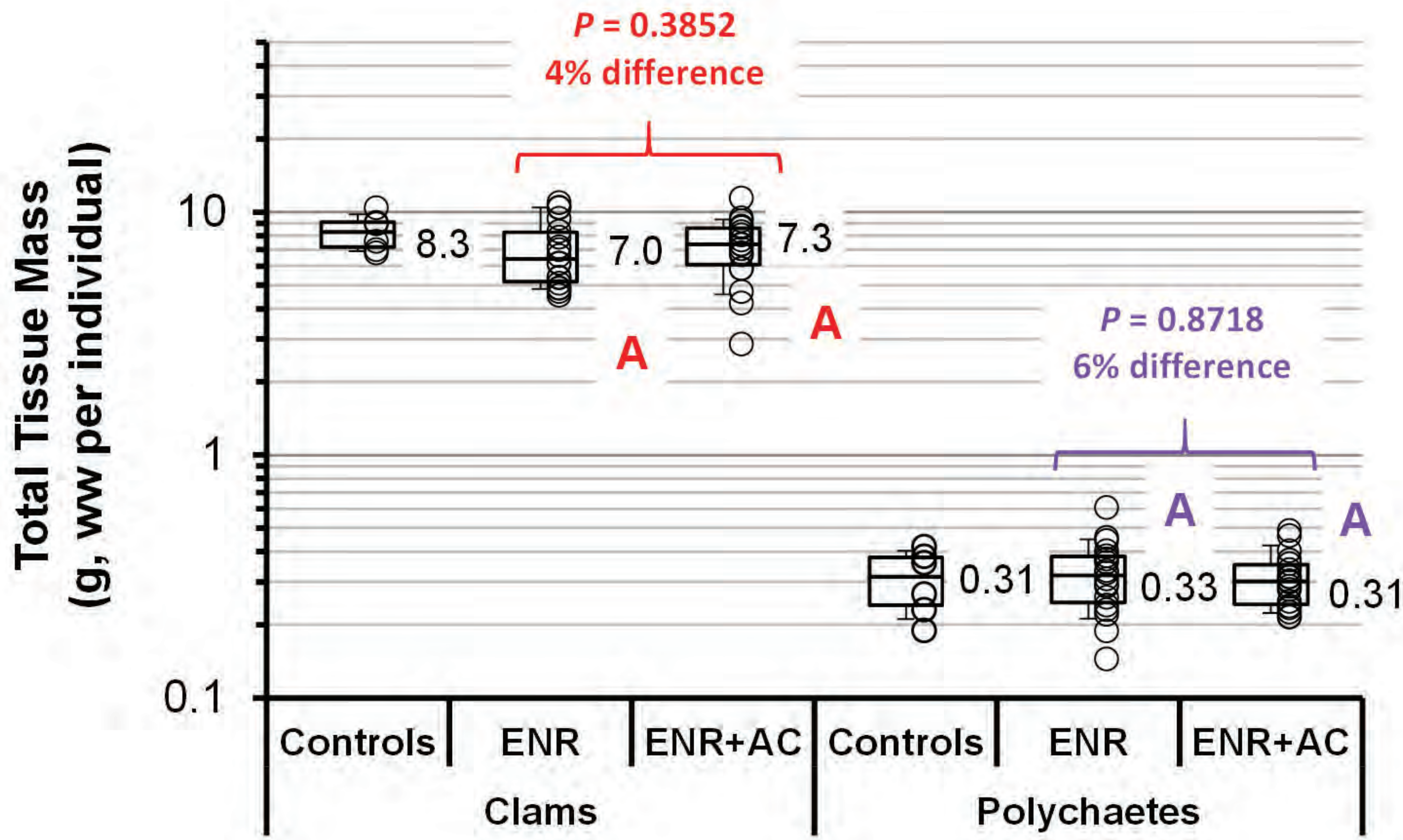
<u>Notes:</u>
ENR and ENR+AC results for each organism are compared statistically (t test) such that if results are labeled with the same colored letter, the results are not statistically .

<u>Abbreviations:</u>
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.5-1
Survival of Clams and Polychaetes Exposed to Control Sediment, Subtidal ENR, and Subtidal ENR+AC in the Laboratory Bioaccumulation Study



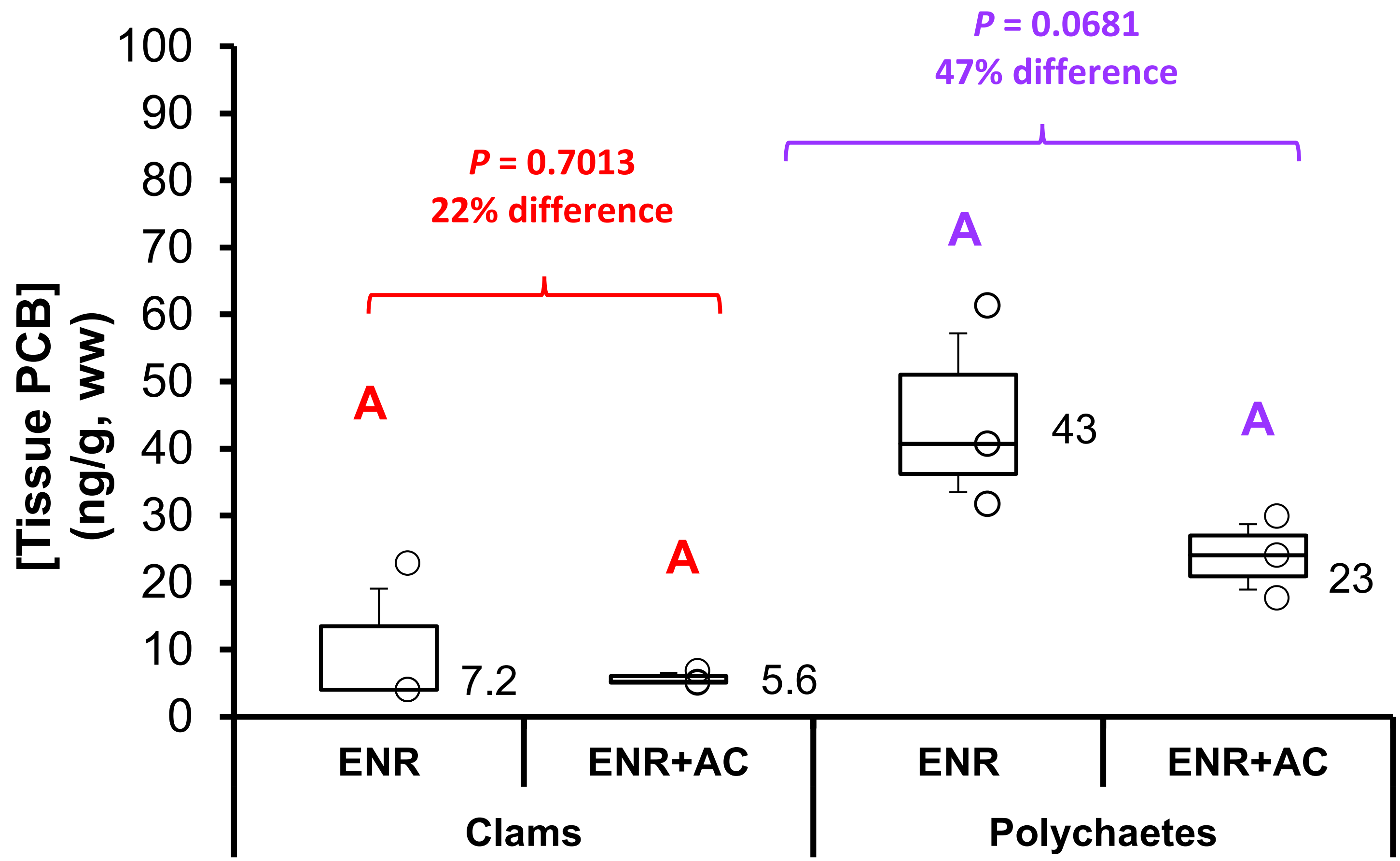
Notes:

ENR and ENR+AC results for each organism are compared statistically (t test) such that if results are labeled with the same colored letter, the results are not statistically different. Results are final tissue mass or organisms at the termination of the study".

Abbreviations:

ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
g. ww = gram(s) wet weight

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.5-2 Growth (final tissue masses) of Clams and Polychaetes Exposed to Control Sediment, Subtidal ENR, and Subtidal ENR+AC in the Laboratory Bioaccumulation Study



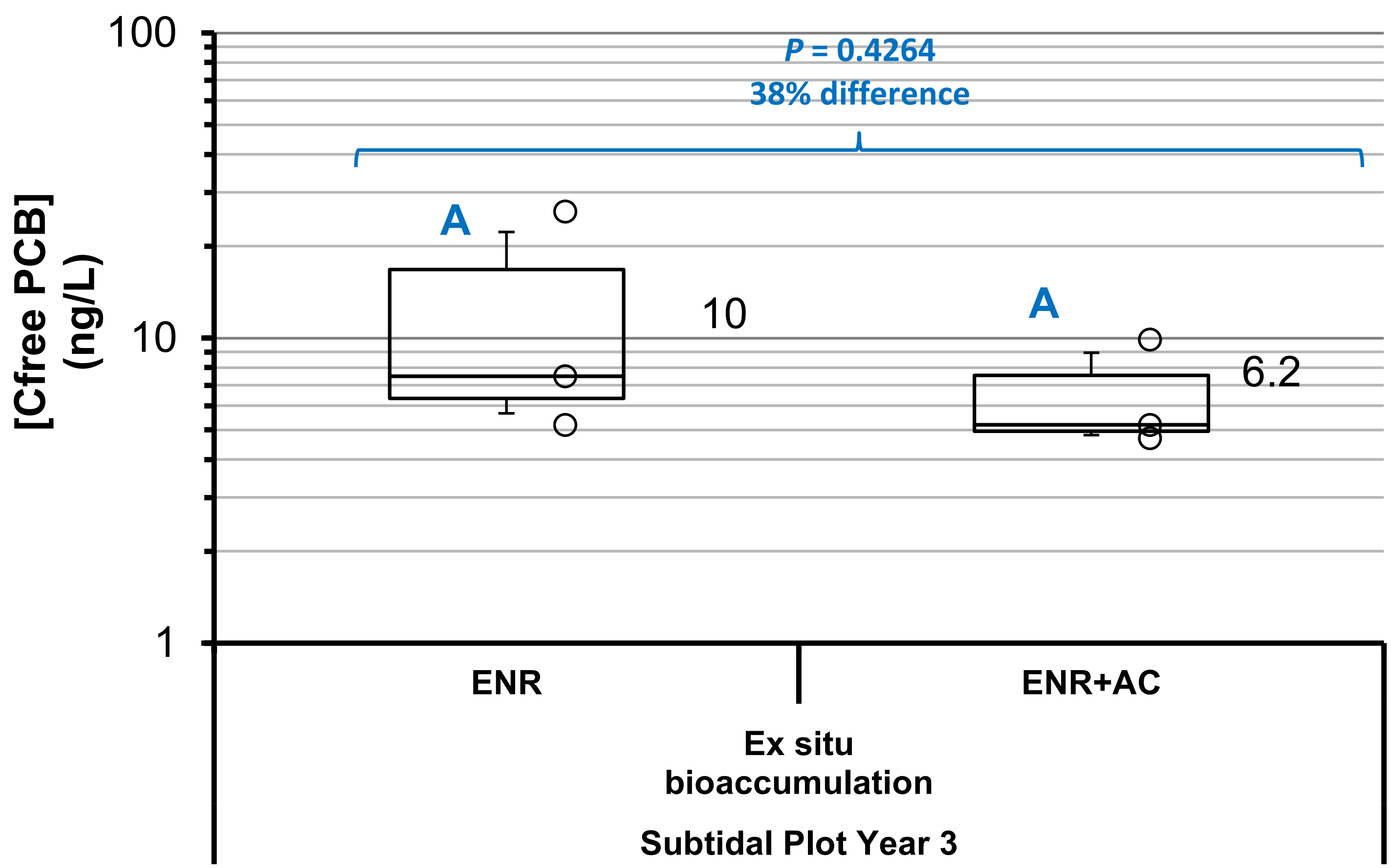
Notes:
ENR and ENR+AC results for each organism are compared statistically (t test) such that if results are labeled with the same colored letter, the results are not statistically different.

Abbreviations:
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
ng/g. ww = nanogram(s) per gram wet weight
PCB = polychlorinated biphenyl

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.5-3
Concentrations of Total PCBs in Clams and Polychaetes Exposed to Subtidal ENR and Subtidal ENR+AC in the Laboratory Bioaccumulation Study



Notes:

ENR and ENR+AC results are compared statistically (t test) such that if results are labeled with the same letter, the results are not statistically different.

Abbreviations:

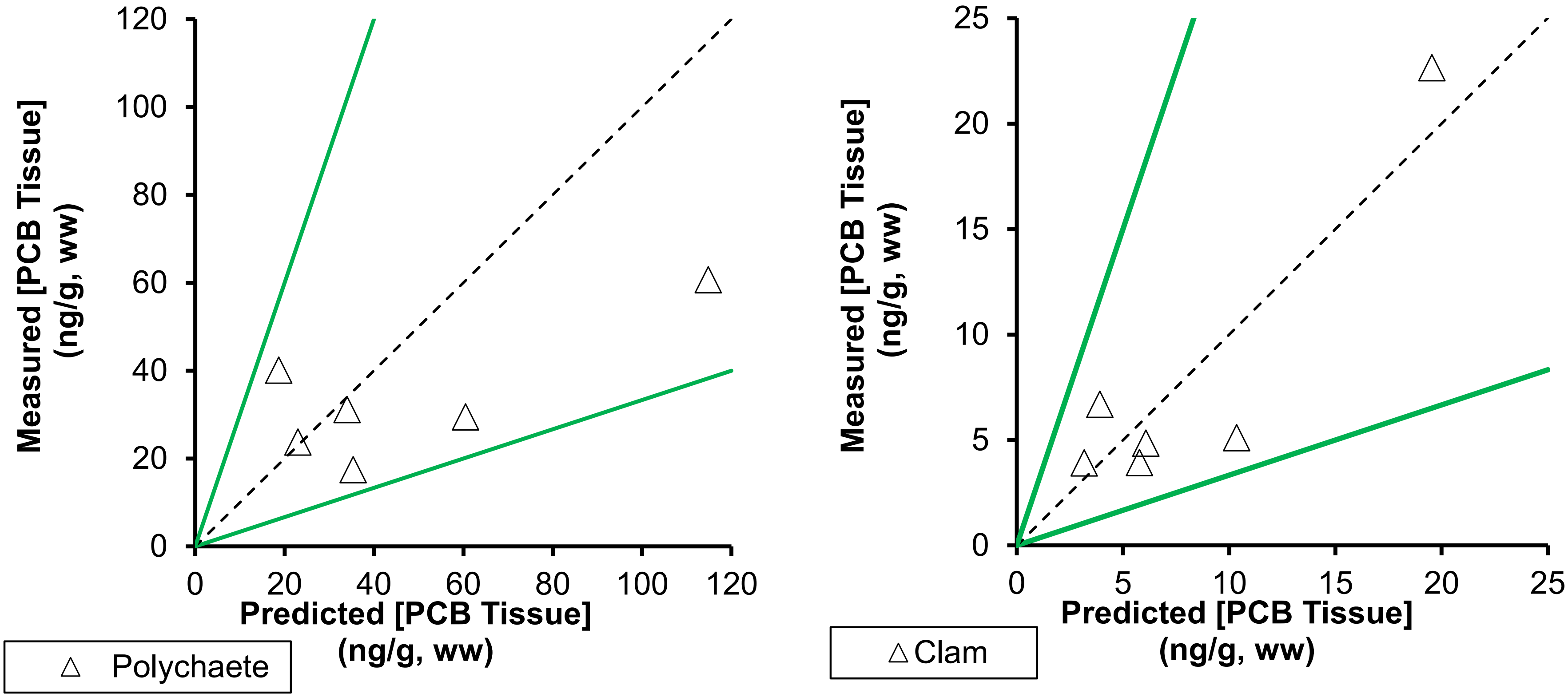
C_{free} = freely dissolved concentrations
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
ng/L = nanogram(s) per liter
PCB = polychlorinated biphenyl

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.5-4
Total C_{free} PCBs in Subtidal ENR and Subtidal ENR+AC Cores in the Laboratory Bioaccumulation Study

3/17/2021



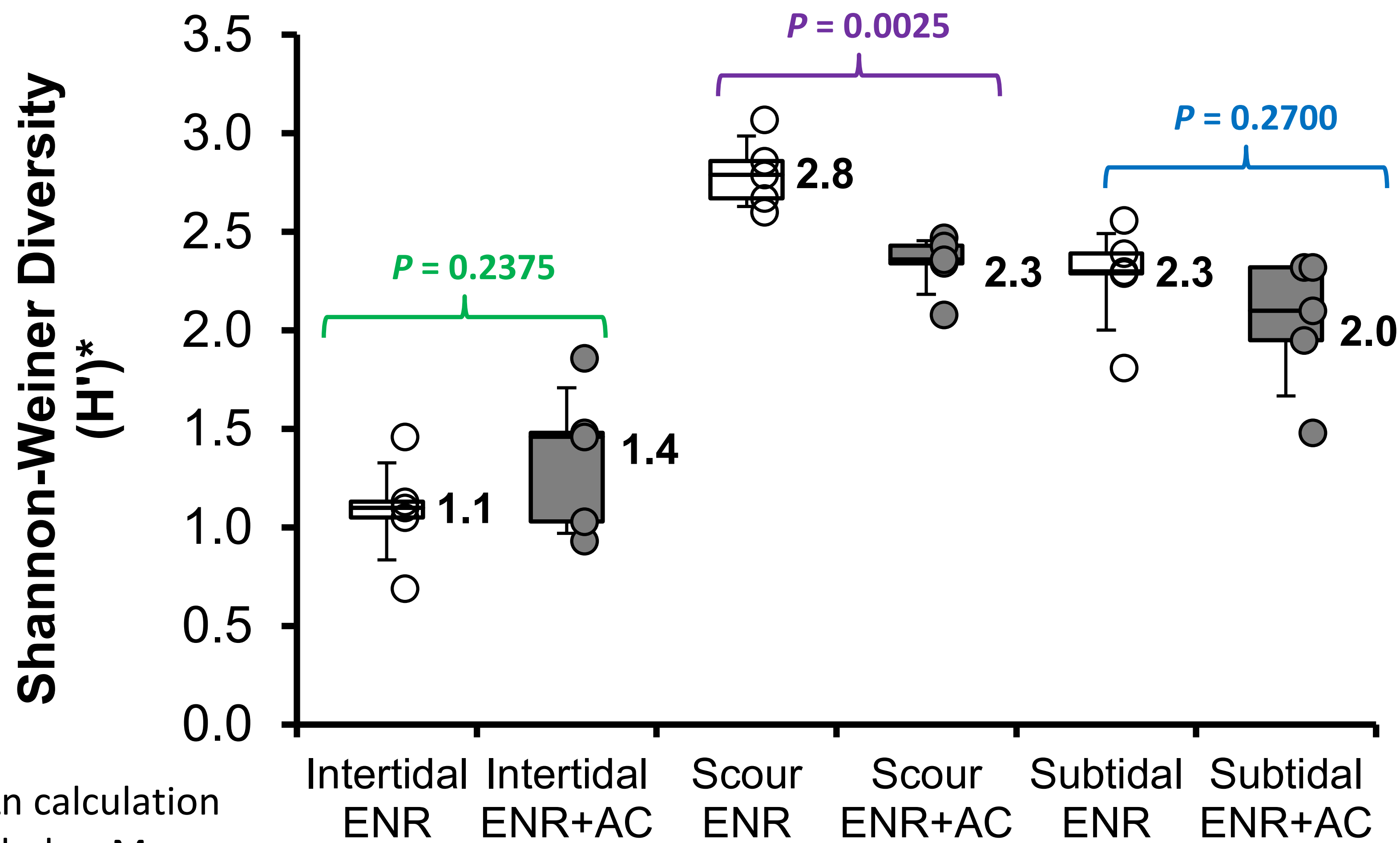
Notes:
Symbols in between the green lines indicate predictions that are within a factor of 3 of measured values; the dashed black line is the 1:1 line.

Abbreviations:
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon
ng/g. ww = nanogram(s) per gram wet weight
PCB = polychlorinated biphenyl

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.5-5
Predicted vs. Measured Concentrations of Total PCBs in Polychaetes and Clams for Six Composite Laboratory Bioaccumulation Study Subtidal Plot Samples



*Ln calculation

Labels = Means

Notes:

Diversity was calculated using the standard natural logarithm (Ln) method (see Appendix D). ENR and ENR+AC results for each plot are compared statistically (t test), with the p-value indicated above each pair.

Abbreviations:

ENR = Enhanced natural recovery

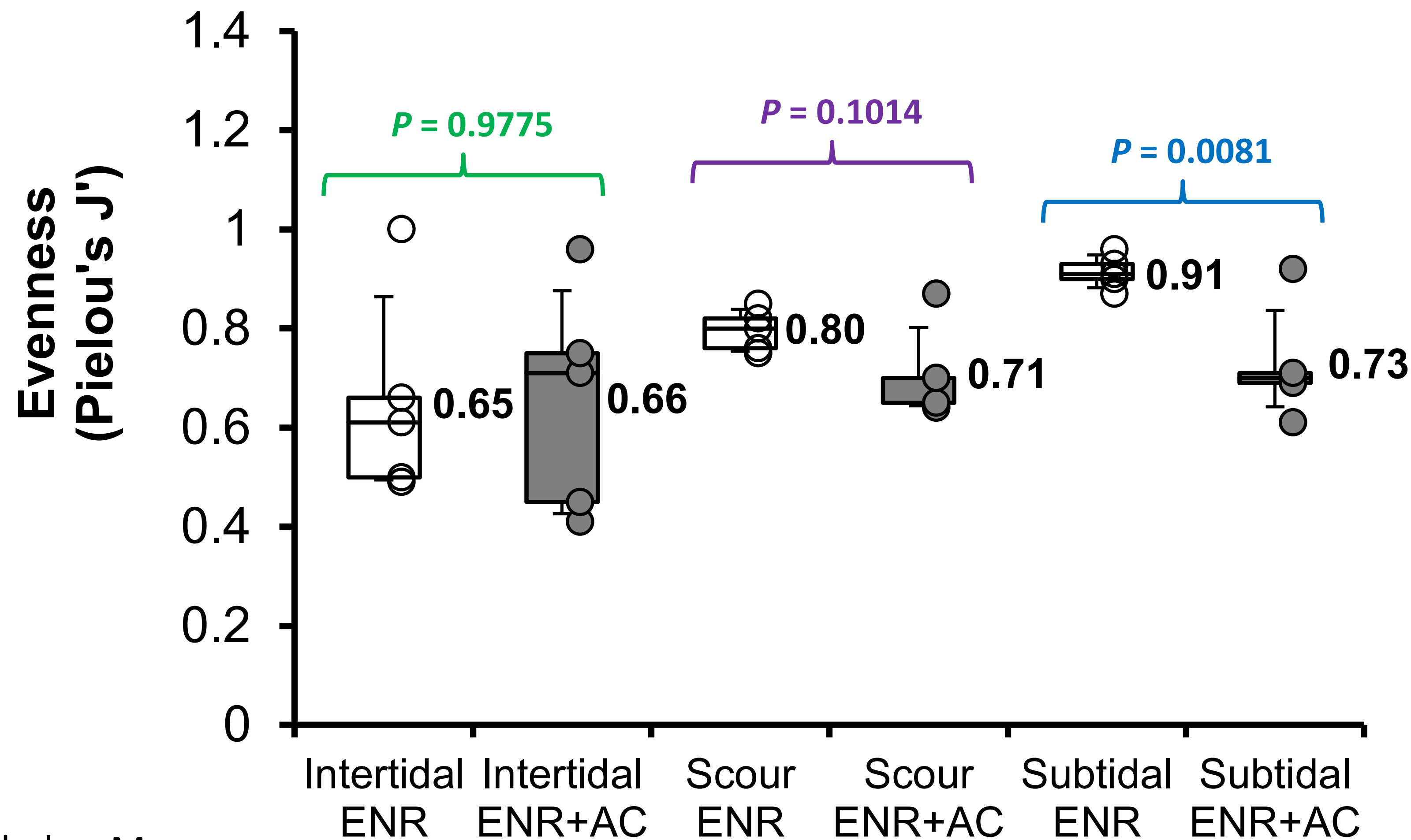
ENR+AC = Enhanced natural recovery amended with activated carbon

Lower Duwamish Waterway Group

Port of Seattle / City of Seattle / King County / The Boeing Company

ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.5-6
Comparison of Shannon-Weiner Diversity Index between ENR and ENR+AC Subplots



Labels = Means

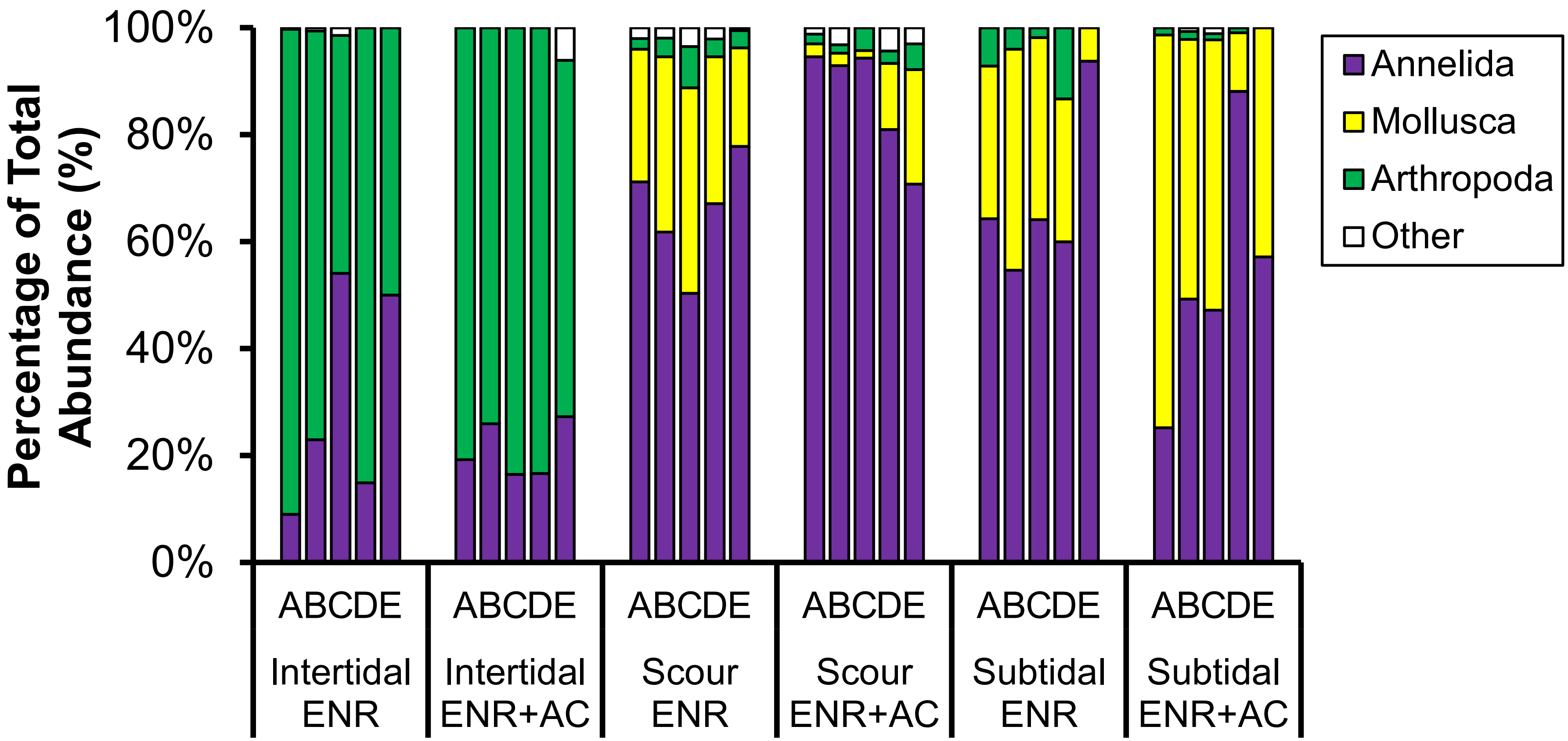
Notes:
ENR and ENR+AC results for each plot are compared statistically (t test), with the p-value indicated above each pair.

Abbreviations:
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

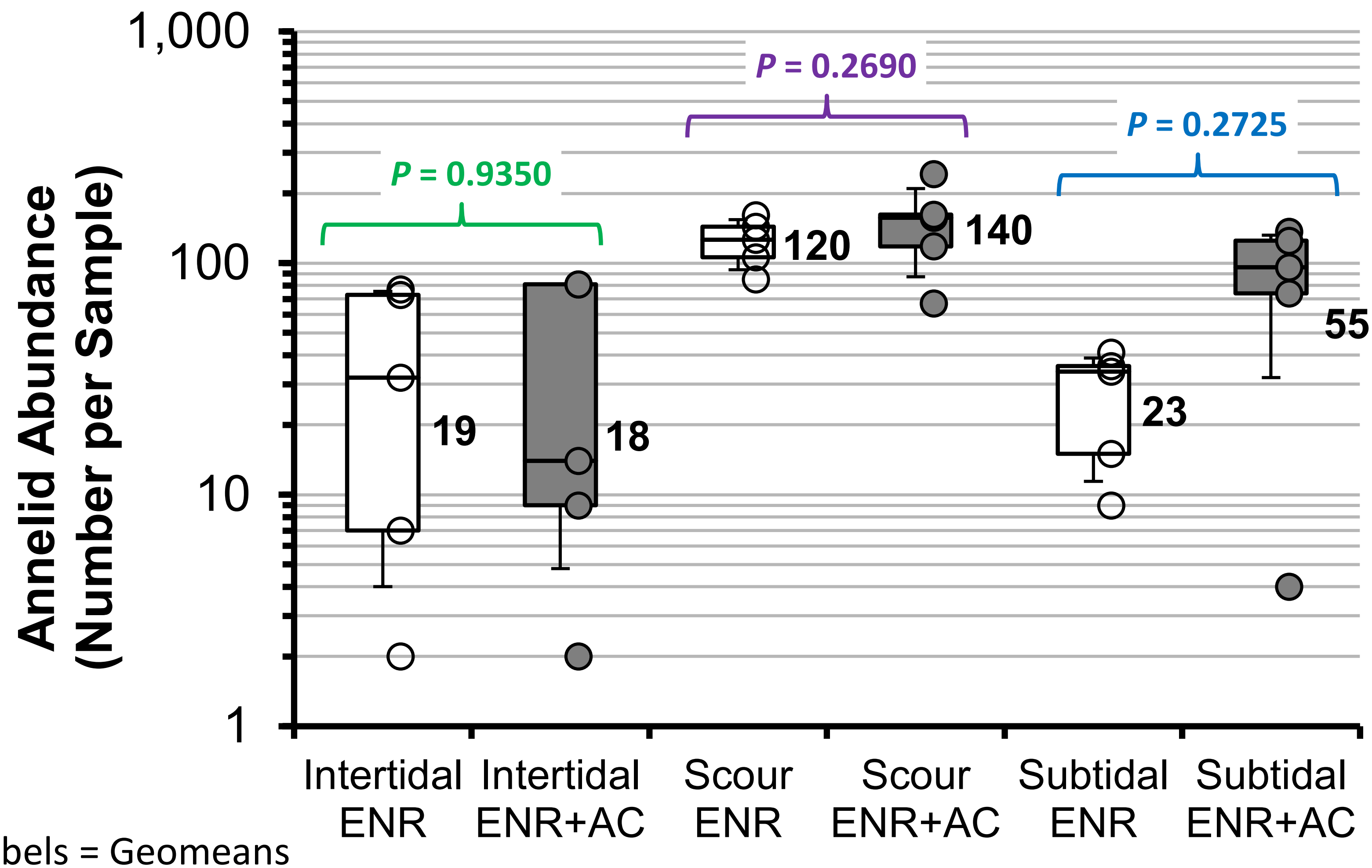
ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.5-7
Comparison of Pielou's Evenness Index Between ENR and ENR+AC Subplots



Abbreviations:
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

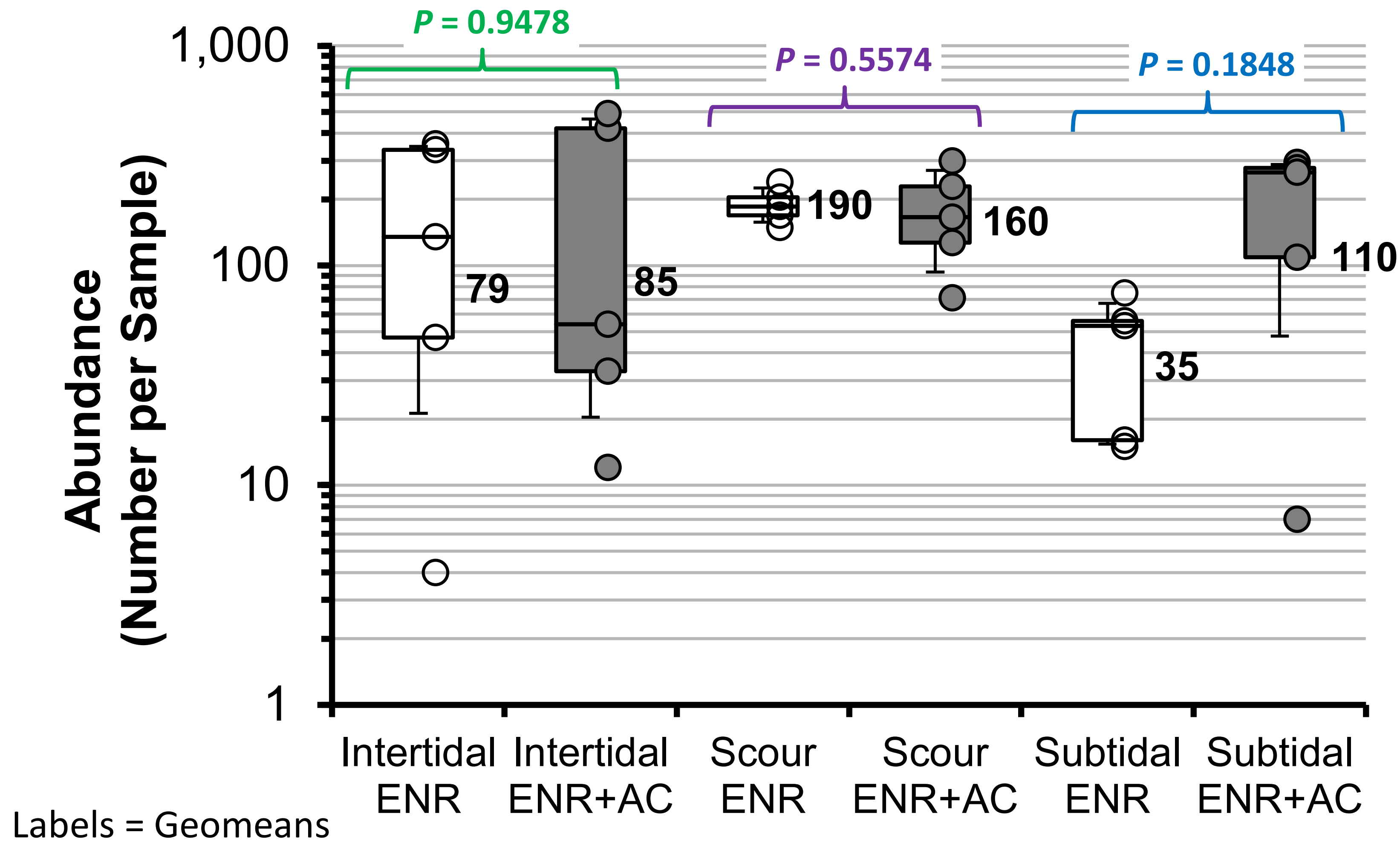
Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.5-8 Distribution of Abundance Among the Major Taxa Groups between ENR and ENR+AC Subplots



Notes:
ENR and ENR+AC results for each plot are compared statistically (t test), with the p-value indicated above each pair.

Abbreviations:
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

Lower Duwamish Waterway Group Port of Seattle / City of Seattle / King County / The Boeing Company	**ENR/AC Pilot Study** **Year 3 Monitoring Report** **Lower Duwamish Waterway**	Figure 3.5-9 Comparison of Annelid Abundance Between ENR and ENR+AC Subplots



Notes:
ENR and ENR+AC results for each plot are compared statistically (t test), with the p-value indicated above each pair.

Abbreviations:
ENR = Enhanced natural recovery
ENR+AC = Enhanced natural recovery amended with activated carbon

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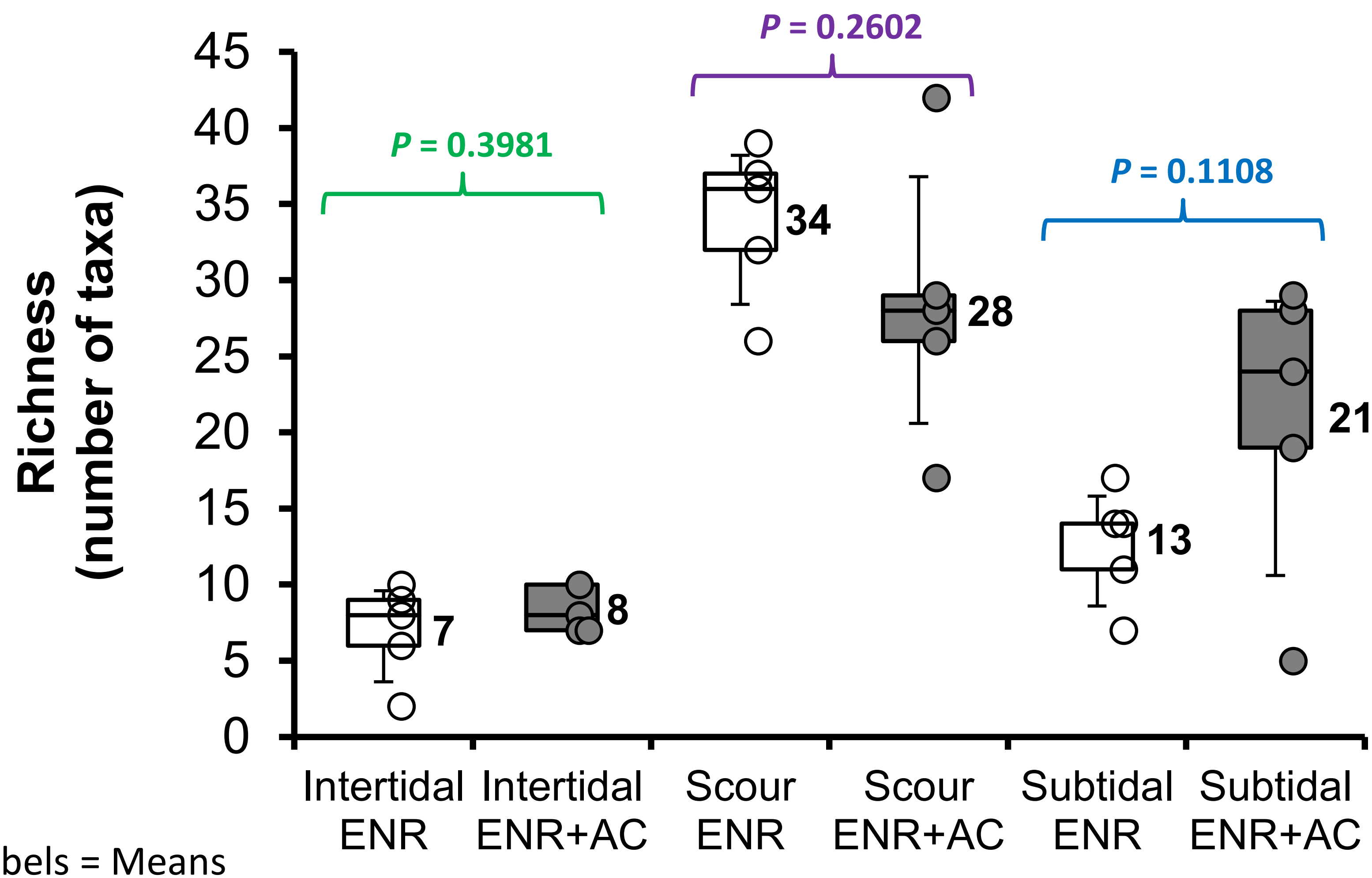
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.5-10
Comparison of Abundance Between ENR and ENR+AC Subplots



Notes:
ENR and ENR+AC results for each plot are compared statistically (t test), with the p-value indicated above each pair.

Abbreviations:
ENR = Enhanced natural recovery
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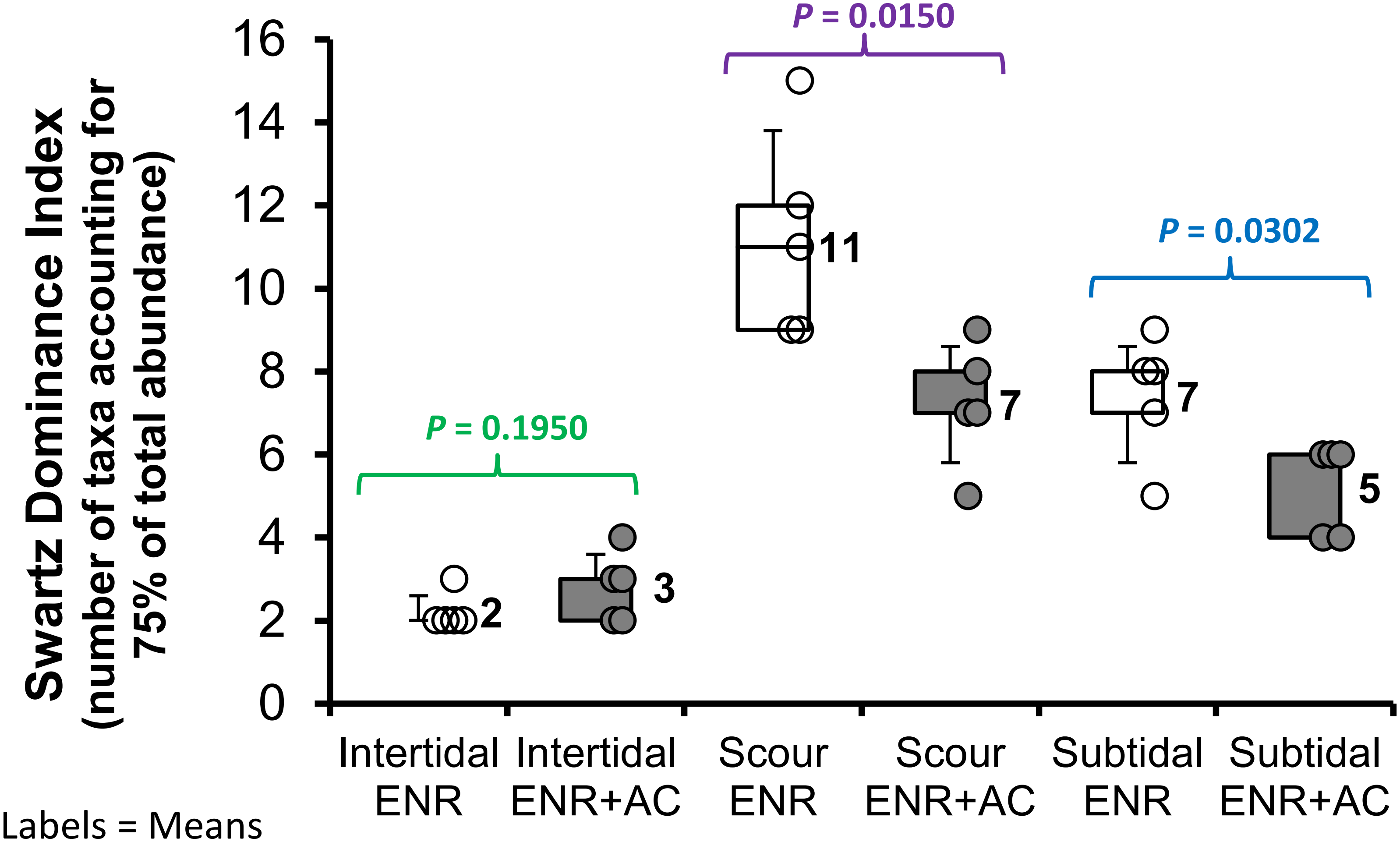
ENR/AC Pilot Study
Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.5-11
Comparison of Taxa Richness Between ENR and ENR+AC Subplots



Notes:
ENR and ENR+AC results for each plot are compared statistically (t test), with the p-value indicated above each pair.

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Year 3 Monitoring Report
Lower Duwamish Waterway

Figure 3.5-12
Comparison of Swartz Dominance Index Between ENR and ENR+AC Subplots