Environmental Effects Monitoring in Sydney Harbour During Remediation of One of Canada's Most Polluted Sites: *A Review and Lessons Learned*

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Overview

- Why Conduct Environmental Effects Monitoring (EEM)?
- Implementation of Marine EEM Program (MEEMP)
- Review of MEEMP Findings
- Changes to MEEMP
- Lessons Learned

Monitoring Effects of Remediation

- **Environmental Impact Statement (EIS) & Joint Review Panel (JRP) concluded**
  - *"Remediation unlikely to cause significant negative environmental impacts with implementation of appropriate mitigation"*
- **EEM program designed to**
  - Determine effectiveness of mitigation
  - Verify effects predictions made in EIS
  - Designed to assess **positive** / **negative** changes potentially attributed to remediation
- **EEM program reviewed by key federal & provincial departments**
  - GW monitoring
  - SW monitoring
  - **Marine EEM Program (MEEMP)**
- **Continuous improvements made to MEEMP**
  - Lessons learned

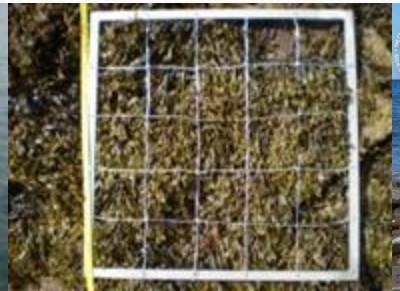
Marine EEM Program

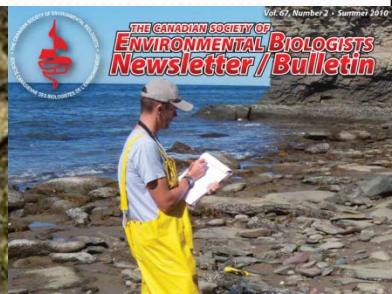
- **Water Quality (WQ)**
  - 24h auto sampler
  - Water grabs (surface & near bottom)
- **Mussel Tissue**
- **Sediment Quality**
  - Sediment Chemistry (grabs & traps)
- **Crab Hepatopancreas Tissue**
- **Benthic Community**
  - Inter-tidal (5 transects using quadrats)
  - Sub-tidal (sieve analysis for benthic invertebrates)

Detection of changes

Short term

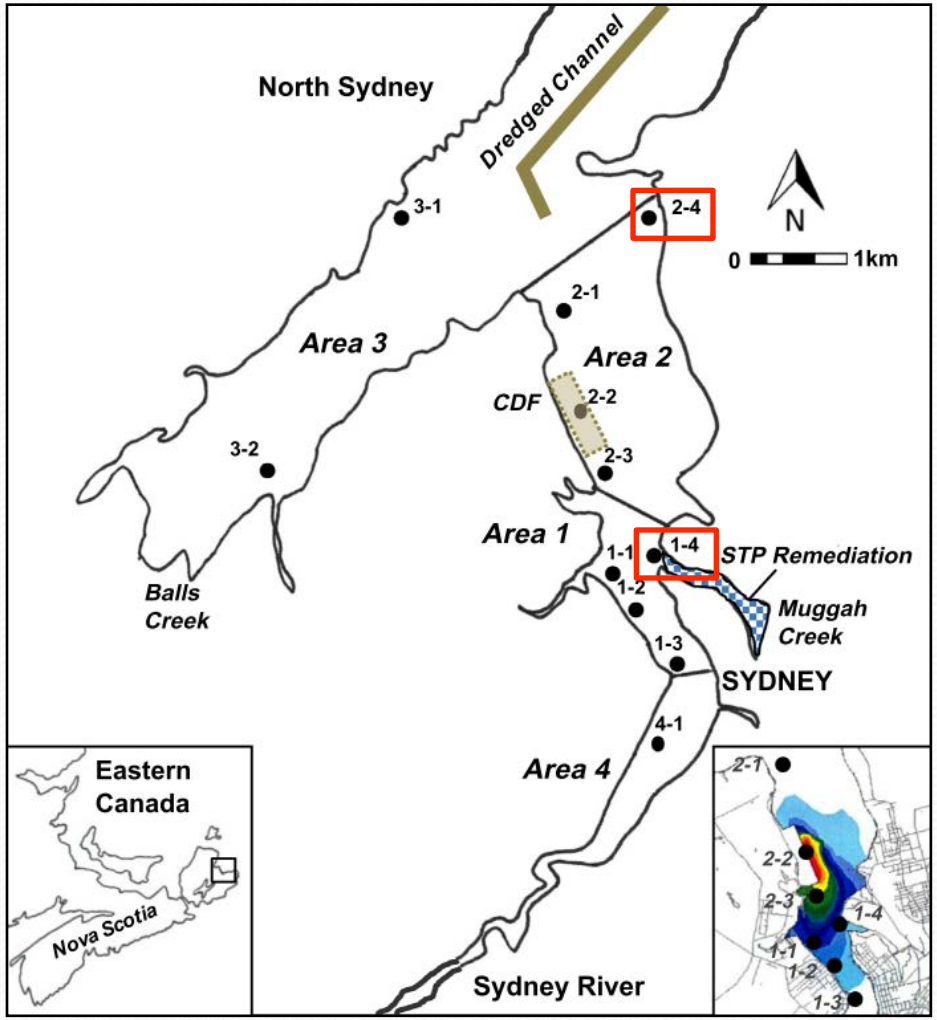
Long term



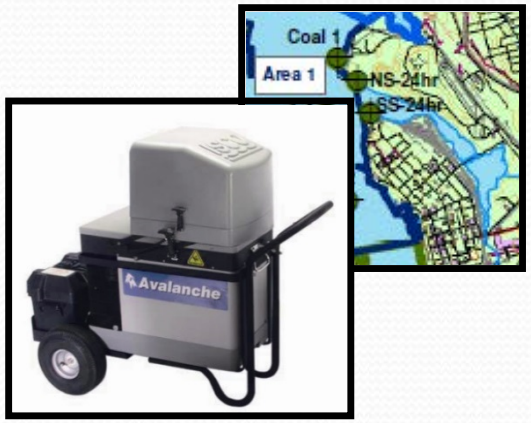


Marine EEM Sampling

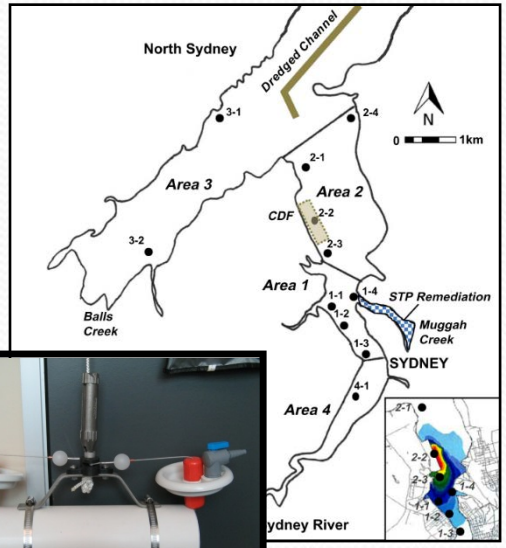
- **Spatial & temporal sampling**
- **Stations - 9**
  - Area 1 – Near-field
  - Area 2 – Mid-field
  - Area 3 – Far-field/reference
  - Area 4 – Sydney River Estuary
- **Sampling**
  - 2009 baseline
  - 2010 1st yr remediation
  - 2011 2nd yr remediation
  - 2012 3rd yr remediation
- **Changes to MEEMP**
  - Added 2 more stations

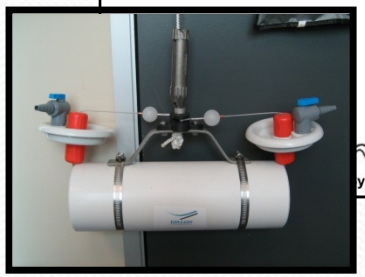


Marine EEM: WQ



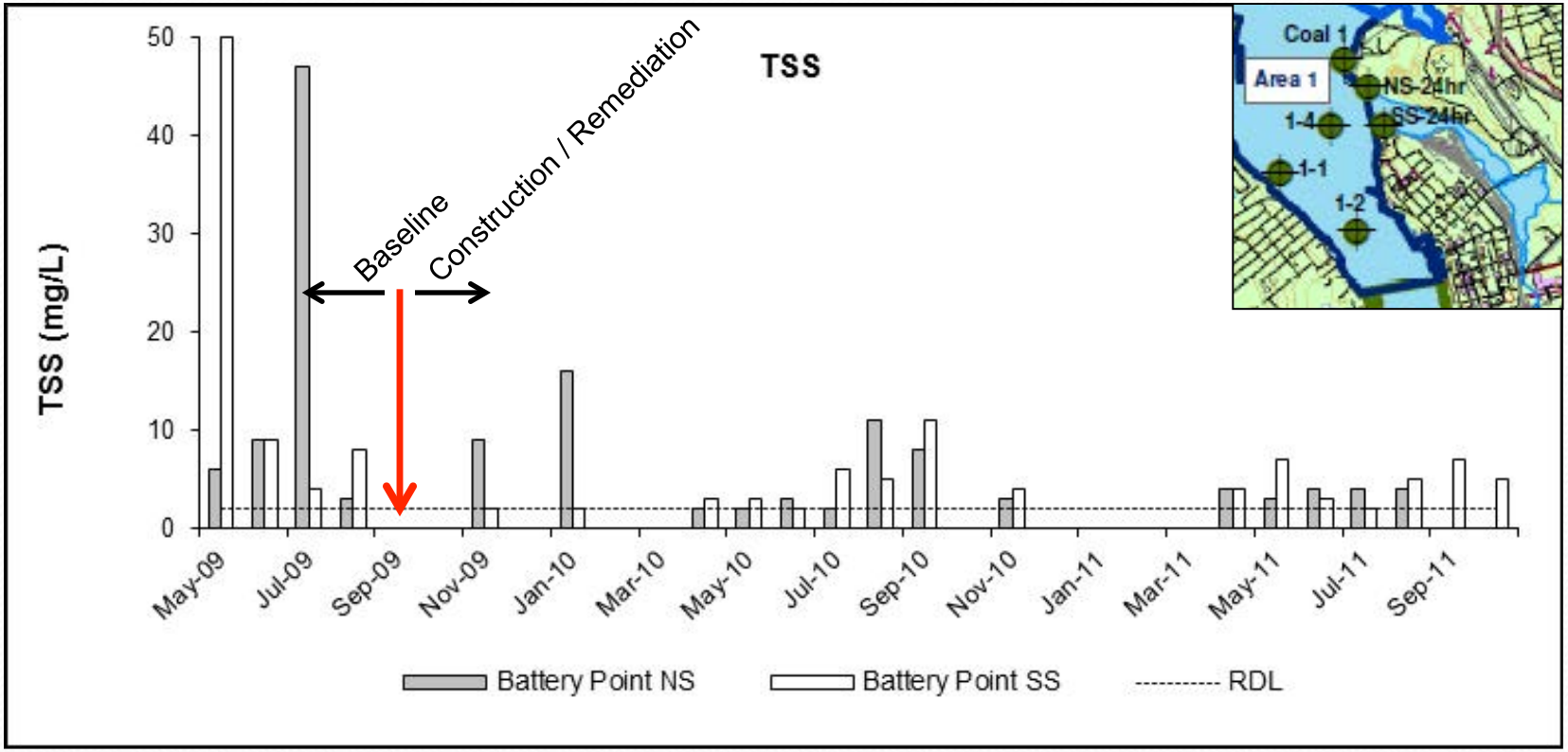
- **Monthly 24h auto-seawater composites**
- **Monthly water grabs (surface & near bottom) at all harbour stations**
- **Parameters**
  - Total Suspended Solids (TSS)
  - Total Organic Carbon (TOC)
  - General chemistry
  - PAHs & PCBs
  - Metals
- **USEPA 95% upper confidence limits (UCL95) calculated for site specific baseline WQ data**



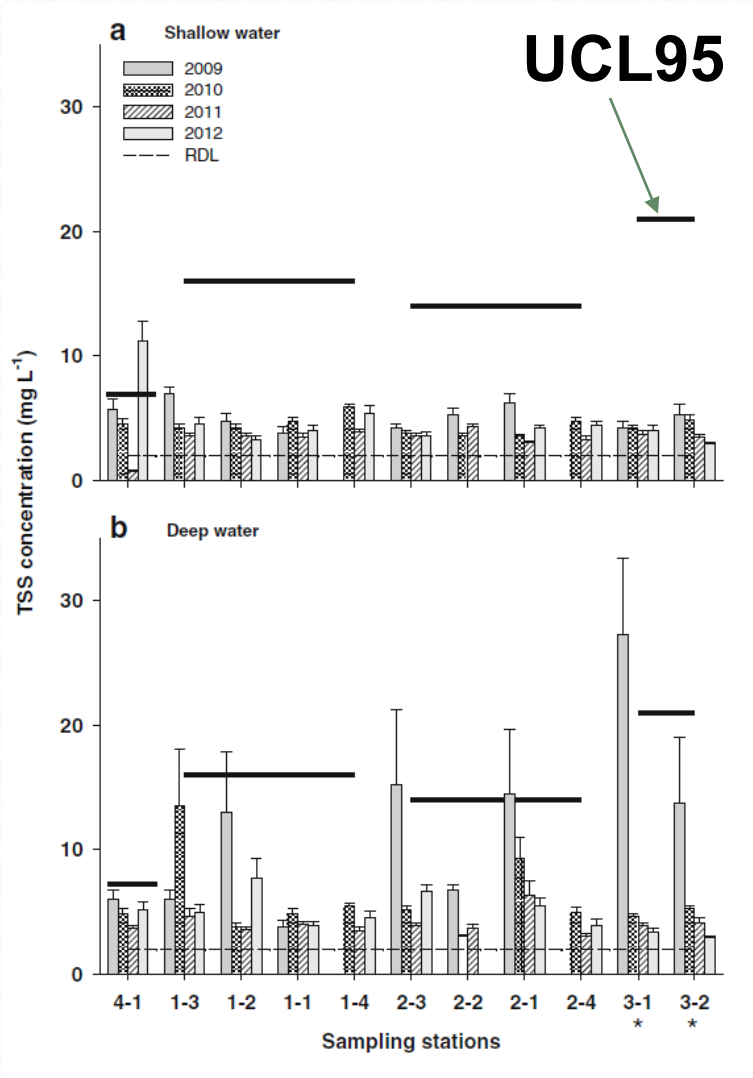


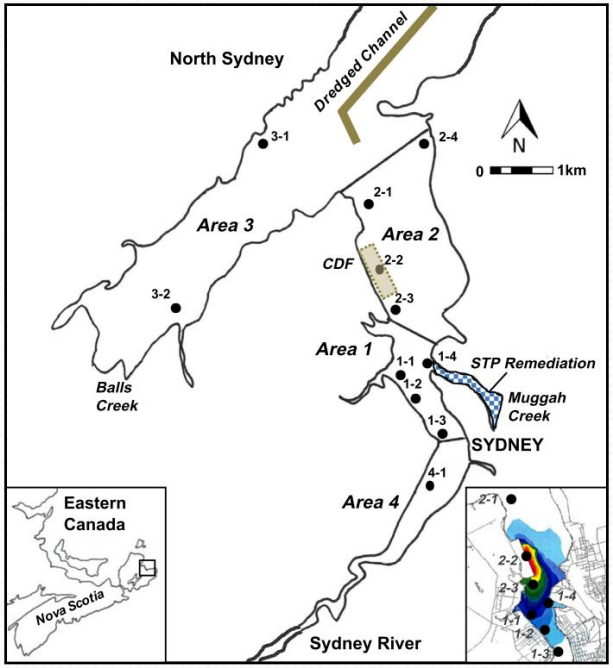
WQ: TSS 24H Auto

- **Highest [TSS] observed during baseline**
- **Peaks correlated to rainfall events NOT remediation**
- **Overall [TSS] low close to reportable detection limits, RDLs (2 mg/L)**



WQ: TSS Harbour Stations





Some regulators requested termination of WQ monitoring program because of lack of detections of many parameters

Walker, T.R., et al. (2013c) Monitoring effects of remediation on natural sediment recovery in Sydney Harbour, Nova Scotia. ***Environ. Monit. Assess.*** 185, 8089-8107.

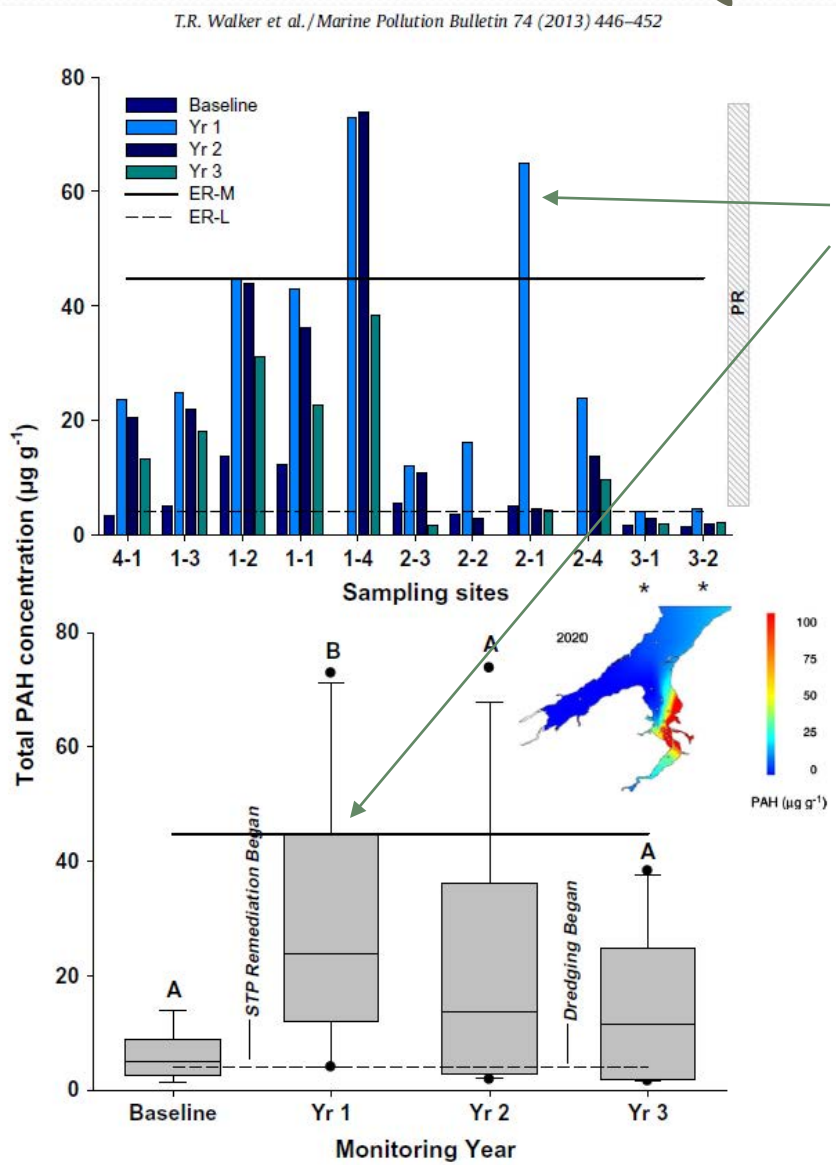
Non Detect Problems: WQ

Sample Location	Sample Date	TSS	NH^3	TOC	Cd	Cu	Pb	Hg	Pyrene	Phenanthrene	Fluoranthene
		mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
RDL		2	0.05	0.5	0.017	2	1	0.013	0.01	0.01	0.01
MarWat-1-1 Deep	04/21/09	6	<0.05	<0.5	0.085	<10	<5	<0.013	<0.01	0.02	<0.01
	04/21/09[D]	8	<0.05	<0.5	0.085	<10	5.9	0.016	<0.01	<0.01	<0.01
	05/21/09	5	<0.05	<0.5	0.13	<10	<5	<0.013	<0.01	<0.01	<0.01
	05/21/09[D]	6	<0.05	<0.5	0.088	<10	<5	<0.013	<0.01	<0.01	<0.01
	06/16/09	<2	<0.05	<0.5	0.085	77	<5	0.021	<0.01	<0.01	<0.01
	07/17/09	49	<0.05	<0.5	0.052	<4	<2	0.019	<0.01	<0.01	<0.01
	07/17/09[D]	2	<0.05	<0.5	0.042	<2	<1	0.017	<0.01	<0.01	<0.01
	11/08/09[D]	6	0.06	<0.5	0.046	<2	<1	0.03	0.02	0.01	0.02
	11/08/09	3	0.07	<0.5	0.93	<10	<5	0.031	0.02	0.01	0.02
	12/10/09[D]	4	0.14	<0.5	0.085	<10	<5	<0.013	0.01	0.01	0.02
	12/10/09	9	<0.05	<0.5	0.19	<10	<5	0.018	<0.01	<0.01	<0.01
	04/28/10[D]	5	<0.05	<0.5	0.056	<2	<1	<0.013	<0.01	<0.01	<0.01
	04/28/10	7	<0.05	<0.5	0.048	<2	<1	<0.013	0.01	0.02	0.02
	06/02/10[D]	4	<0.05	<0.5	0.1	<2	<1	<0.013	<0.01	0.02	0.02
	06/02/10	<2	<0.05	<0.5	0.038	<2	<1	<0.013	<0.01	0.02	0.01
	06/29/10[D]	5	<0.05	<0.5	0.18	<20	<10	<0.013	0.01	0.01	0.01
	06/29/10	3	<0.05	<0.5	<0.017	<20	<10	<0.013	0.05	0.05	0.06
	07/29/10	5	0.11	<0.5	0.05	<2	<1	<0.013	<0.01	<0.01	<0.01
	08/26/10	5	<0.05	<0.5	0.2	<20	<10	<0.013	<0.01	<0.01	<0.01
	09/30/10	4	<0.05	<0.5	0.097	<2	<1	<0.013	<0.01	0.01	<0.01
	10/28/10	6	<0.05	<0.5	<0.017	<20	<10	<0.013	0.02	0.02	0.01
	11/17/10	4	<0.05	<0.5	<0.17	<20	<10	0.014	<0.01	<0.01	<0.01
	04/20/11	<2	<0.05	<0.5	0.24	<20	<10	<0.013	<0.01	0.01	<0.01
	05/19/11	6	0.05	<5	<0.17	<20	<10	<0.013	<0.01	0.01	0.01
	06/28/11	4	0.08	0.6	<0.17	<20	<10	0.013	<0.01	<0.01	<0.01
	07/18/11	4	0.06	<5	<0.17	<20	<10	<0.013	<0.01	<0.01	<0.01
	08/31/11	5	<0.05	<5	<0.17	<20	<10	<0.013	<0.01	<0.01	<0.01
	09/29/11	3	0.05	<5	<0.17	<20	<10	<0.013	<0.01	0.01	<0.01
	10/25/11	6	0.06	<5	<0.17	<20	<10	<0.02	<0.01	<0.01	<0.01
	12/09/11	6	<0.05	0.7	0.26	<20	<10	<0.013	<0.01	<0.01	<0.01
	04/27/12	2.5	<0.05	<5	<0.17	<20	<10	0.017	<0.01	<0.01	<0.01
	05/31/12	3.5	<0.05	<5	<0.17	<20	<10	<0.013	<0.01	0.02	<0.01
	06/12/12	2	<0.05	<5	<0.17	<20	<10	<0.013	<0.01	0.03	<0.01
	07/23/12	5	<0.05	<5	<0.17	<20	<10	<0.013	<0.01	<0.01	<0.01
	08/14/12	2	<0.05	<5	<0.17	<20	<10	0.016	<0.01	<0.01	<0.01

Non Detect Problems: WQ

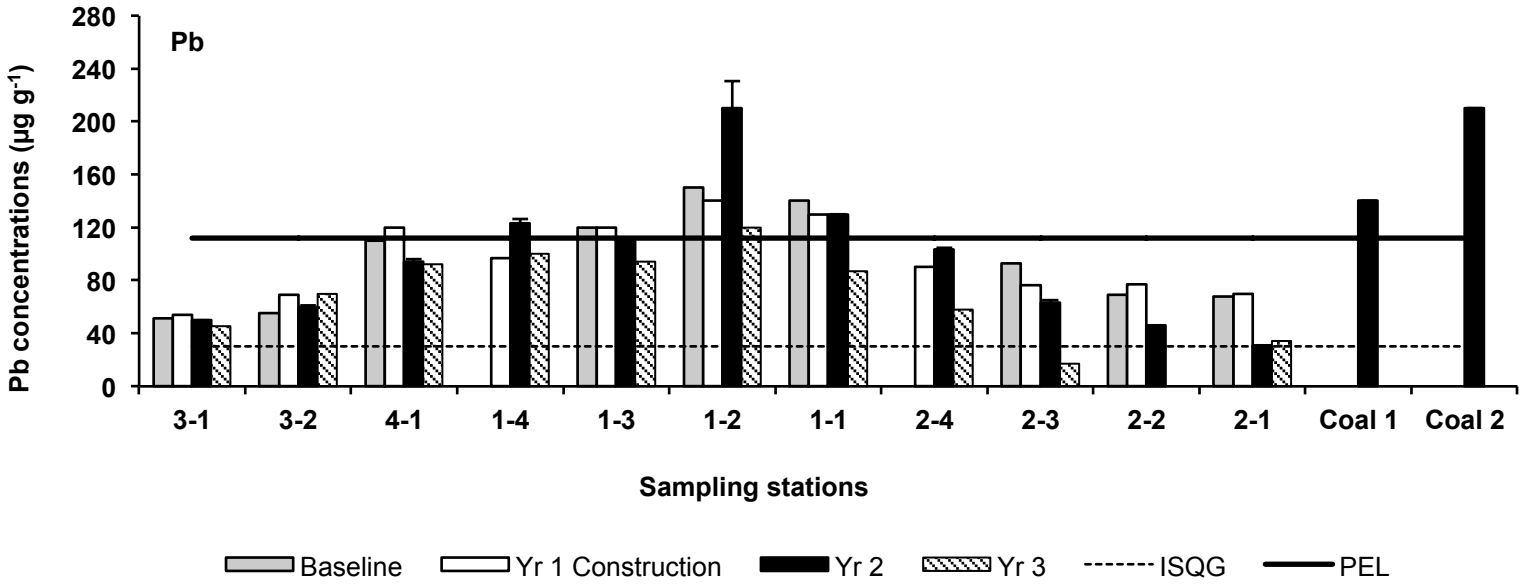
- **Non detects**
  - Many WQ parameters <RDLs
  - **<RDLs** make determination of *positive* or *negative* temporal **changes difficult**
- **Some metals had increased RDL values up to 10x**
  - Cu = 2, 4, 10, 20 µg/L
- **Different approaches for using non detect data**
  - Common approach uses **½RDL** value as substitution
  - Robust method - assumes normal distribution of data
  - Replace <RDL value with **zero** - biased low
  - Replace <RDL value **actual RDL** - biased high
- **US EPA UCL95 includes WQ data with <RDLs**
- **Changes to MEEMP**
  - Used **actual RDL value** to be overly conservative
  - Argued for **continuance of WQ monitoring** to detect potential contaminant releases

Sediment Quality: PAHs



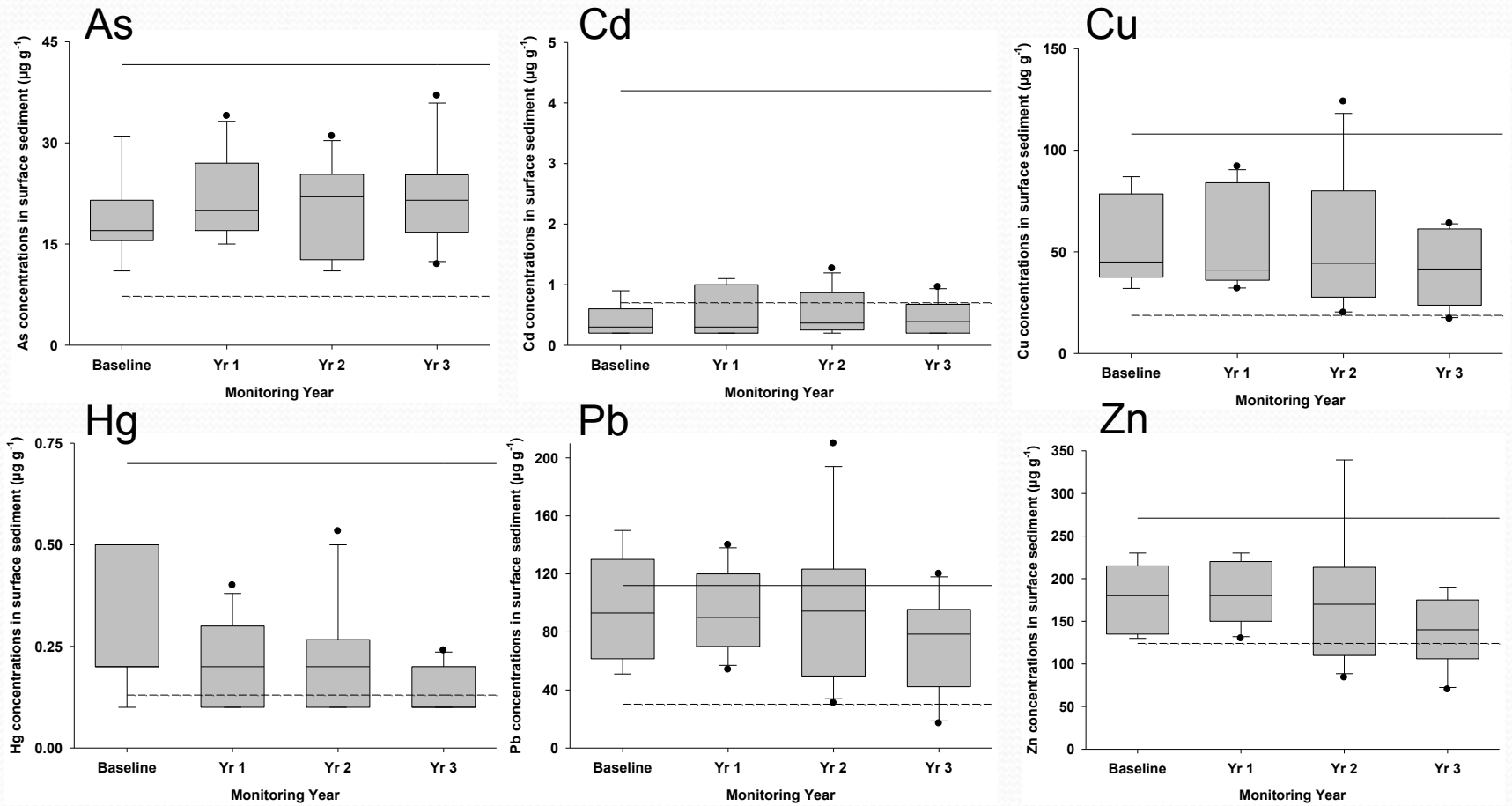
- **Significant increase in PAHs in Yr 1**
  - Some agencies called for termination of remediation after 1st year (Premature?)
- **Subsequent monitoring showed a continued decrease in PAHs**
  - Not significantly different from baseline
  - Within predicted ranges reported by Smith et al. (2009)
- **EIS prediction of no significant environmental impacts in SH confirmed?**

Sediment Quality: Pb



- **Little spatial / temporal variation**
- **Within predicted [Pb] ranges reported by Smith et al. (2009)**
- **Highest [Pb] measured at 1-2 & Coal 2**

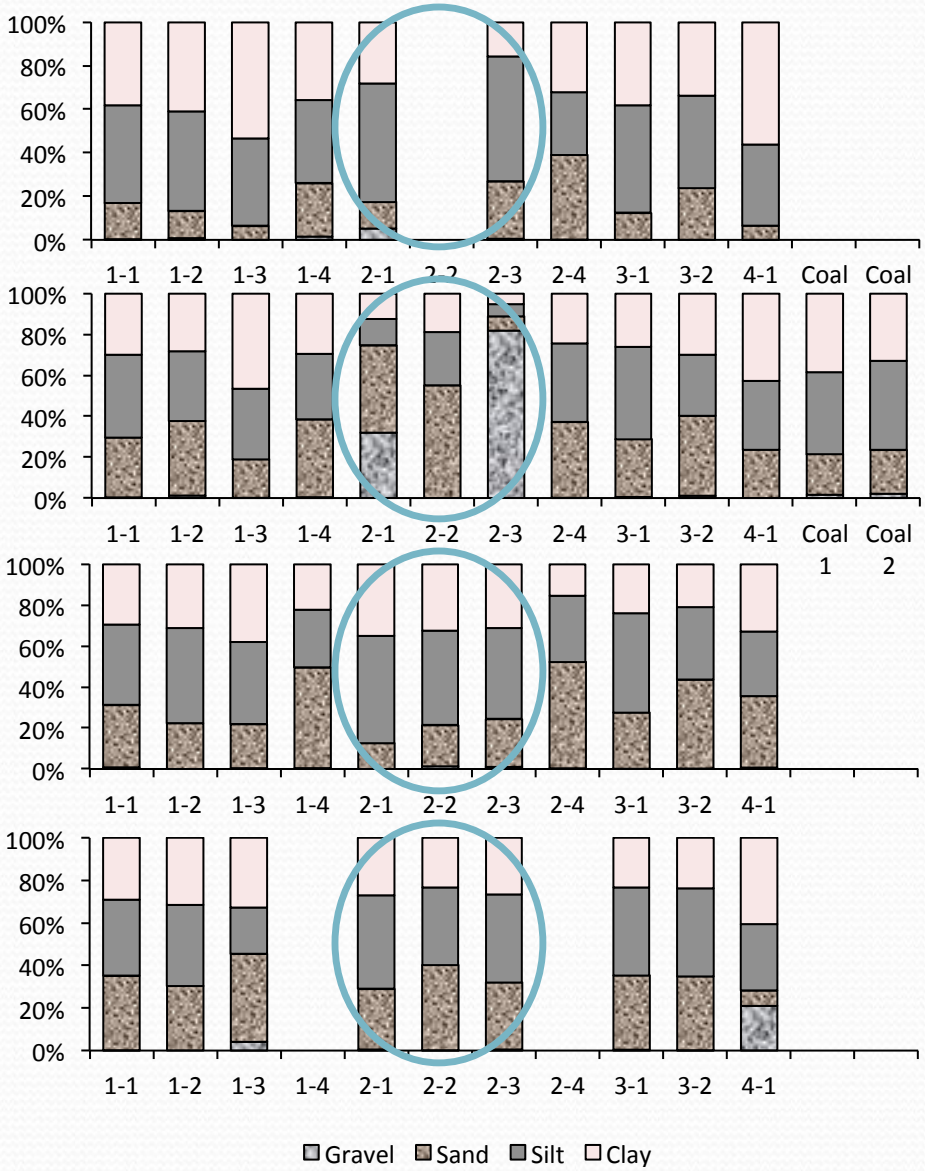
Sediment Quality: Metals



- **Little apparent temporal variation**
- **Some metals may show subtle decreases (eg. Hg, Pb & Zn)?**
- **EIS prediction of no significant environmental impacts in SH confirmed?**

Heavy Metal(s) Lives On!

Sediment Quality: Grainsize



Year 3: >75% Silt/Clay

Changes in composition likely due to harbour dredging – now similar to baseline

Year 2: <30% Silt/Clay

Dramatic changes in composition possibly from uncovering event(s)

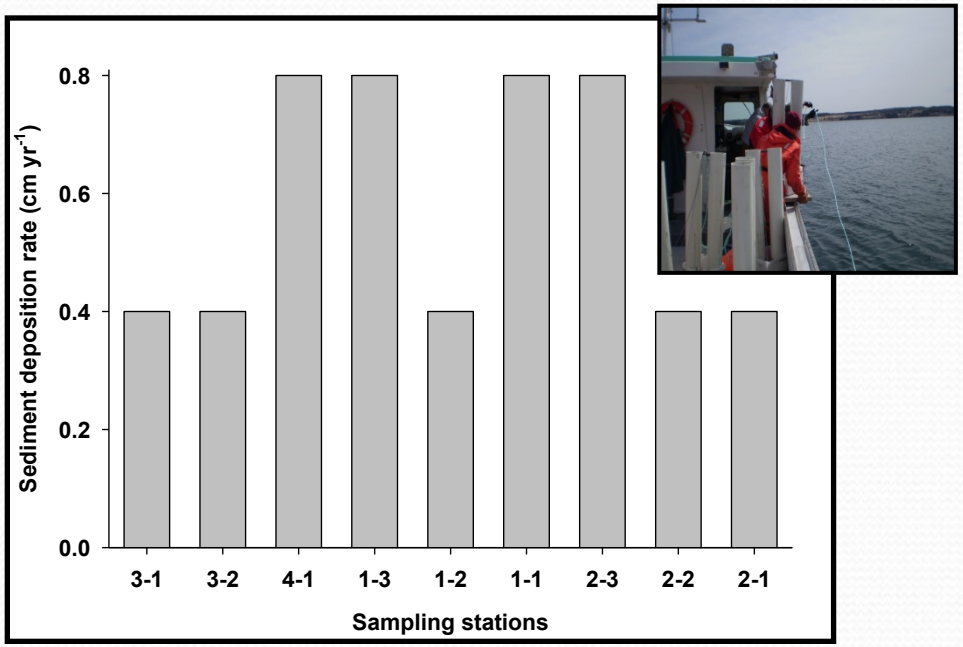
Year 1: >75% Silt/Clay

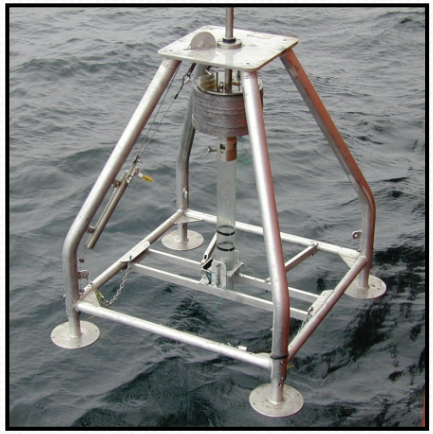
Baseline: >60% Silt/Clay

Highly dynamic

Sediment Quality: Sediment Traps

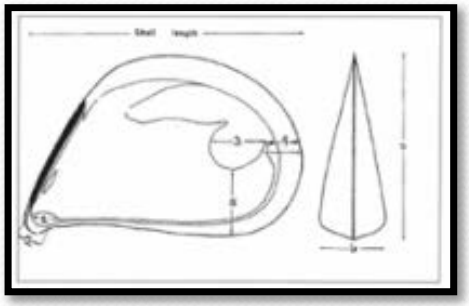
- **Low sedimentation rates**
  - 0.4 – 0.8 cm/yr
- **Limited material for**
  - Sediment chemical analysis
  - Amphipod toxicity testing
- **Changes to MEEMP**
  - Sediment traps discontinued
  - Some triplicate sampling to assess intra-station variation
  - Grabs and DFO gravity SLO-CORER compared





In situ Mussels

- **Commercial blue mussels deployed & analyzed for**
  - PAHs, PCBs, As, Cd, Cu, Hg, Pb, Zn & Lipids
  - Condition Index
- **Most PAHs <RDLs**
  - Except fluoranthene & pyrene
- **[PCB] <RDLs in baseline, yrs 1 & 3**
  - Some detections in yr 2
- **[Metals] showed little spatial variation**
- **EIS prediction of no significant environmental impacts in SH confirmed?**



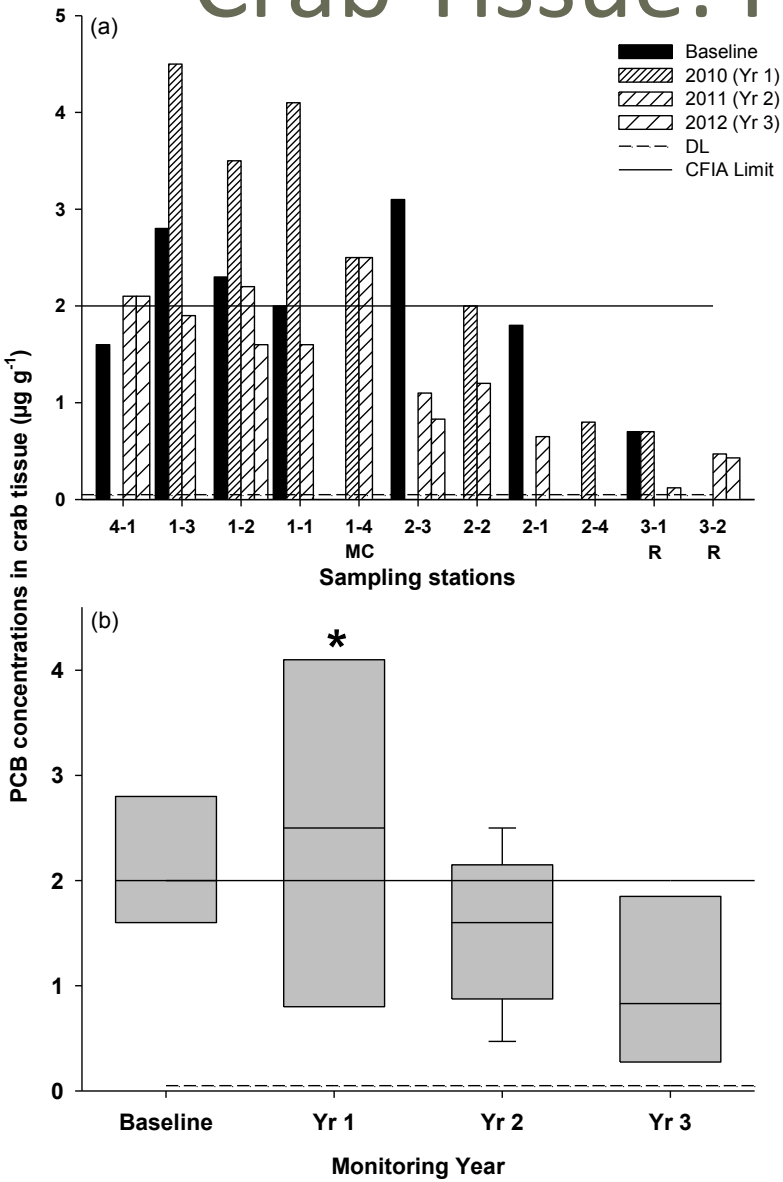
In situ Mussels: Challenges

- **Invasive tunicates covered frames**
- **Missing frames**
  - Suspect stealing of buoys & shackles
- **Massive dredging project**
  - Between Oct 2011-Jan 2012 **~4.2 million m^3 of dredged sediment** used for infilling in a confined disposal facility (CDF) for proposed container terminal
- **Changes to MEEMP**
  - Chemistry measured prior to deployment
  - Condition Index discontinued – *inconclusive*
  - Mussel **monitoring temporarily suspended** during dredging
  - **Station 2-2** permanently **lost**

Crab Tissue

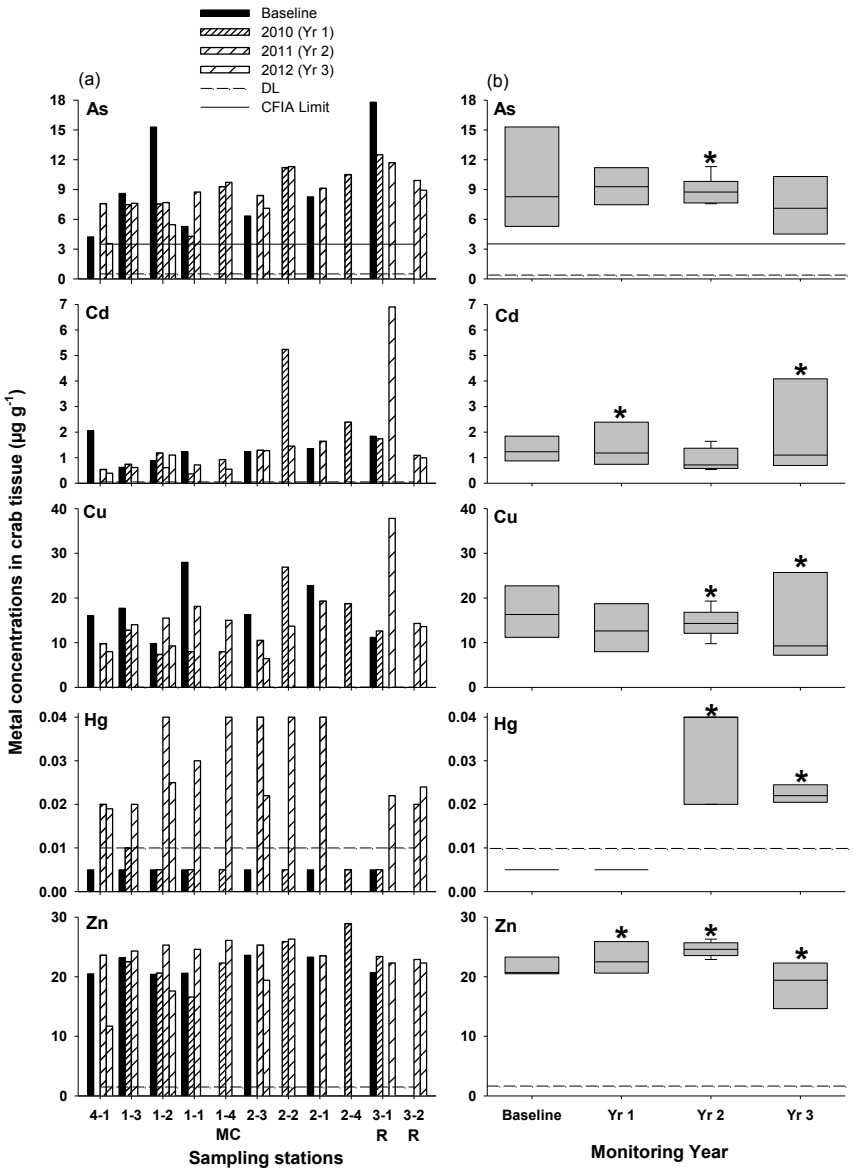
- **Adult male rock crabs** collected each July (102-130 mm)
- DFO **scientific crab licenses** obtained prior to collection
- **Triplicate crab traps**, baited with mackerel, deployed at each station & retrieved 2d later
- Crabs (6-13) from triplicate traps **pooled** to obtain min. wt required for **composite hepatopancreas tissue** analysis
- Hepatopancreas tissue from live crabs analyzed for
  - **PAHs, PCBs, As, Cd, Cu, Hg, Pb & Zn**

Crab Tissue: PAHs & PCBs



- **[PAHs]**
  - Mostly <RDL (0.05 µg g^{-1})
- **[PCBs]**
  - Significantly higher in yr 1
  - Potential decrease in yr 2 & 3
  - Below CFIA guidelines (2 µg/g) in yr 3
- **EIS prediction of no significant environmental impacts in SH confirmed?**

Crab Tissue: Metals



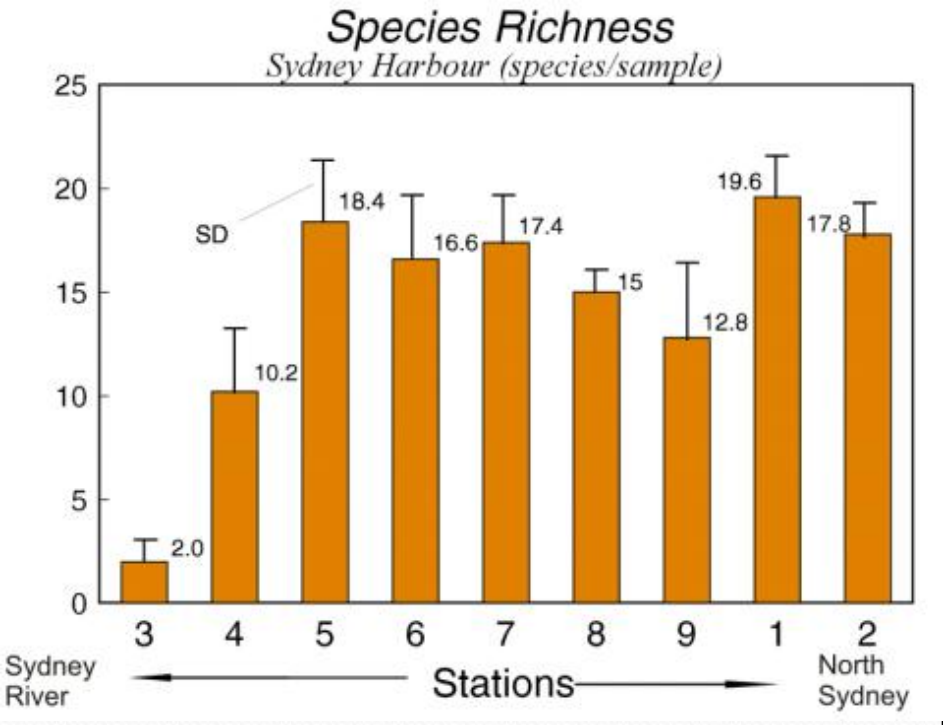
- **Highest** concs of **As, Cd & Cu** measured at **reference** stations
- No pattern of elevated [metals] in crabs close to remediation
- [**Metals**] showed some temporal variability, but **not directly related to remediation**
- **EIS prediction of no significant environmental impacts in SH confirmed?**

Crab Tissue: Challenges

- **Occasional by-catch**
  - Invasive green crabs
  - American lobster
- Sometimes no crabs caught
- **Massive dredging project**
  - Infill for CDF for new container terminal (2011-2012)
- **Other traps lost or stolen**
- **Changes to MEEMP**
  - Station 2-2 permanently lost

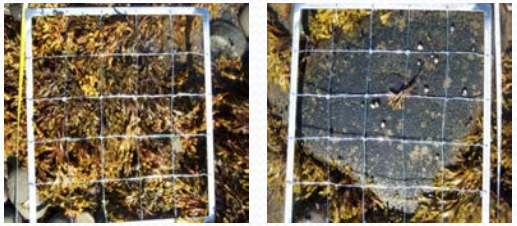
Benthic Community Assessment

- **Composition & distribution**
  - Yr 1 & 2 similar to baseline & earlier study by Stewart et al. (2002)
- **Total animal abundance**
  - Significantly higher since baseline
  - Positive changes since baseline
- **Community differences**
  - Driven more by organic enrichment rather than contaminant concentrations
- **Changes to MEEMP**
  - Discontinued after 3 seasons - *inconclusive*



Intertidal Communities

- **Intertidal transects established at baseline**
- **HW & LW quadrats assessed on transects for**
  - Algal species & cover
  - Faunal species & abundance
- **Remediation results similar to baseline**
  - Dominated by *Fucus* sp. algal cover
  - Faunal species dominated by periwinkles & barnacles
- **Species diversity higher with increasing distance from STP site**
- **Changes to MEEMP**
  - Discontinued after 2 seasons - *inconclusive*



Contaminants in Various Media

Media	Detection of Effects	PAH	PCB	As	Cd	Cu	Hg	Pb	Zn	JRP Significance	Reference
Water quality	Short term	→	→/nd	→	↓	→	→	→	→	Not significant	(Dillon 2013)
Blue mussels	↓	→/nd	→/nd	→	→	→	→	↑	↑	Not significant	(Walker et al. 2013b)
Surface sediment	↓	→	→	→	→	→	↓	→	↓	Not significant	(Walker et al. 2013c,d)
Rock crabs	Longer term	→/nd	↓	→	→	→	→	→/nd	→	Not significant	(Walker et al. 2013a)

→ = Stable
↓ = Decreasing
↑ = Potentially increasing
nd = Not detected

Walker, T.R., et al. (2013a) Legacy contaminant bioaccumulation in rock crabs in Sydney Harbour during remediation of the Sydney Tar Ponds, Nova Scotia, Canada. ***Mar. Pollut. Bull.*** 77, 412-417.
Walker, T.R., et al. (2013b) Blue mussels (Mytilus edulis) as bioindicators of stable and improving water quality in Sydney Harbour during remediation of the STPs, NS, Canada. ***Water Qual. Res. J. Can.*** 48, 358-371.
Walker, T.R., et al. (2013c) Monitoring effects of remediation on natural sediment recovery in Sydney Harbour, Nova Scotia. ***Environ. Monit. Assess.*** 185, 8089-8107.
Walker, T.R., et al. (2013d) Environmental Recovery in Sydney Harbour, Nova Scotia: Evidence of Natural and Anthropogenic Sediment Capping. ***Mar. Pollut. Bull.*** 74, 446-452.
Dillon (2013) Final Marine Report for Year 3 Construction. Submitted to the Sydney Tar Ponds Agency.

Summary

- **EEM in SH did not detect substantial contaminant releases**
  - Many parameters decreased despite ongoing remediation
- **[PAHs] in sediments increased during yr 1, but now decreasing**
  - Results within predicted 'natural recovery' ranges reported by Smith et al. (2009)
- **Dredging may have had positive environmental effect on Sydney Harbour**
- **Detection of these changes attests to effectiveness of EEM programs**
- **EIS prediction of no significant environmental impacts in SH confirmed?**

Lessons Learned

- **Calls for termination** of remediation by regulators after 1 yr was **premature**
- **Several years of baseline data required** to properly understand range of natural inter-annual variation
- Some EEM components removed **only** after several years of inconclusive data
- **Cumulative impacts from other industrial activities** / weather events should be considered during large-scale remediation projects
- Some agencies requested reduction in MEEMP to reduce costs, but collecting a range of multimedia helps build stronger evidence of potential effects
- **Longer term monitoring** of fewer multimedia to assess long-term performance of S/S remediation over decadal timeframes
- **EEM programs can also become important research studies**

Thank You

Sydney Tar Ponds Agency

Public Works and Government Services Canada

Travaux publics et Services gouvernementaux Canada

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