Assessing the performance of an activated carbon sediment amendment to remediate contamination at a site located in Sinclair Inlet, Puget Sound, WA*

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*2016 Salish Sea Ecosystems Conference, April 13-15, 2016, Vancouver, BC, Canada
#Presenter

Outline of Talk

Introduction

Site Description and Amendment Placement

SEA Ring In situ Bioassay Assessment

Results

- Total Organic Carbon/Black Carbon
- Bioaccumlation in Worms and Clams
- Pore Water Concentrations
- Benthic Community Response

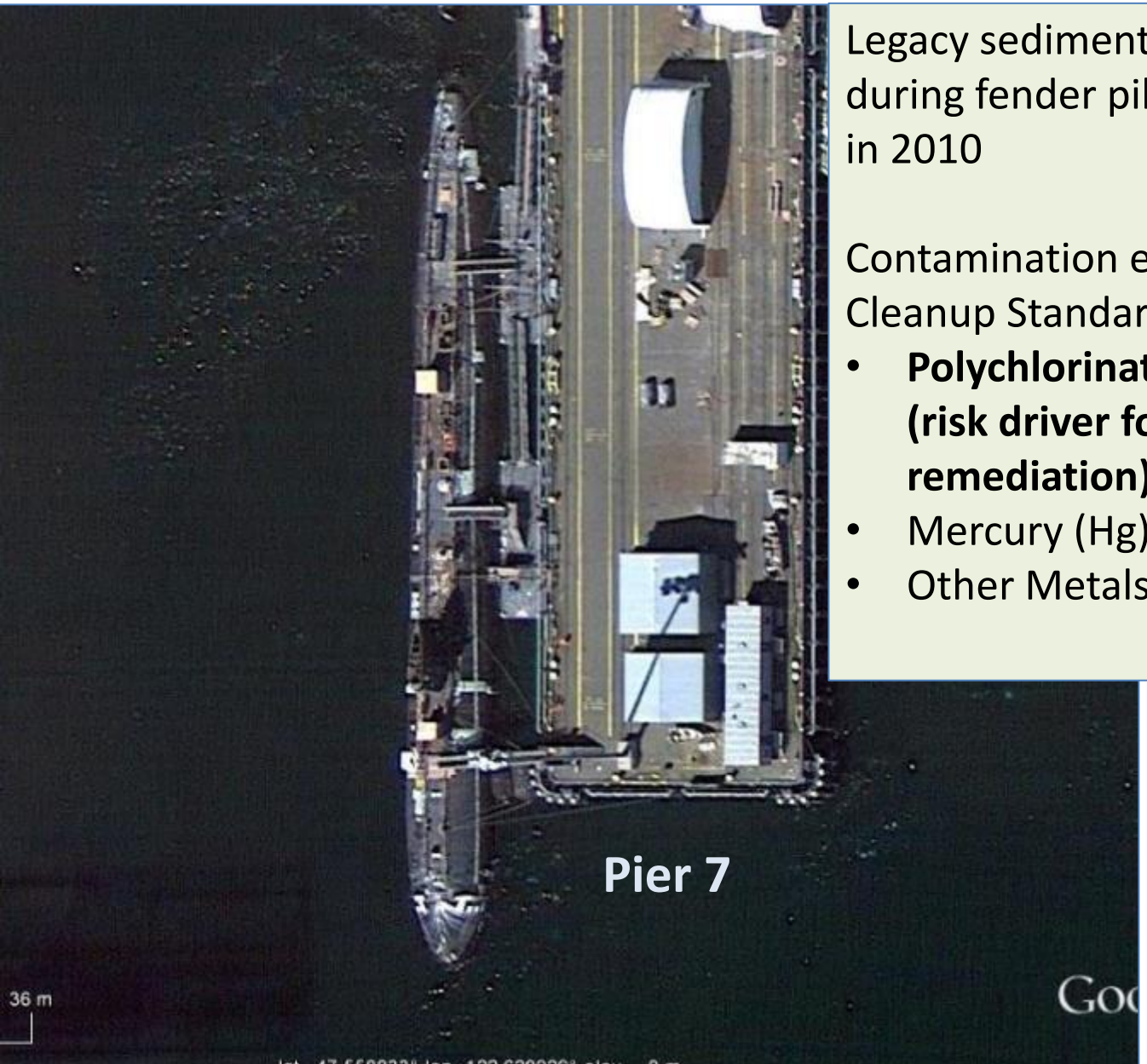
Summary


ABERDEEN


You Are Here
Pacific Ocean
Sinclair Inlet

Naval Base Kitsap Bremerton, Puget Sound Naval Shipyard & IMF (Bremerton Naval Complex)

Pier 7 Site Location



Legacy sediment contamination found during fender pile replacement project in 2010

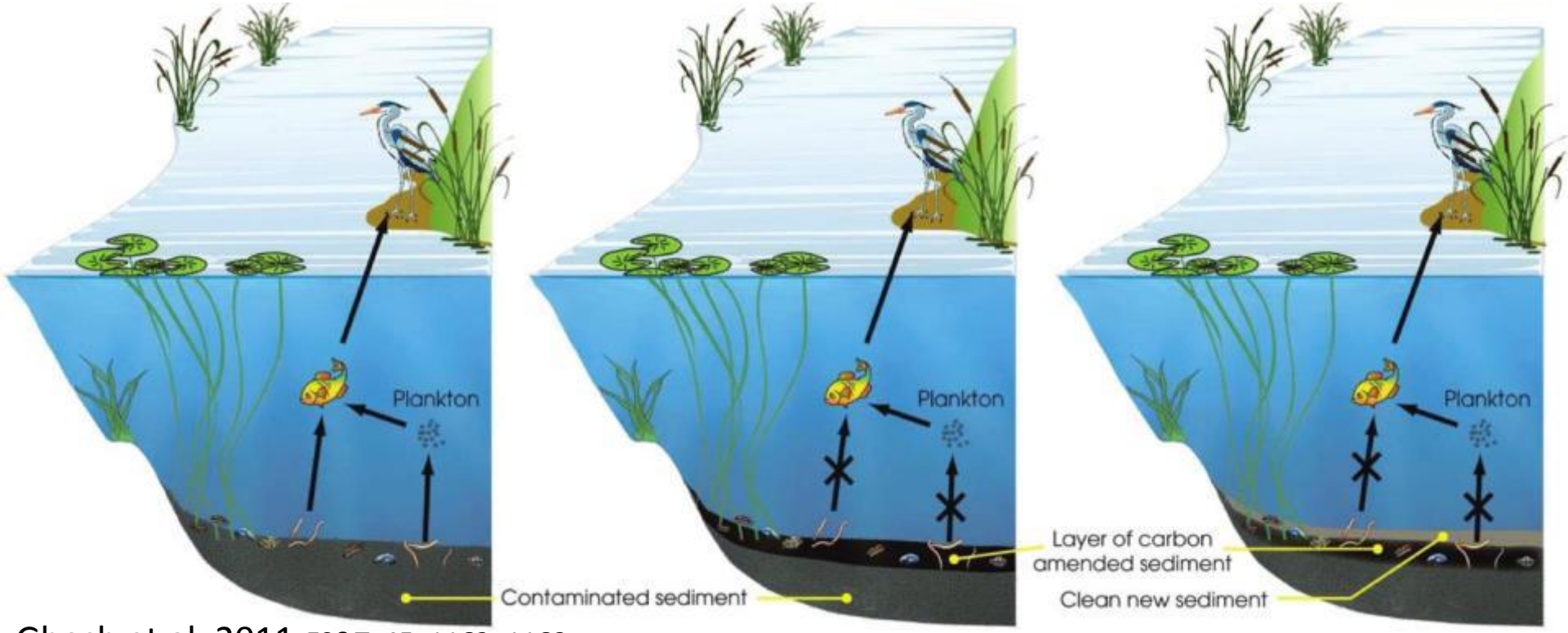
Contamination elevated above State Cleanup Standards for:

- **Polychlorinated Biphenyls (PCBs) (risk driver for sediment remediation)**
- Mercury (Hg)
- Other Metals (Copper, Zinc)

Why Amend with Activated Carbon?

- Less obtrusive than dredging/capping
- Focused on reducing bioavailability and mobility
- Shorten ecosystem recovery time
- Expand site management options for active harbors
- Less costly and more expedient

Need Large Scale Demonstrations to Gain Acceptance



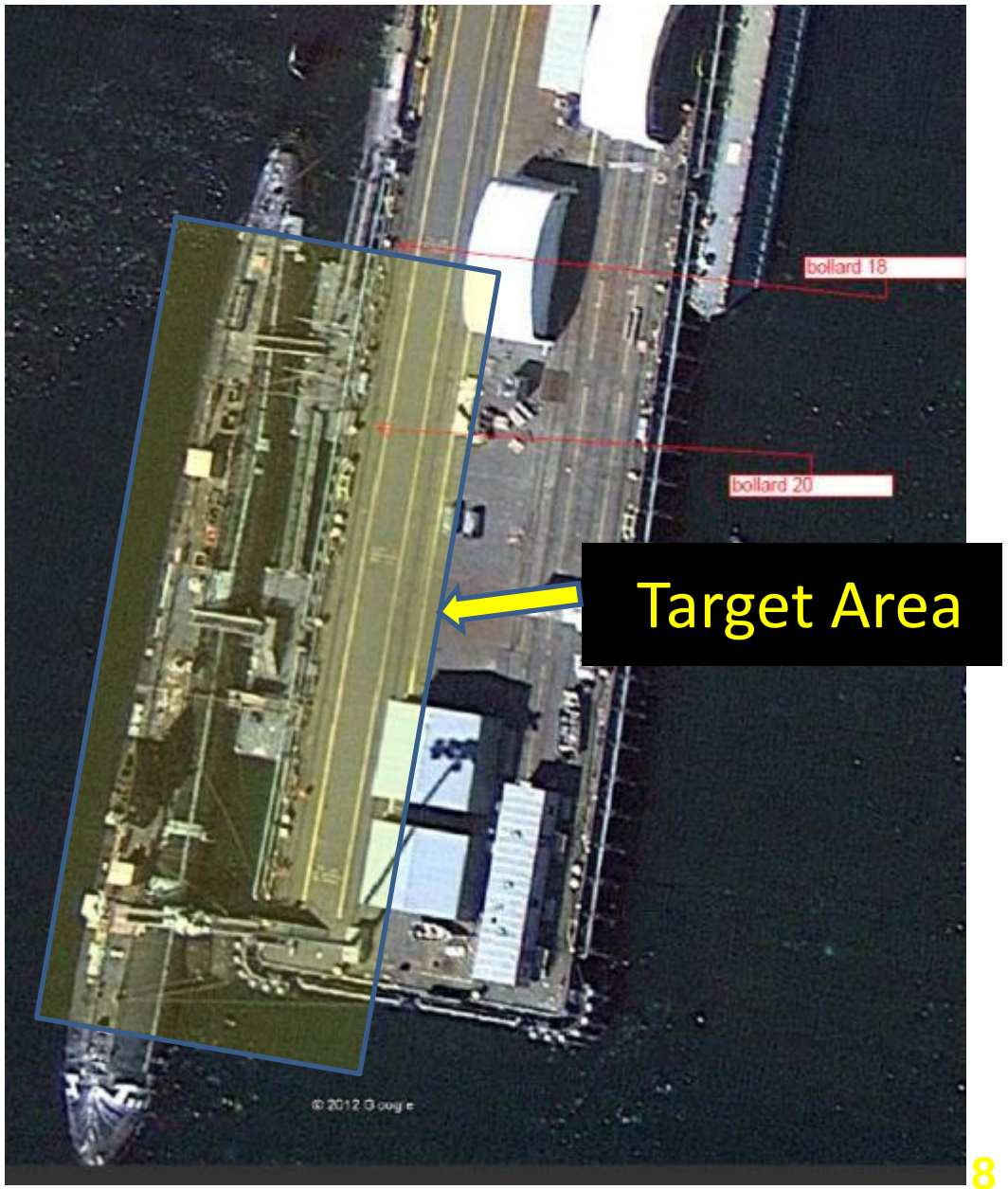
Ghosh et al. 2011 *ES&T 45, 1163–1168*

Pier 7 Amended Cap Demonstration Project

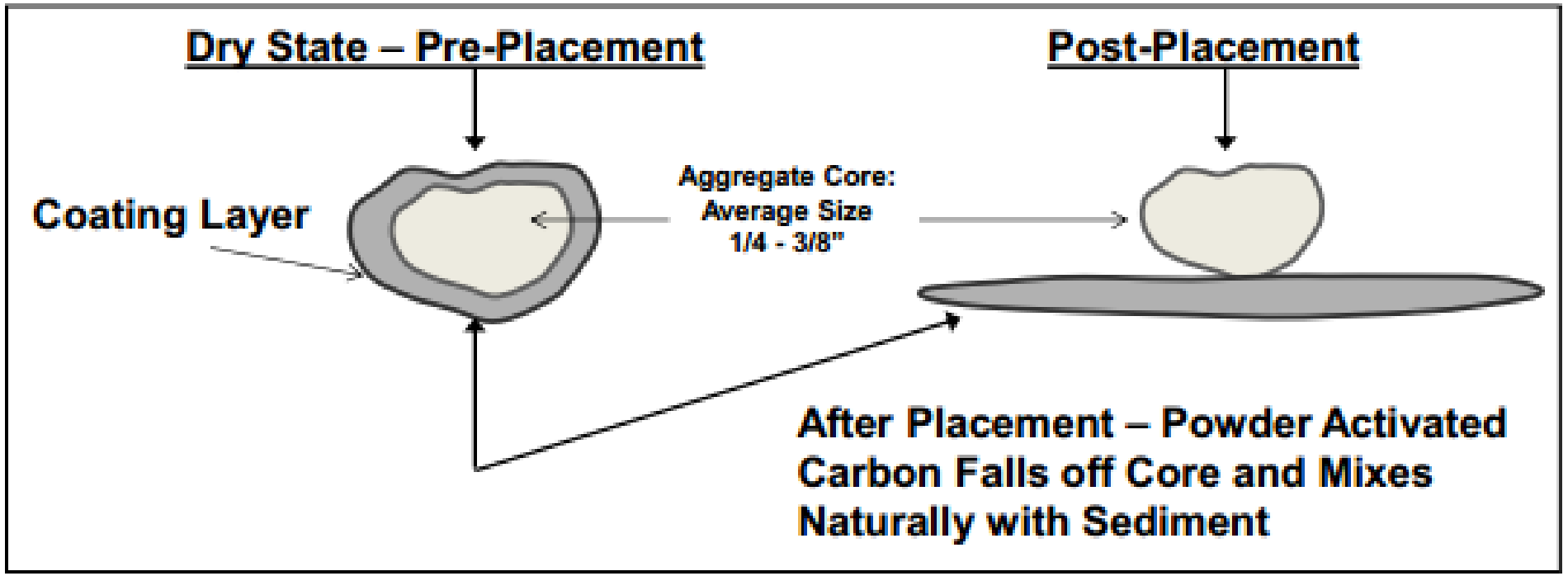
Schedule

- 2011 Laboratory Evaluation Study Results Support **GO**
- 2012:
  - Aug 1-17 Pre-Placement Monitoring (**Baseline**)
  - Oct 15-19 Placement
  - Oct 30-31 Placement Verification (**T=0.5 month**)
- 2013
  - Jan (**T=3 month**) Monitoring
  - Aug (**T=10 month**) Monitoring
- 2014
  - July (**T=21 month**) Monitoring
- 2015
  - July (**T=33 month**) Monitoring

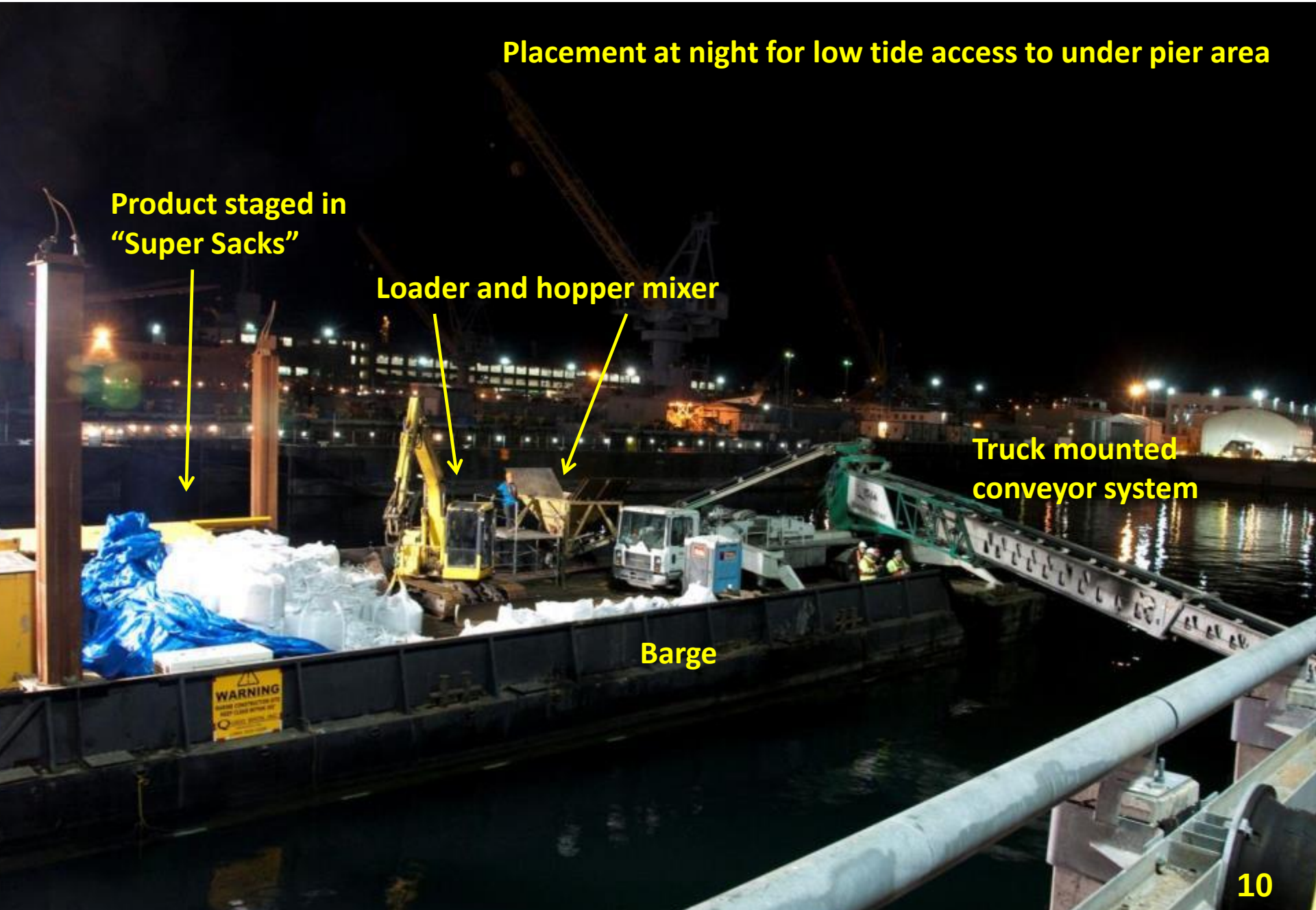
Pilot project under "Superfund" as part of the Record of Decision for site clean up



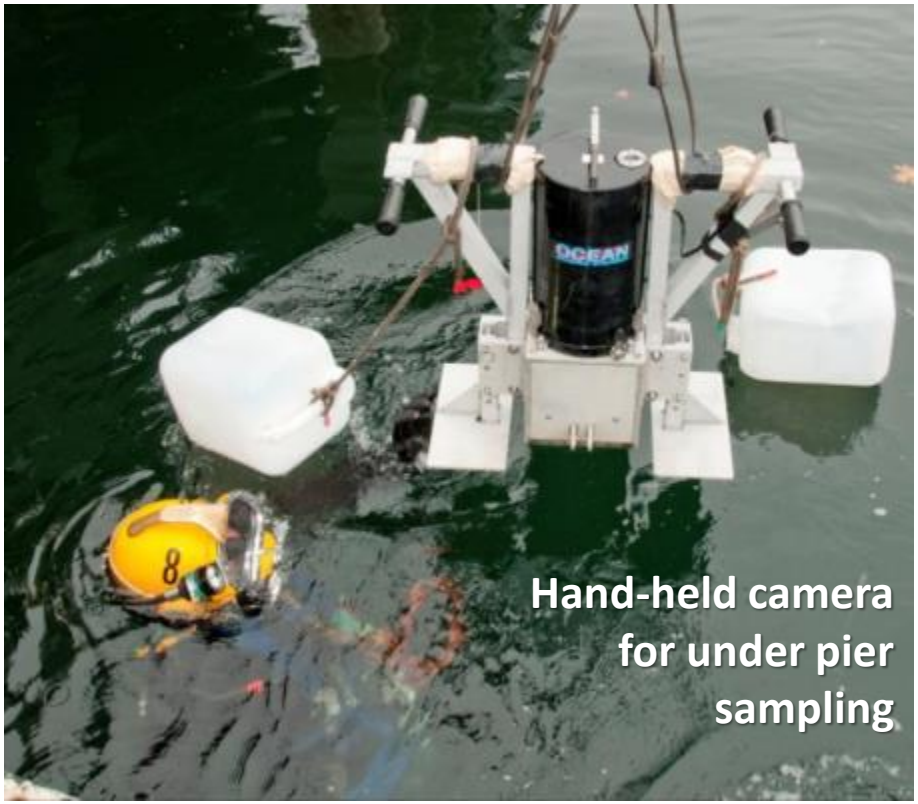
AquaGate+PAC™ Composite Aggregate



Product Staging and Placement

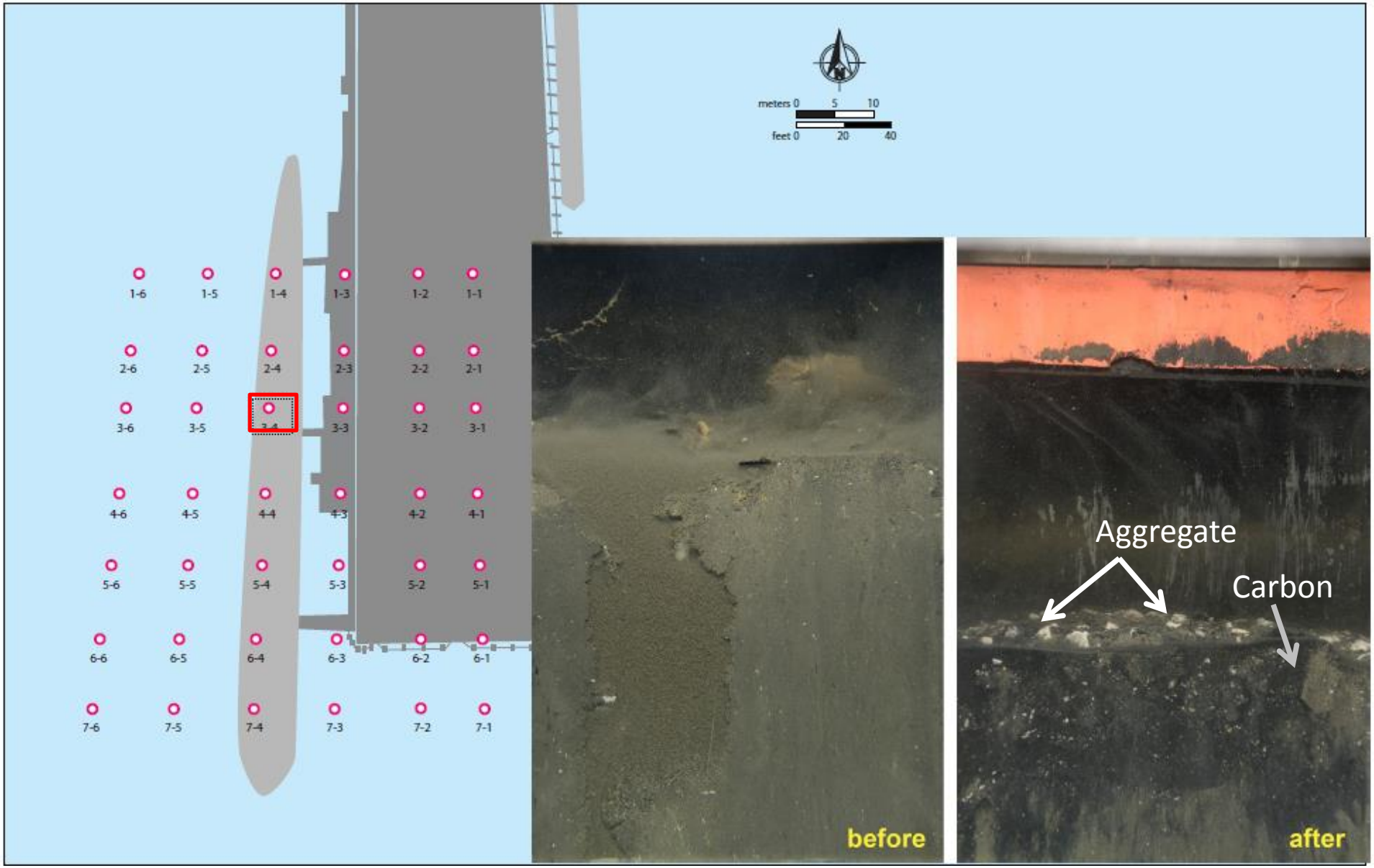


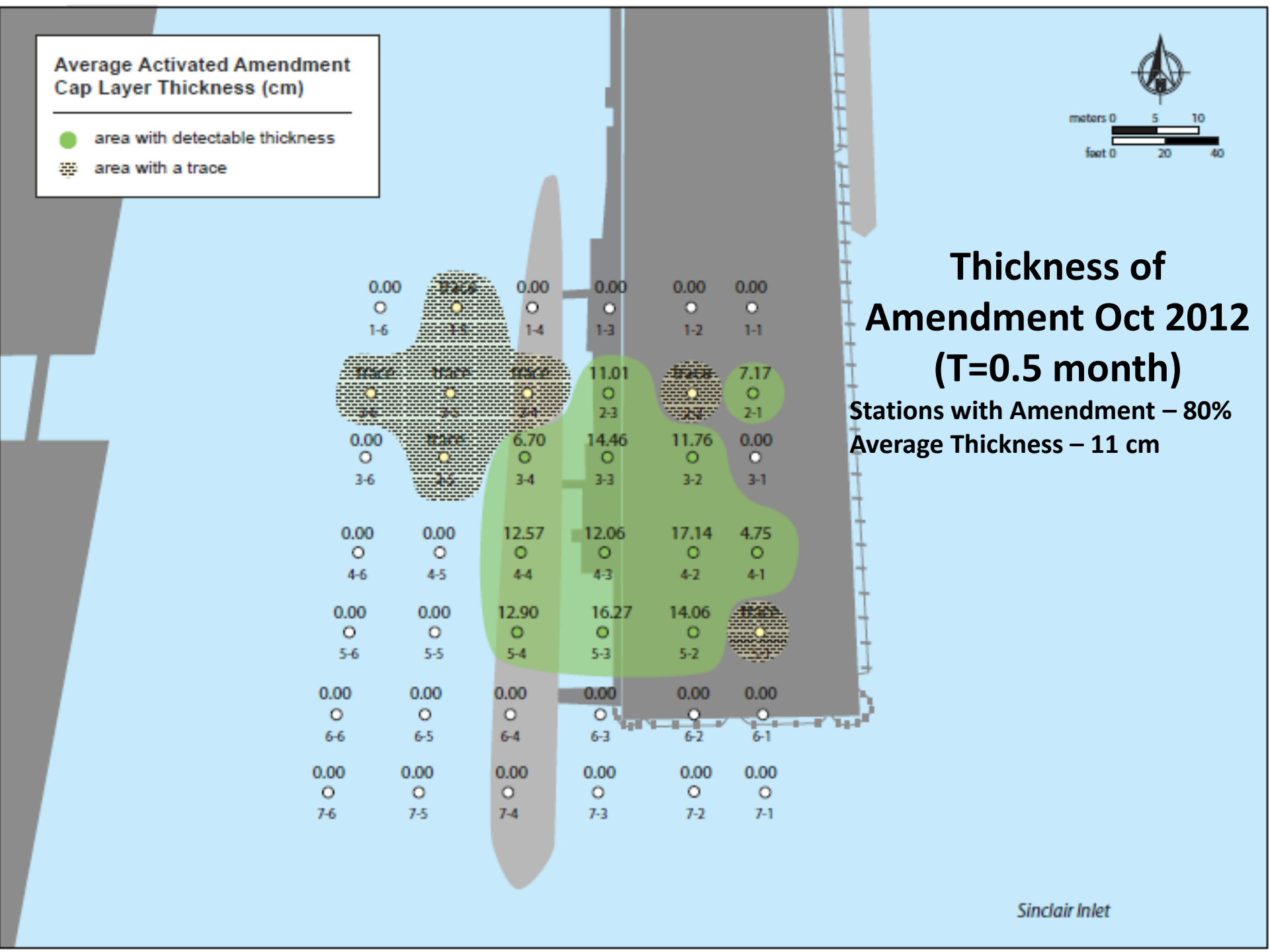
Sediment Profile Imaging (SPI) Camera

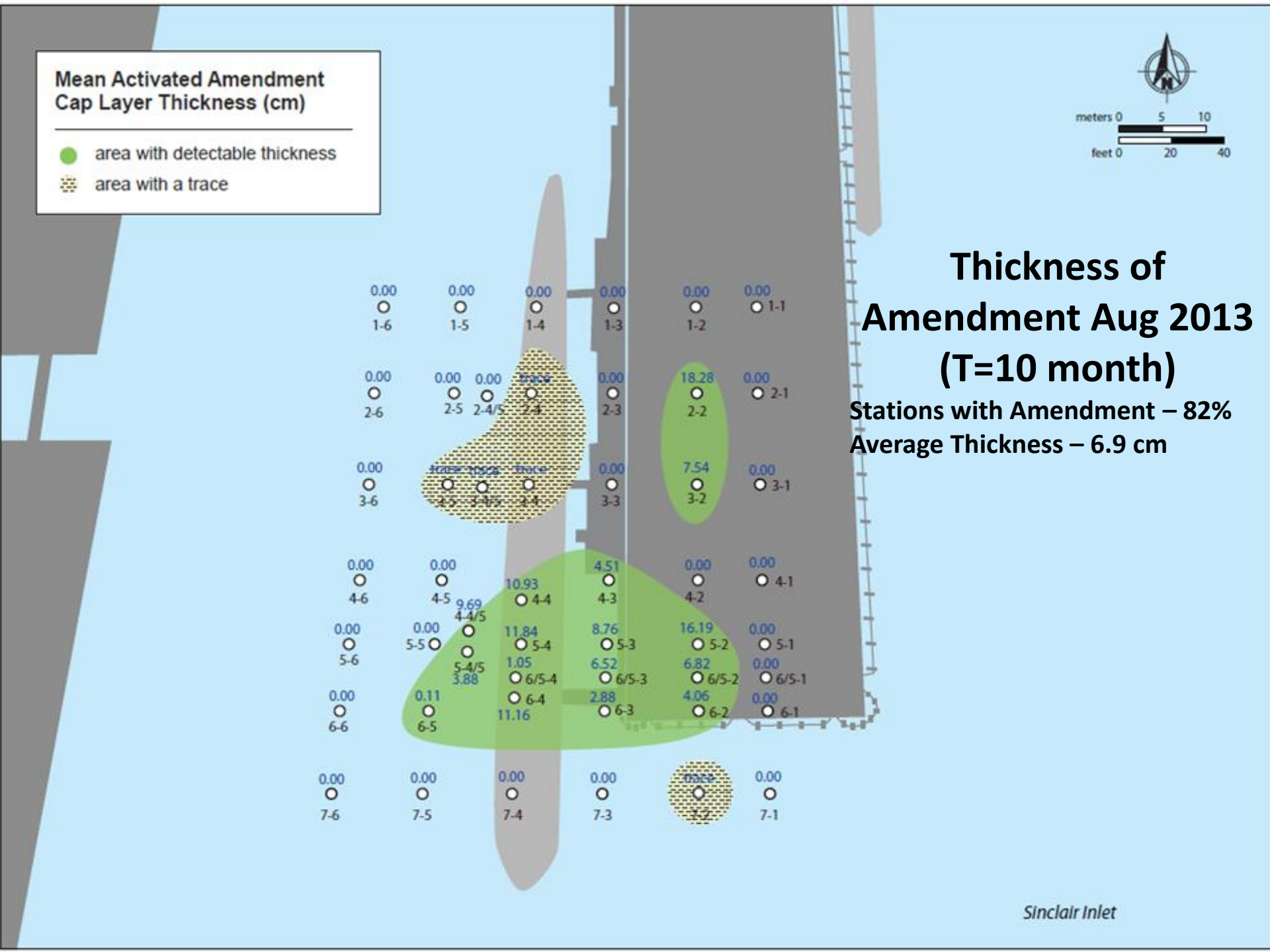


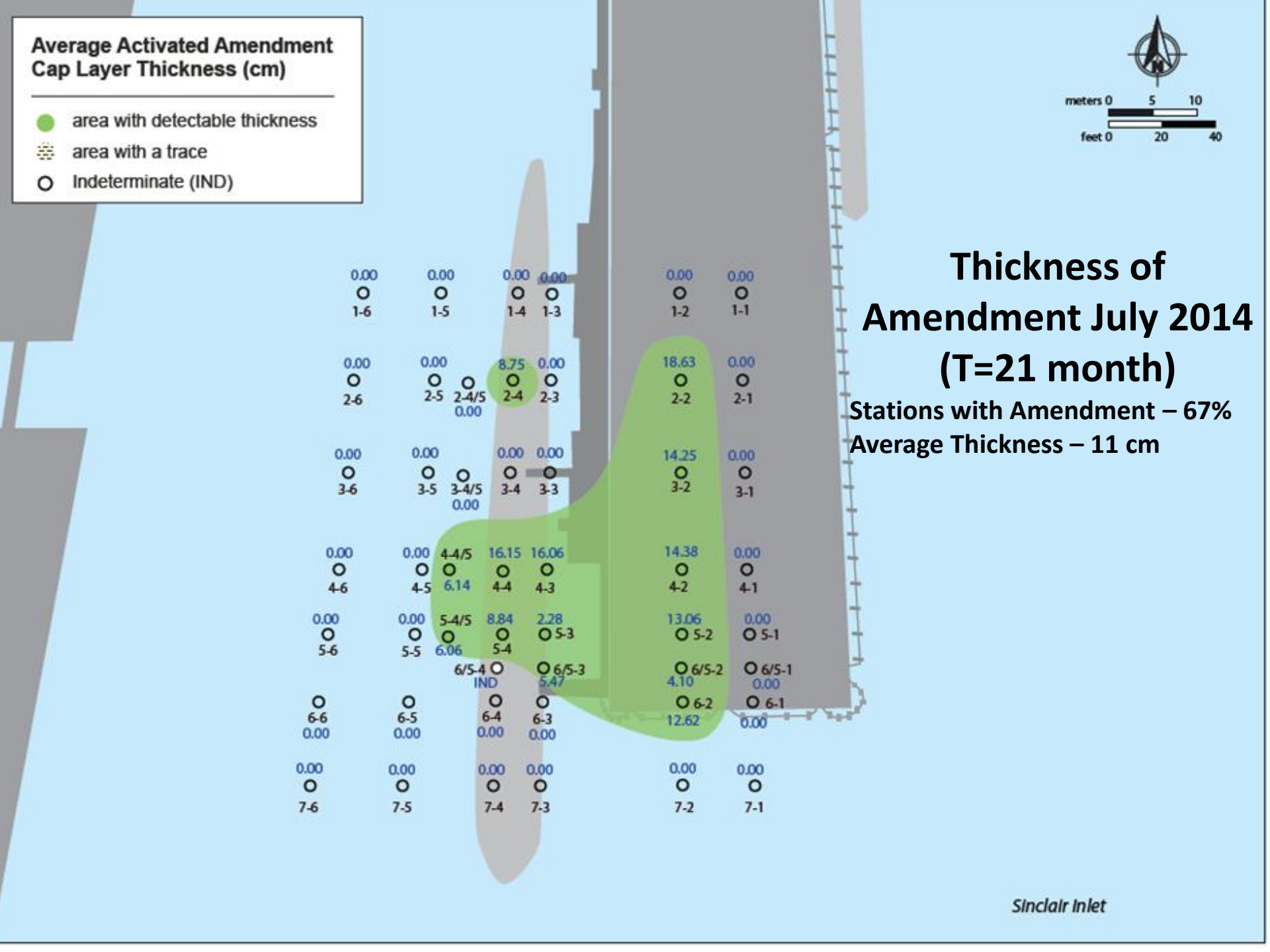
Sediment Profile Images

Sediment Profile from SPI camera




Average Activated Amendment Cap Layer Thickness (cm)
area with detectable thickness
area with a trace
meters 0 5 10
feet 0 20 40
0.00 1-6
trace 1-5
0.00 1-4
0.00 1-3
0.00 1-2
0.00 1-1
trace 2-6
trace 2-5
trace 2-4
11.01 2-3
trace 2-2
7.17 2-1
0.00 3-6
trace 3-5
6.70 3-4
14.46 3-3
11.76 3-2
0.00 3-1
0.00 4-6
0.00 4-5
12.57 4-4
12.06 4-3
17.14 4-2
4.75 4-1
0.00 5-6
0.00 5-5
12.90 5-4
16.27 5-3
14.06 5-2
trace 5-1
0.00 6-6
0.00 6-5
0.00 6-4
0.00 6-3
0.00 6-2
0.00 6-1
0.00 7-6
0.00 7-5
0.00 7-4
0.00 7-3
0.00 7-2
0.00 7-1
Thickness of Amendment Oct 2012 (T=0.5 month)
Stations with Amendment – 80%
Average Thickness – 11 cm
Sinclair Inlet

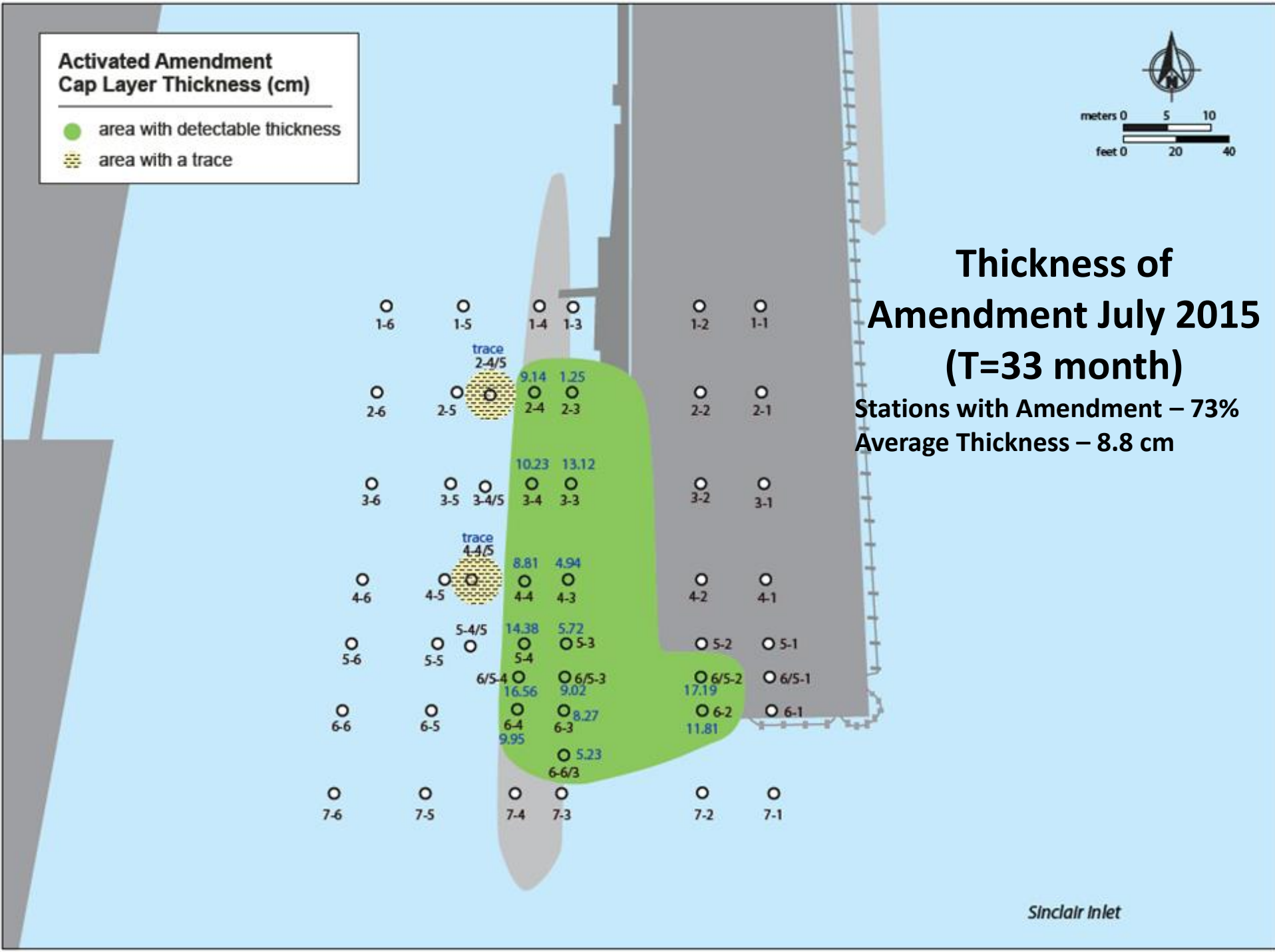

Mean Activated Amendment Cap Layer Thickness (cm)
area with detectable thickness
area with a trace
meters 0 5 10
feet 0 20 40
0.00 1-6
0.00 1-5
0.00 1-4
0.00 1-3
0.00 1-2
0.00 1-1
0.00 2-6
0.00 2-5
0.00 2-4/5
trace 2-4
0.00 2-3
18.28 2-2
0.00 2-1
0.00 3-6
trace 3-5
trace 3-4/5
trace 3-4
0.00 3-3
7.54 3-2
0.00 3-1
0.00 4-6
0.00 4-5
9.69 4-4/5
10.93 4-4
4.51 4-3
0.00 4-2
0.00 4-1
0.00 5-6
0.00 5-5
5-4/5 3.88
11.84 5-4
8.76 5-3
16.19 5-2
0.00 5-1
1.05 6/5-4
6.52 6/5-3
6.82 6/5-2
0.00 6/5-1
0.00 6-6
0.11 6-5
6-4 11.16
2.88 6-3
4.06 6-2
0.00 6-1
0.00 7-6
0.00 7-5
0.00 7-4
0.00 7-3
trace 7-2
0.00 7-1
Thickness of Amendment Aug 2013 (T=10 month)
Stations with Amendment – 82%
Average Thickness – 6.9 cm
Sinclair Inlet



Thickness of Amendment July 2014 (T=21 month)

Stations with Amendment – 67%

Average Thickness – 11 cm



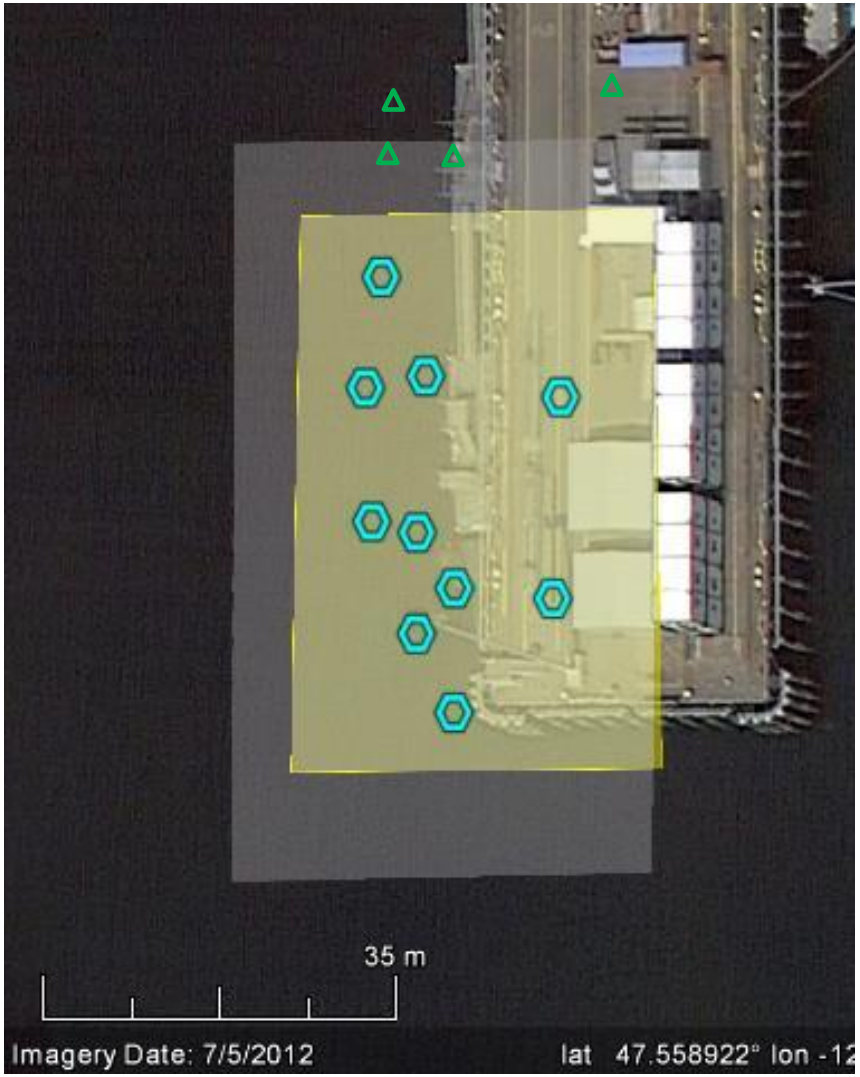
Thickness of Amendment July 2015 (T=33 month)

Stations with Amendment – 73%

Average Thickness – 8.8 cm

Monitoring for Baseline and Post Placement

- SEA Ring Chambers Deployed at 10 stations for 14 Days
  - Bioaccumulation
    - Clam – *Macoma nasuta*
    - Worm – *Nephtys caecoides*
    - Passive Sampler – solid phase micro extraction (SPME)
  - Physical and chemical characterization including Black Carbon (BC) and Total Organic Carbon (TOC)
- Benthic Infuana Community Analysis



Amendment Target Area
SPI Monitoring
SEA Ring Chamber
Reference Site


SEA Ring chambers


Clam

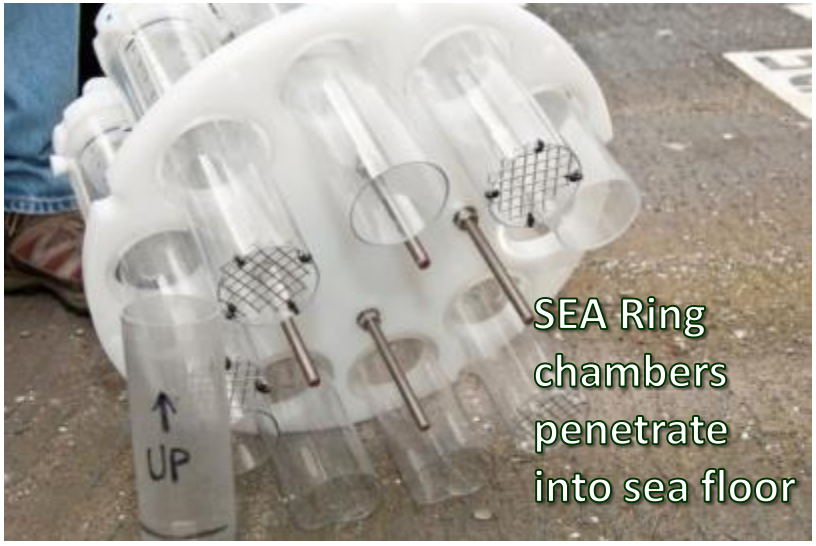

Worm


Amphipod


Divers use syringe to “inject” worms

Sediment Ecotoxicity Assessment

SEA Ring


SEA Ring chambers penetrate into sea floor


SEA Ring chamber on bottom


SEA Ring after retrieval


Divers deploying
SEA-Ring on sea floor
07/08/2015


Divers deploying
SEA-Ring on sea floor
07/08/2015

Divers deploying
SEA-Ring on sea floor

Video and Audio Commination With Dive Team

Recovering SEA-Ring on surface


Collecting samples from SEA Ring
07/21/2015

Collecting Clam sample

Collecting Worm Sample

Worms and Clams purged for 24 hr prior to processing

Passive sampler deployed in SEA-Ring chamber

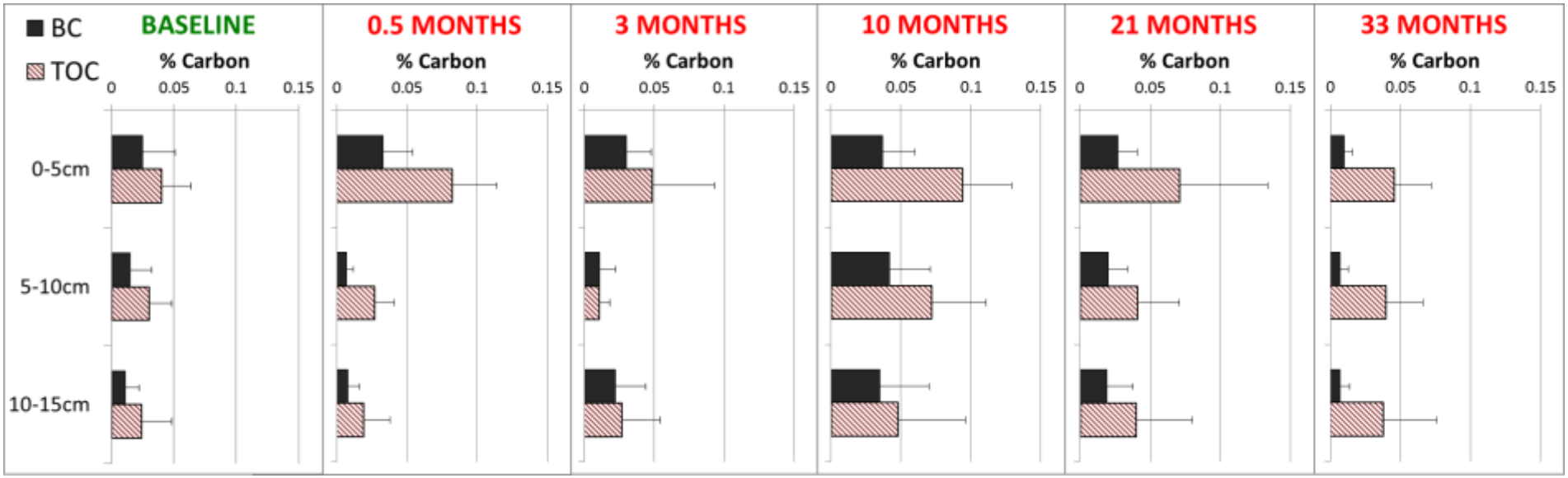
Collecting Benthic Community Sample

Results to Date

Compare results from Post-Placement Surveys to Baseline

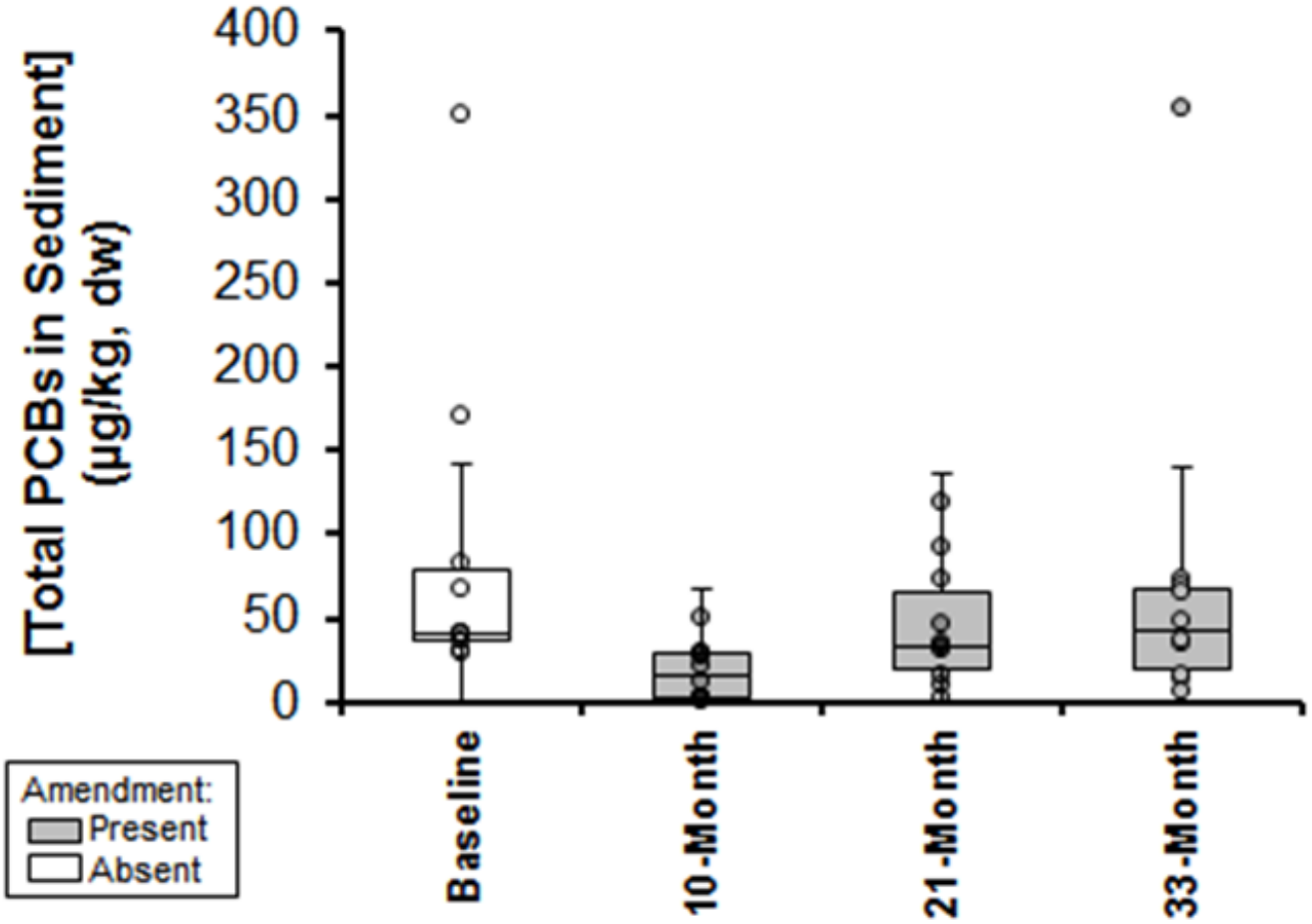
- Carbon Content (BC/TOC)
- Sediment Bulk Chemistry
  - Total PCBs
  - Total Mercury
  - Methyl Mercury
- Bioavailability of Total PCBs
  - Clams
  - Worms
  - Porewater
- Benthic Community Response
- Amendment Persistence

Average Black Carbon (BC) and Total Organic Carbon (TOC) measured in Sediment Cores



- Measurements confirm initial increase in carbon content.
- At 10 months there was more carbon at deeper levels.
- Similar to Baseline after 21 months; amended carbon appears to have mixed into sediments
- High variability in data caused by patchiness of site and interferences from aggregate, gravel, shell hash, and sample processing procedures

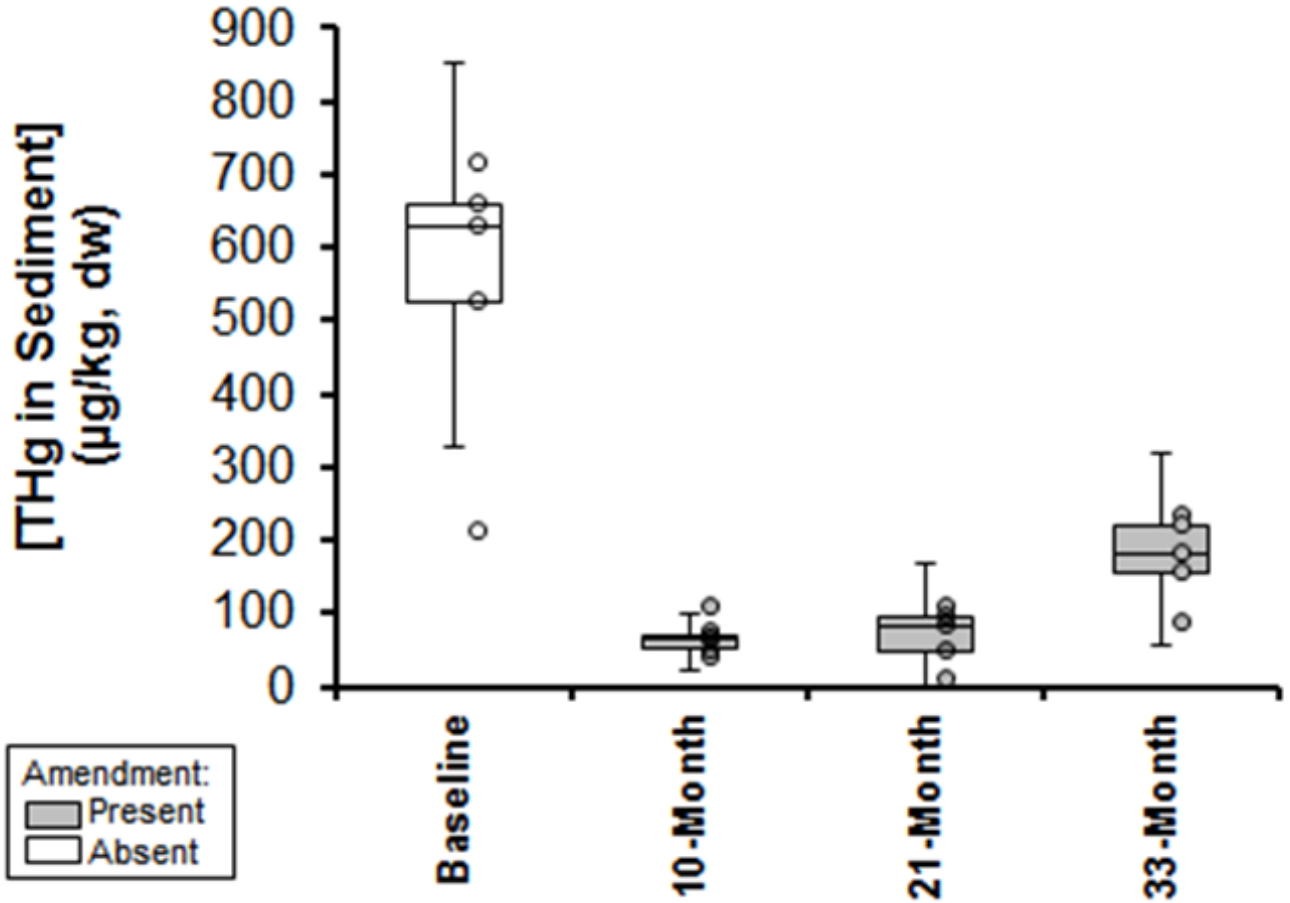
Total PBCs in Sediment



No Difference between Baseline and 21- and 33-month

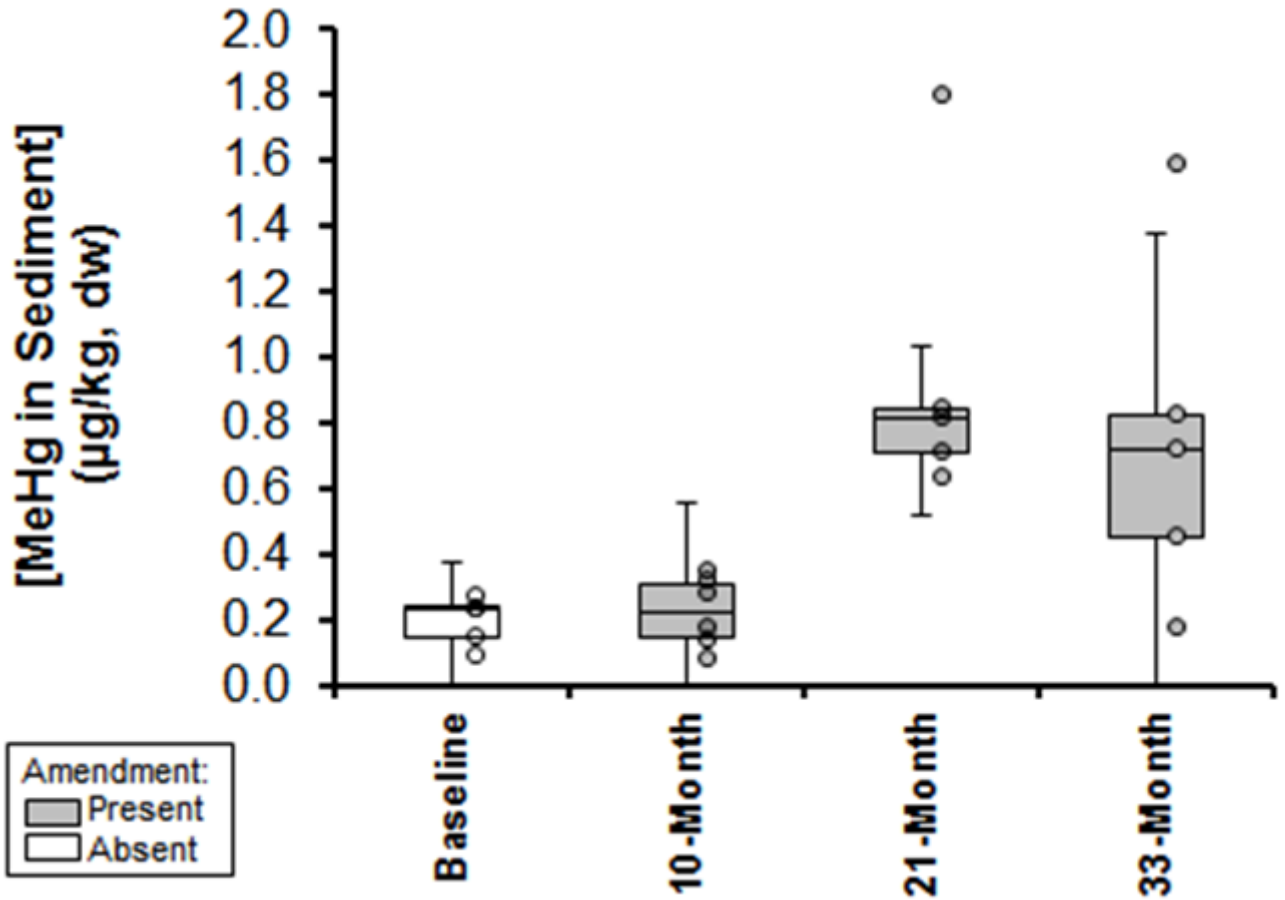
Reduced PCB after 10-month maybe due to more tightly bound PCBs after amendment or dilution by amendment

Total Mercury in Sediment



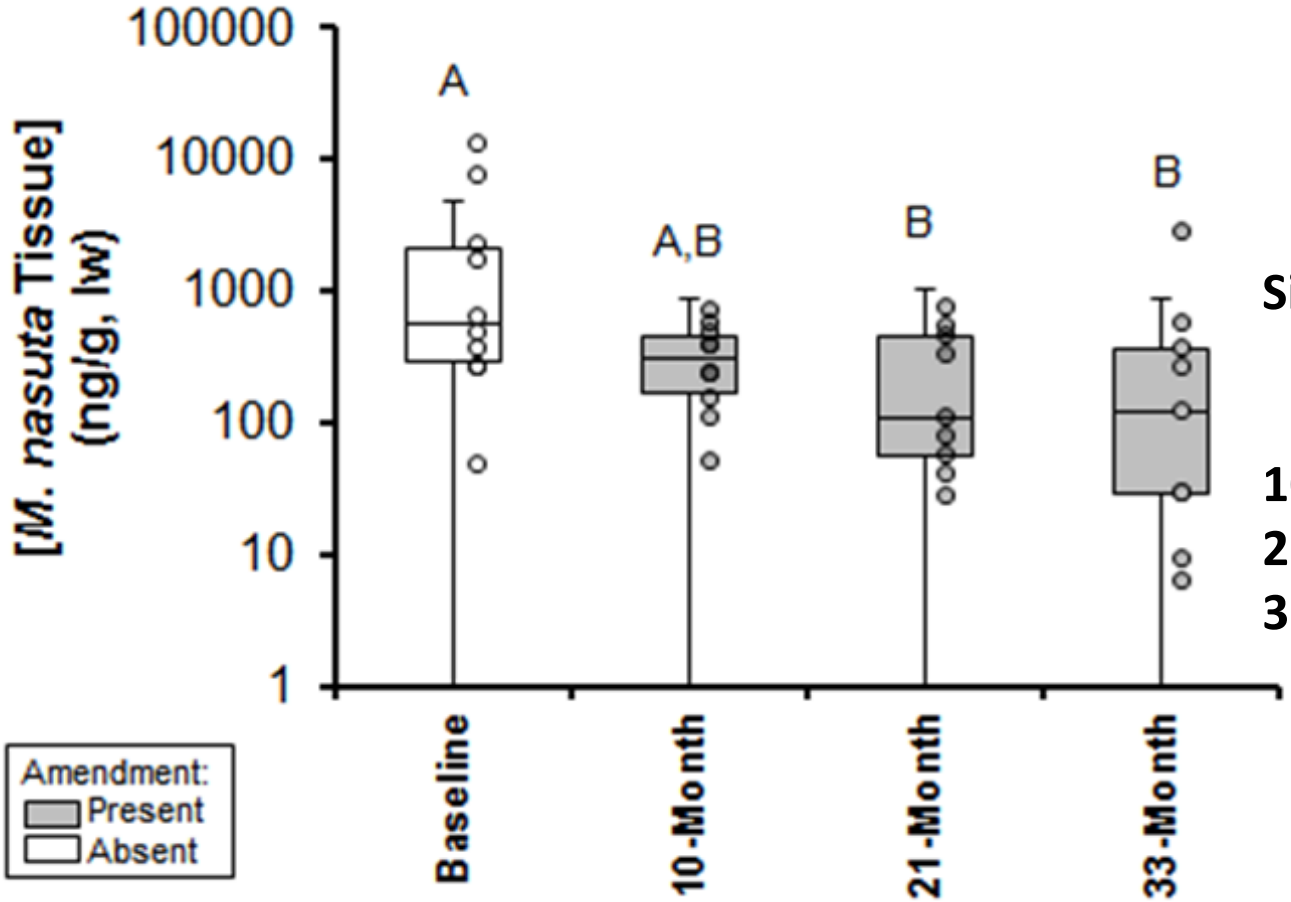
- Hg reduced between Baseline and post-treatment
- Reduced Hg after amendment may be due to more tightly bound Hg after amendment or dilution by amendment

Methyl Mercury in Sediment



- MeHg was increased for 21- and 33-month surveys
- MeHg concentrations in Sinclair Inlet sediments average 3.5 – 4.0 ug/kg (Moran and Paulson 2012)

Total PCB in Clams *Macoma nasuta*

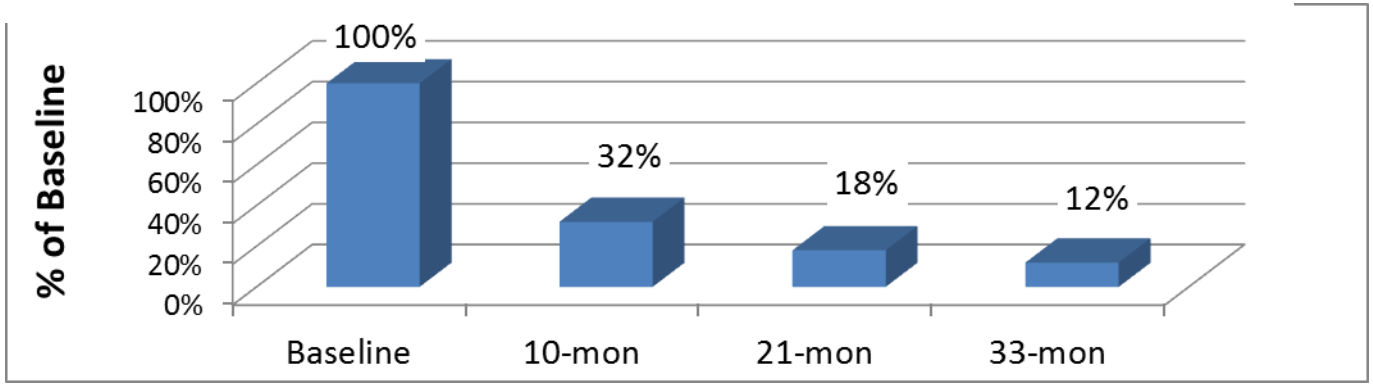


Significant reduction in Total PCBs up taken by clams

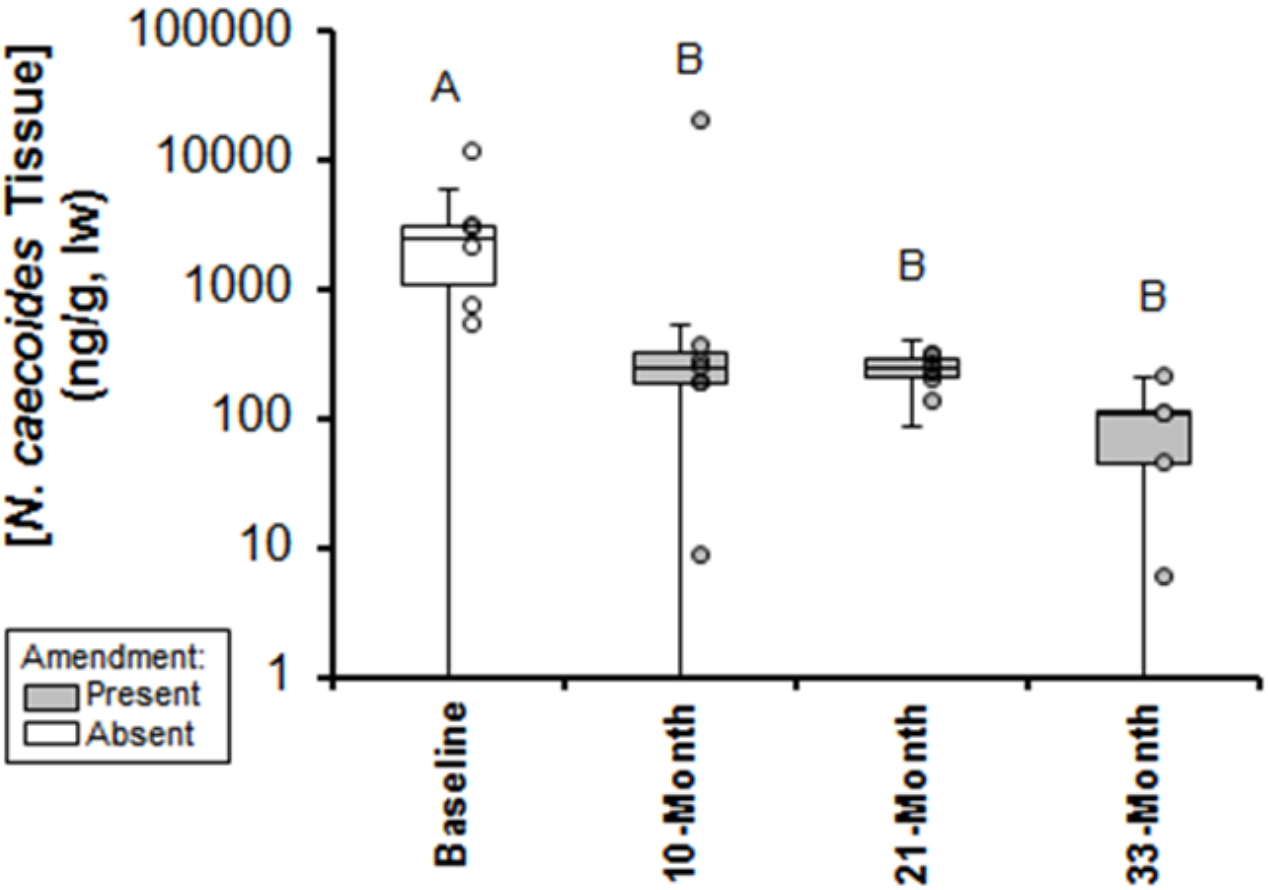
10-month 68% reduction

21-month 82% reduction

33-month 88% reduction



Total PCB in Worms *Nephtys caecoides*

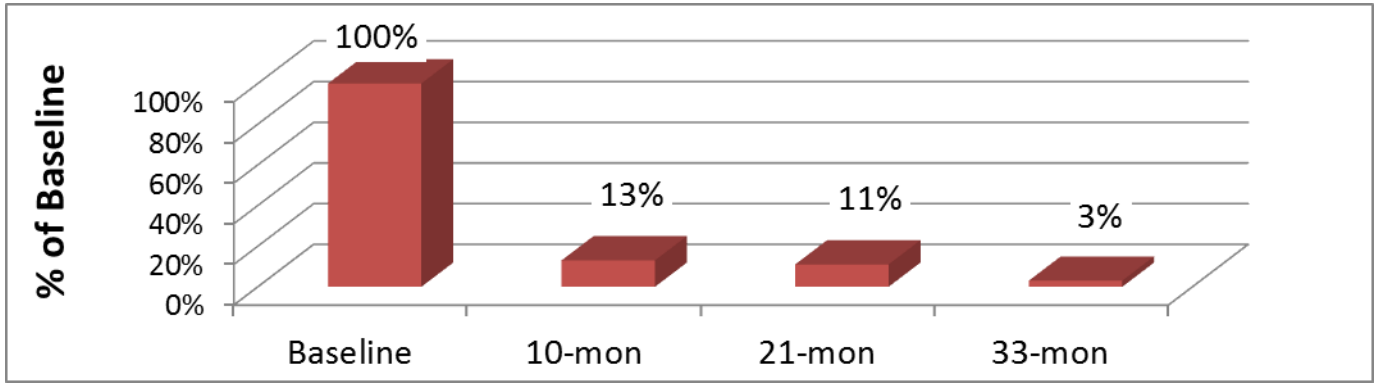


Significant reduction in Total PCBs up taken by worms

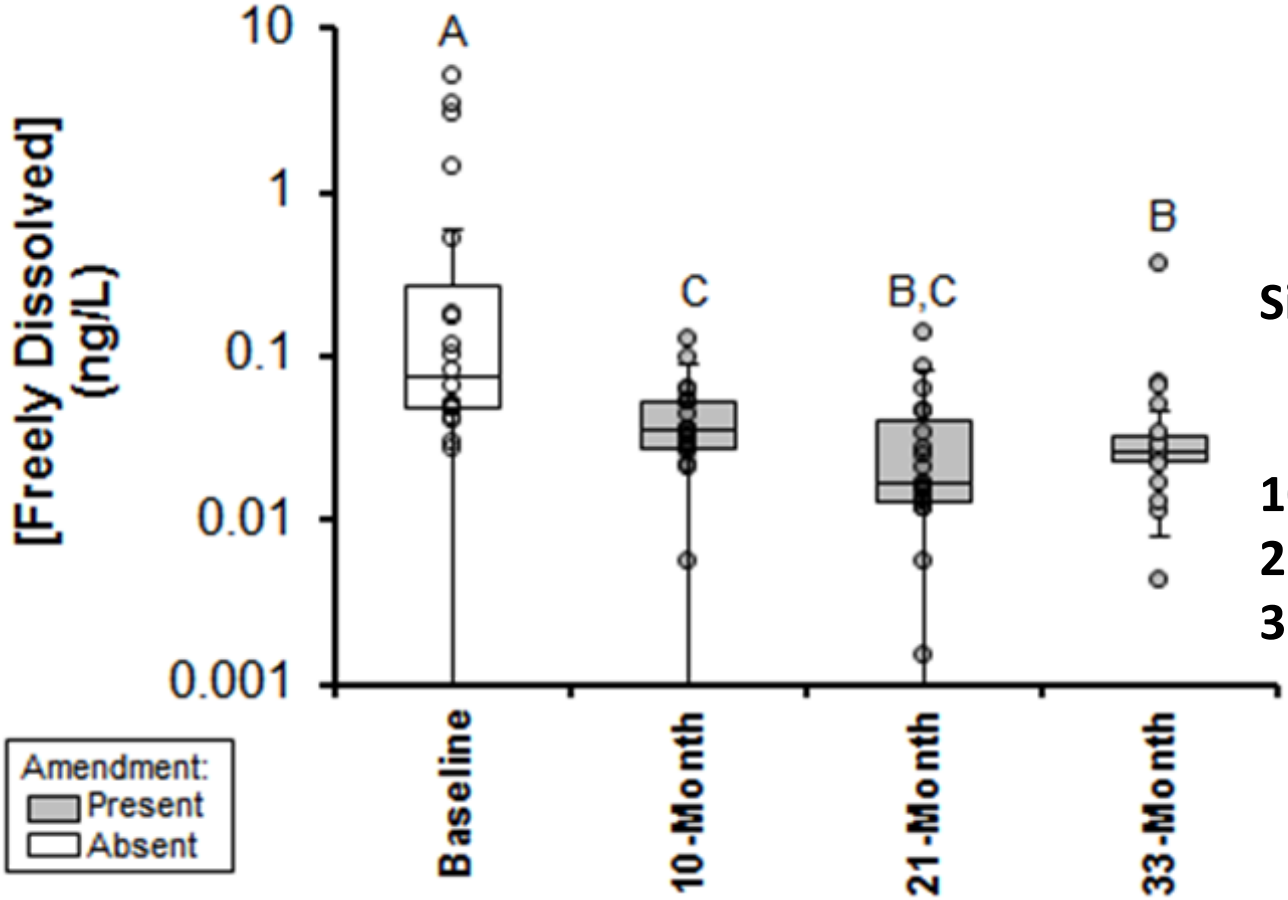
10-month 87% reduction

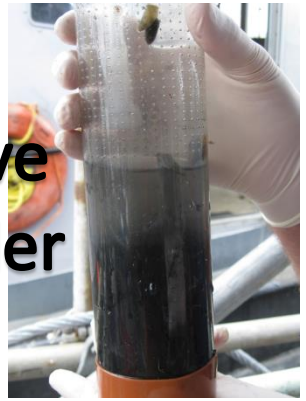
21-month 89% reduction

33-month 97% reduction



Total PCBs in Porewater





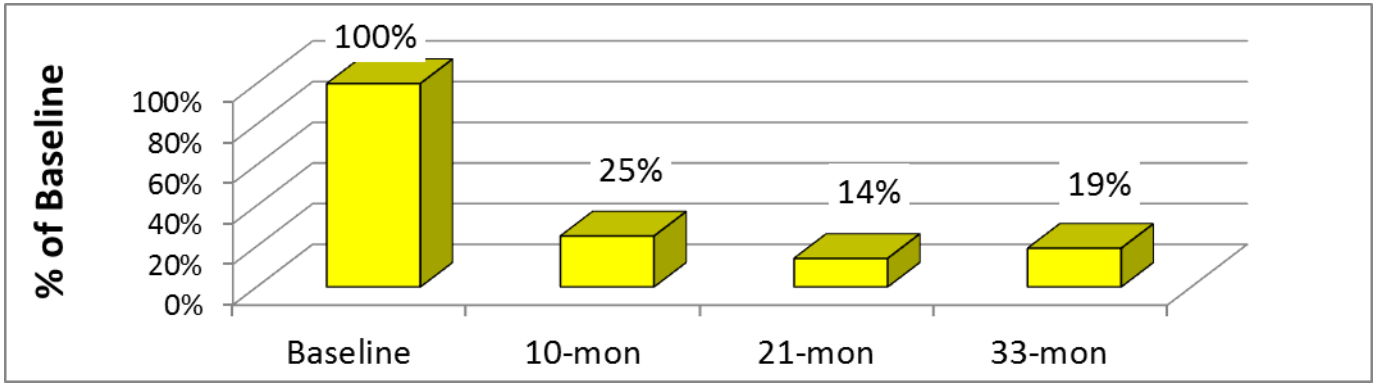
Passive Sampler

Significant reduction in Freely Dissolved Total PCBs in pore water

10-month 75% reduction

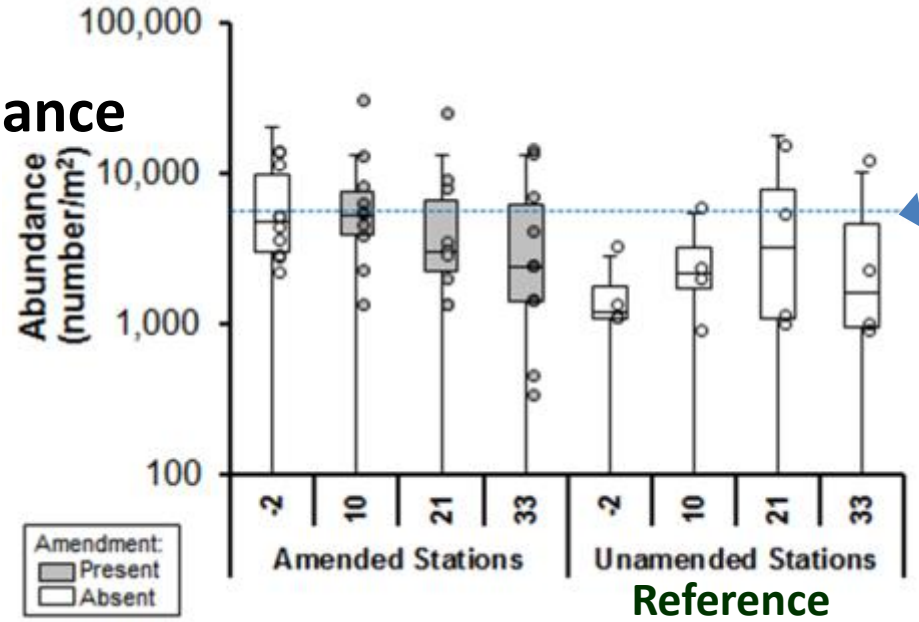
21-month 86% reduction

33-month 81% reduction



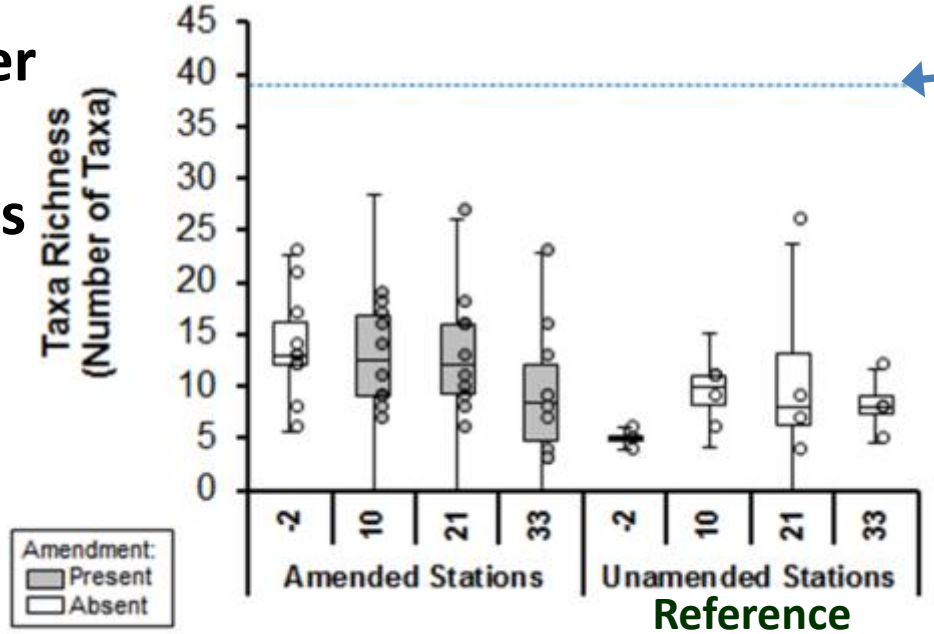
Benthic Invertebrates

Total Abundance



- Similar abundance as baseline
- Similar abundance as nearest Puget Sound Ambient Monitoring (PSAMP) station
- Similar to reference stations

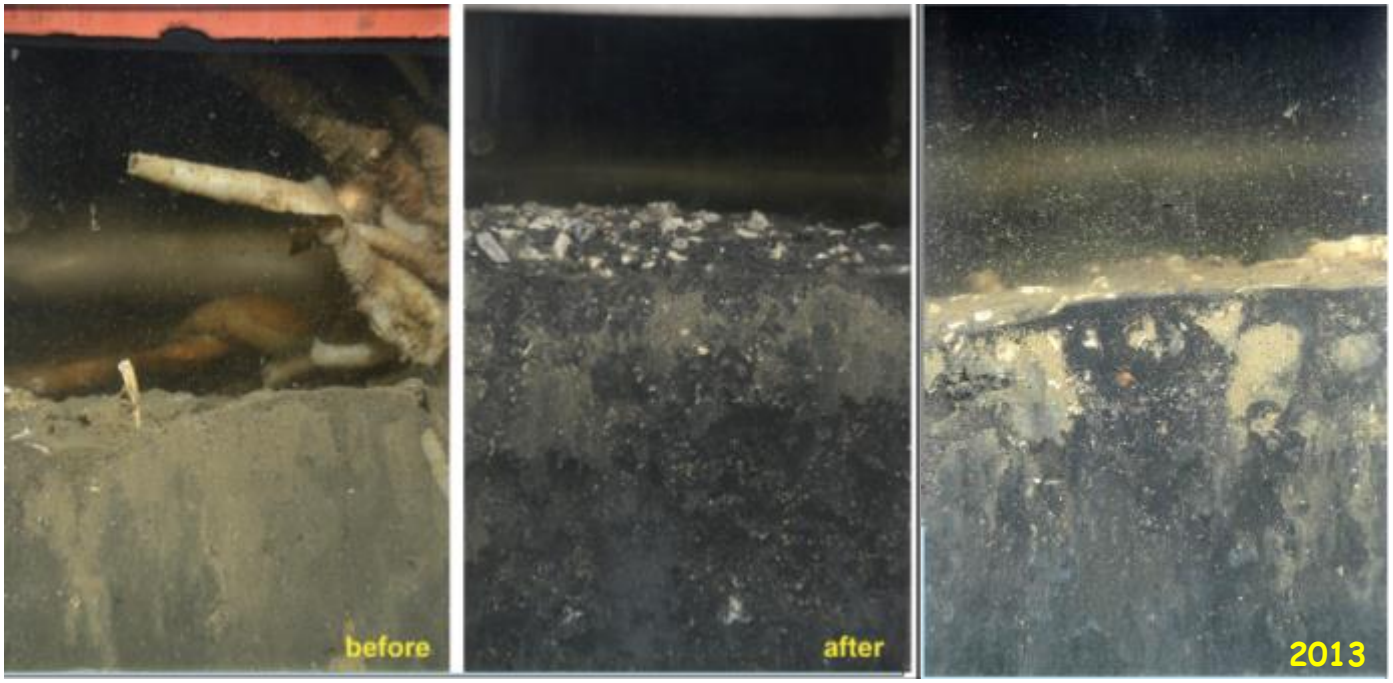
Number of Species

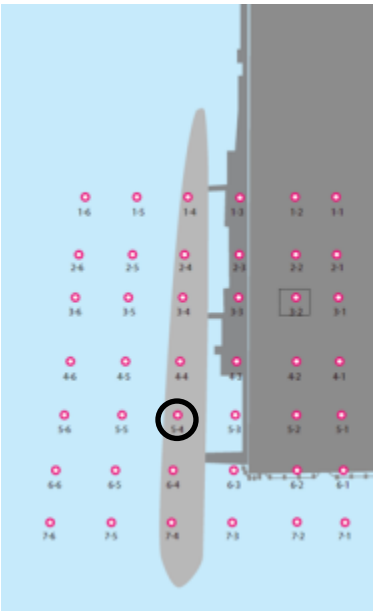


- Less richness than nearest PSAMP station
- Similar richness as baseline
- Similar to reference stations

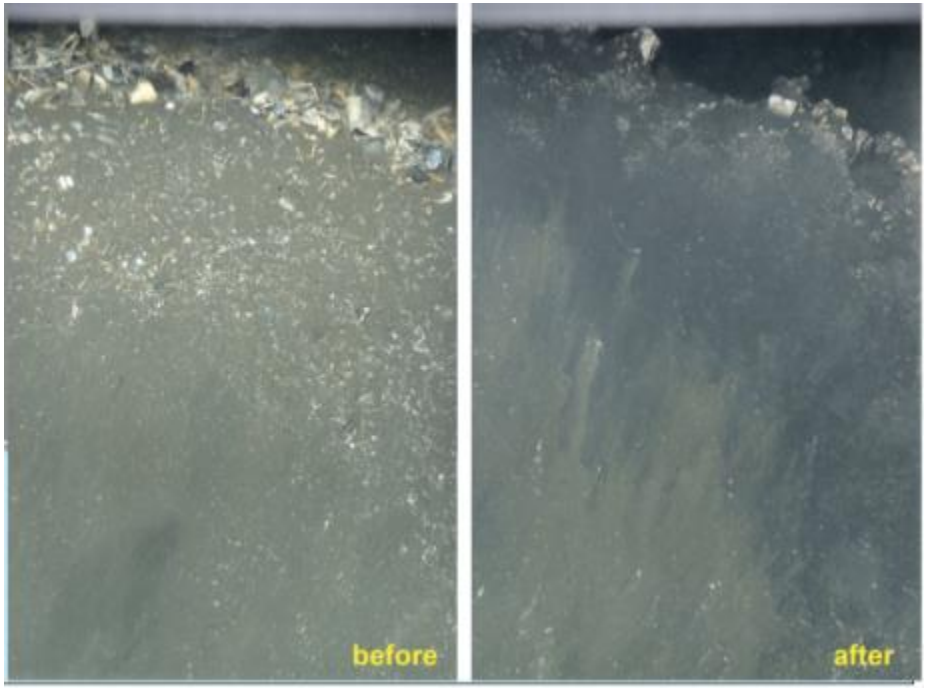
SPI System used to document bottom conditions and assess benthic community response

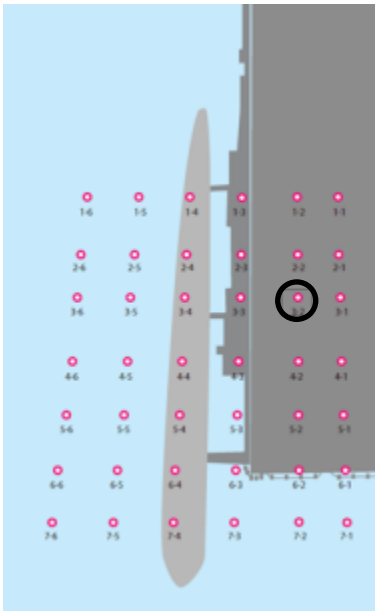
SPI 5-4 Berthing Area



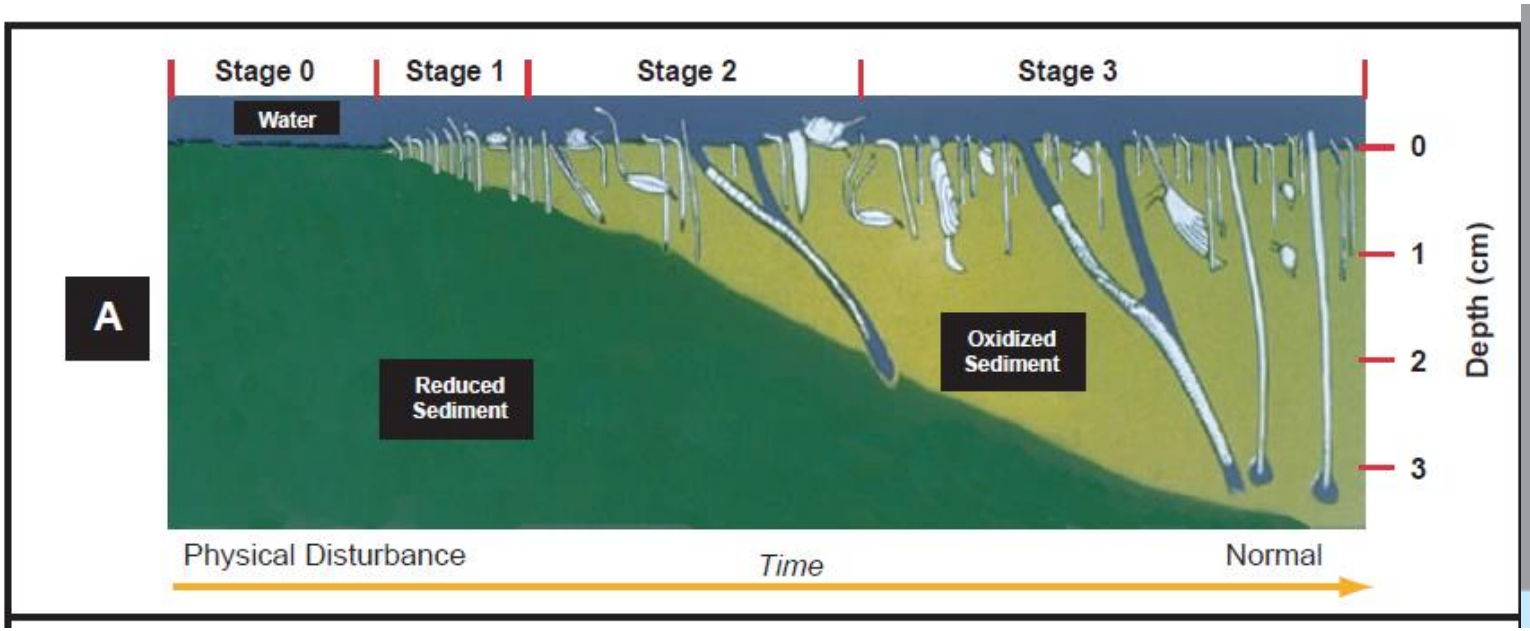


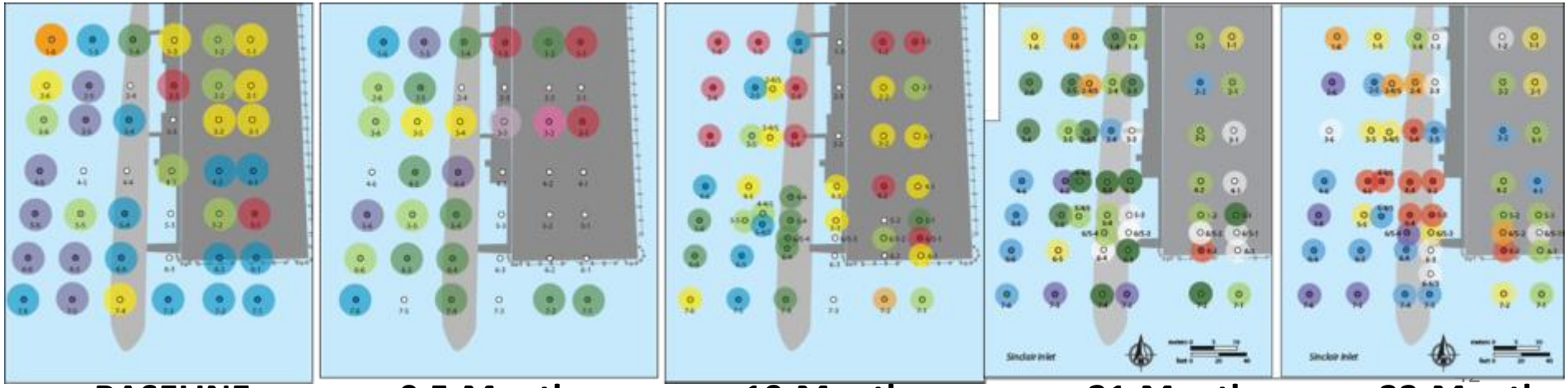
SPI 3-2 Under Pier





Stages of Infaunal Succession





BASELINE | 0.5-Month | 10-Month | 21-Month | 33-Month

Cost for Monitoring and Placement*

Monitoring (per event)		
Field Work	$ 97,000	
Dive Support	$ 27,000	
Laboratory Analysis	$ 59,000	
Reporting	$ 40,000	
	$ 223,000	
Placement		cost/ton
Product (140 tons)	$ 56,000	$ 400
Shipment	$ 42,000	$ 300
Staging/Delivery	$ 140,000	$ 1,000
Verification	$ 16,000	$ 114
	$ 254,000	$ 1,814
Placement Unit Cost		
Area Treated	0.502	acre
Placement Cost/ft^2	$ 11.62	

* Costs do not include management, oversight, and coordination.

Summary

- Conducted full scale demonstration of AC placement in active harbor
- Verified placement in berthing and under pier areas
- Bioavailability of Total PCBs relative to Baseline was Significantly Reduced in:
  - Clam tissues
  - Worm tissues
  - Porewater
- Benthic Community response similar to baseline and appears to show recovery
- Final Report in Prep


PUGET
SOUND

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Quigg Bros Inc.