An Environmental Health Risk Assessment: Fish Consumption Among Southeast Asian Fishermen in Rhode Island and Risk from PCB Exposure

Undergraduate Thesis in Environmental Science

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Outline

- Introduction to PCBs
- From Production to Exposure
- History of Narragansett Bay
- Study Population: Southeast Asian Fishermen
- Health Effects of PCBs
- Study Design (interviews, sample analysis)
- Results
- Study limitations, uncertainties
- Remediation
- Future work

Study Questions

- What is the consumption rate of fish of Southeast Asian fishermen in Rhode Island?
- What are the concentrations of PCBs in fish in Rhode Island waters?
- What level of health risk do PCBs in fish pose to Southeast Asian fishermen in Rhode Island?
- Should any immediate action be taken to protect SE Asian fishermen's health?
- Is any long-term action needed to reduce the levels of toxics in Narragansett Bay fish (remediation)?

Study Goals

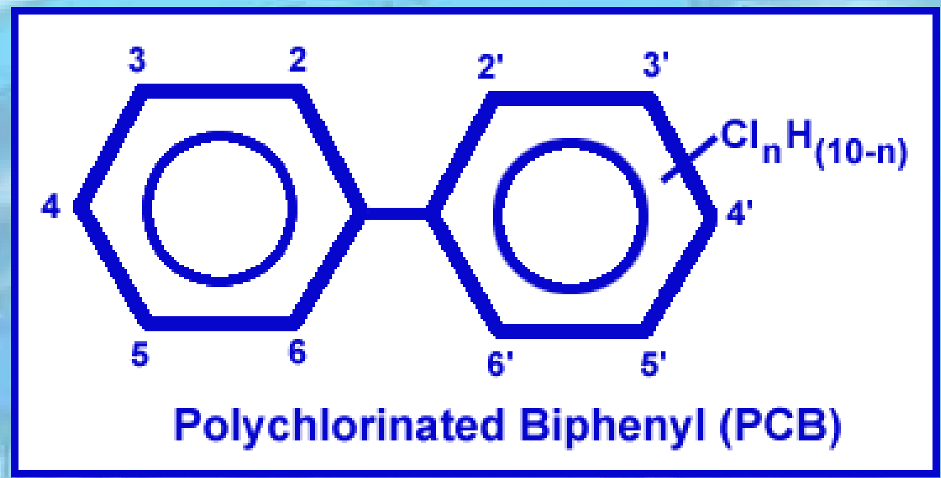
- Conduct a human health risk assessment, which determines the magnitude and probability of potential harm to human health by exposure to toxic substances

1. Hazard Identification—identify harmful chemical
2. Exposure Identification—identify extent and rate of exposure
    - Risk interviews—determine consumption levels
    - Fish sampling—determine PCB concentrations
3. Toxicity Assessment—dose response relationship
    - Done with literature review
4. Risk Characterization—estimation of potential risks of adverse health effects

Introduction to PCBs

Chemical Properties

•PCBs (polychlorinated biphenyls) are persistent organic pollutants.



Polychlorinated Biphenyl (PCB)

•The chlorines can be arranged in many combinations of positions, making 209 distinct compounds, each known as a congener.

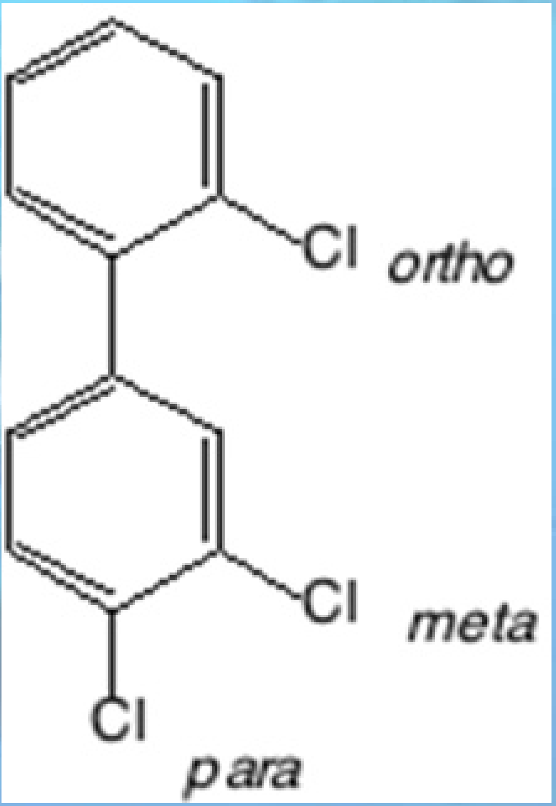
Intro (cont)

- Each congener has a different toxicity profile, meaning that certain congeners are more toxic than others

- Range from oily liquids to waxy solids and vapors.

- There are no known natural sources of PCBs.

- PCBs have high chemical, thermal, and biological stability, and low vapor pressure, making them useful for industries.



History of PCBs

- Used as coolants and lubricants in transformers, capacitors, and other electrical equipment.
- PCBs were produced in the US from 1929-1977, with peak production in 1970.
- Aroclors—mixtures of congeners in set ratios.
- Between 1935 and 1975, 568,000 metric tons of PCBs were sold in the US.
- Globally, approximately 12% of all PCB production has made its way into the environment
- Since the ban, the major sources of PCBs are from cycling of PCBs between reservoirs, and various geological processes.

Regulation of PCBs

Government Agencies

2 Federal agencies

- FDA (Food and Drug Administration)
  - Responsible for providing and enforcing national standards (action levels) to protect the *general public, not subpopulations*
  - **2 ppm in fish**
- EPA (Environmental Protection Agency)
  - Creates water quality criteria based on fish consumption rates
  - More geared towards subpopulations
    - Establishes **reference dose (0.00002 mg/kg-day)**
    - Establishes **cancer slope (2 per mg/kg-day)**

Regulation of PCBs

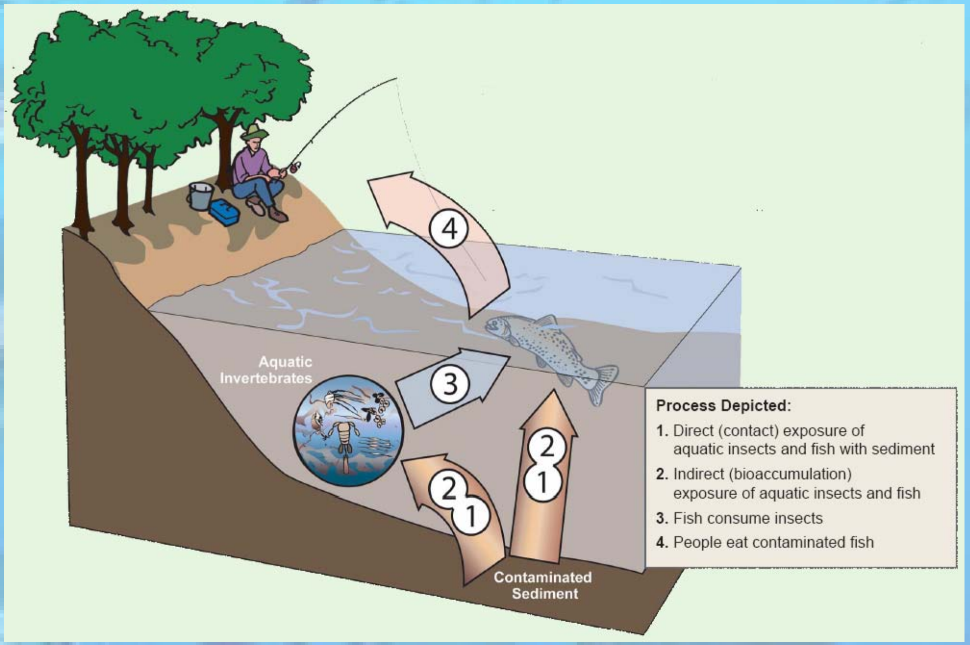
3 RI State agencies

- RIDOH (Department of Health)
- RIDEM (Department of Environmental Management)
  - Together, these agencies set a water quality standard.
- CRMC (RI Coastal Resources Management Council)
  - Control over dredging.

From Production to Exposure

•Source—PCBs enter the environment during manufacture, use, and disposal.

- PCBs are lipophilic, and bind to soil.
- They move into vegetation during the uptake of nutrients.



•Biomagnification—higher trophic level = higher concentration.

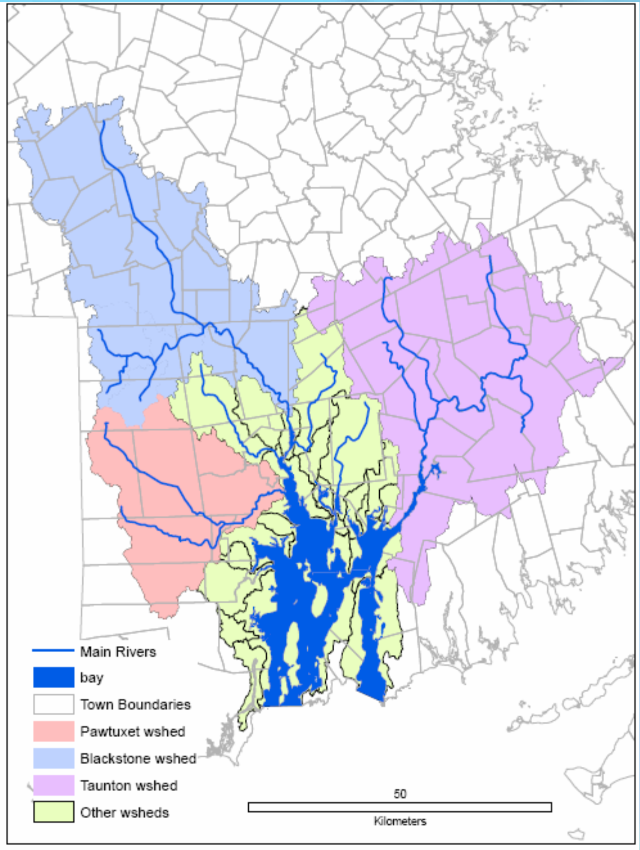
•Humans at the top of the food web.

Bioaccumulation

- Not only are humans at elevated risk because at top of the food chain, but also because of preferential bioaccumulation.
- As PCBs bioaccumulate and biomagnify up the food chain, the congeners that bioaccumulate preferentially are generally more toxic.
- Once absorbed in humans, PCBs enter the circulation, and eventually accumulate in fat and skin.

Narragansett Bay

- One of the most densely populated watersheds in the U.S.
- Drains about 4708 square km of RI and Massachusetts.
- Supports 2800 acres of salt marsh
- 4400 acres of tidal flats.
- Long history of industrial activity that have contributed large quantities of PCBs to the bay's sediments.



Narragansett Bay Contamination

- Approximately 14.5 kg of PCBs are discharged into Narragansett Bay each year, from chronic point and non-point source discharges
- Non-point sources—mostly rivers
    - Blackstone River and Pawtuxet River
- Point sources contribute from 5-17% of the total flow.
    - Fields Point—60% of point sources

Narragansett Bay Contamination

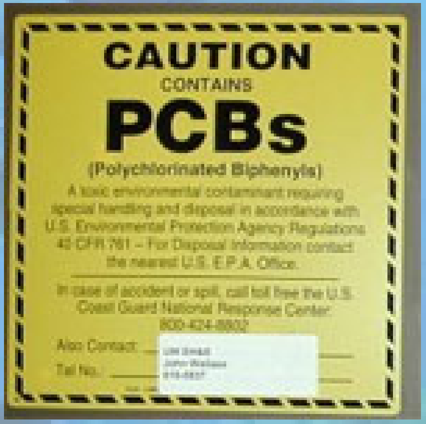
•The New England Coast basin, as a result of being very developed, has the highest average concentration of PCBs in streambed sediments (155 µg/kg, vs the rest of the country, 50 µg/kg), as well as fish tissue (325 µg/kg, vs the rest of the country, 50 µg/kg).

Study Population: SE Asian Fishermen

- Rhode Island has a large and growing SE Asian population
  - About 2% of the RI population is Asian. Nearly half of these are Southeast Asian, including Cambodians (20%), Laotians (14%), and Hmong (5%).
  - RI has the highest percentage increase of Asian Americans (245.6%) over 10 years in the nation.
- SE Asian fishermen consume more fish than the general population, and therefore have higher exposures to PCBs
  - Studies have found that SE Asians consume an average of 89 g of fish/day, compared to the general population rate of 17.8 g/day.

Health Effects of PCBs

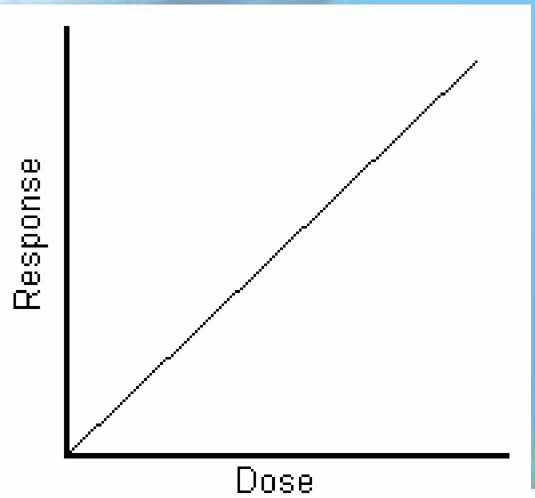
- Cancer (liver, gall bladder, biliary tract, gastrointestinal tract, and malignant melanomas.)
- Immune system damage (thymus gland damage)
- Reproductive system damage (birth weight reduction)
- Neurological damage (impaired fetal brain development, impaired learning)
- Endocrine system damage (decreased thyroid levels)



Estimating Cancer Risk

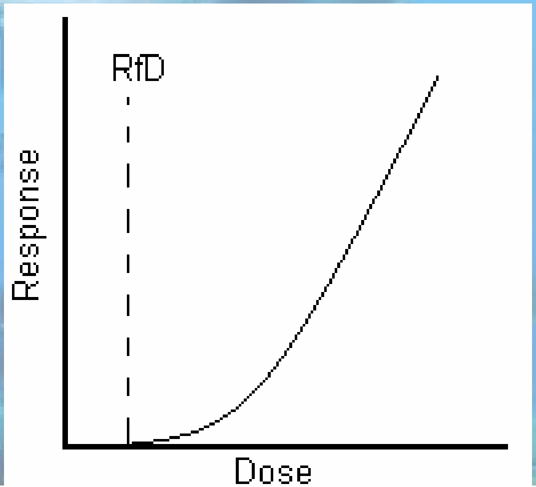
- Cancer risk—measured as 1 in 100,000 increased lifetime cancer risk
  - The dose-response relationship is assumed to be linear
  - **Excess lifetime cancer risk =**

    (average daily dose) * (cancer potency slope)
  - If risk is under 10^{-5}, the risk is considered acceptable by EPA



Estimating Non-cancer Risk

- Non-cancer risk—measured as hazard index (HI)
  - Assumed that there is a threshold below which there are no adverse health effects
  - Reference dose—estimate of daily exposure that is likely to be without appreciable risk of deleterious effects during a lifetime
  - **Hazard Index = (Average Daily Dose) / (RfD)**



Tiered Approach

- Ideal—assess each congener separately, but impossible
- We use a tiered approach with dioxin toxic equivalents
  - There are 2 types of PCBs—dioxin like (planar), and non-dioxin like
- Non-dioxin like congeners—use Aroclor data.
  - Different Aroclors have different toxicities (tiers), ranging from 0.07 to 2.
  - For human consumption, we will use the highest tier—a slope of 2 per mg/kg-day

Tiered Approach (cont)

•Dioxin like congeners—each assigned a toxic equivalence factor (TEF)

Table 3–4. WHO interim TEFs for human intake of dioxin-like PCBs

Non-ortho congeners	TEF	Mono-ortho congeners	TEF	Di-ortho congeners	TEF
77: 3,4,3',4'–TeCB	0.0005	105: 2,3,4,3',4'–PeCB	0.0001	170: 2,3,4,5,2',3',4'–HpCB	0.0001
81: 3,4,4',5-TCB	0.0001	114: 2,3,4,5,4'–PeCB	0.0005	180: 2,3,4,5,2',4',5'–HpCB	0.00001
126: 3,4,5,3',4'–PeCB	0.1	118: 2,4,5,3',4'–PeCB	0.0001		
169: 3,4,5,3',4',5'–HxCB	0.01	123: 3,4,5,2',4'–PeCB	0.0001		
		156: 2,3,4,5,3',4'–HxCB	0.0005		
		157: 2,3,4,3',4',5'–HxCB	0.0005		
		167: 2,4,5,3',4',5'–HxCB	0.00001		
		189: 2,3,4,5,3',4',5'–HpCB	0.0001		

•Dioxin—slope of 150,000 per mg/kg-day

•Each TEF is multiplied by the concentration of that congener to get its individual toxicity equivalency (TEQi)

•All of the TEQis are then summed to get the total toxicity of the dioxin like congeners (TEQ).

Estimating Daily Exposure

- Lifetime average daily dose (LADD)
- 2 separate LADDs—1 for dioxinlike congeners, and 1 for non-dioxinlike congeners
- **LADD = C*IR*ED / (BW*LT)**
  - C = TEQ or concentration
  - IR = intake rate
  - ED = exposure duration (set as 30 years)
  - BW = bodyweight (set as 70 kg)
  - LT = lifetime (set as 70 years)

Estimating Cancer and Non-cancer Risk

- Cancer risk = (slope)*(LADD)
  - Nondioxin-like congeners—slope 2.0 per mg/kg-day
  - Dioxin-like congeners—slope is 150,000 per mg/kg-day
- **Cancer risk =**

  $$(2.0)*(LADD_{nondioxin\text{-}like}) + (150{,}000)*(LADD_{dioxin\text{-}like})$$

- Noncancer risk: Hazard Index = $LADD_{total}$ / RfD
  - RfD = 0.00002 mg/kg-day
- **Hazard Index =** $(LADD_{total}) / (0.00002)$

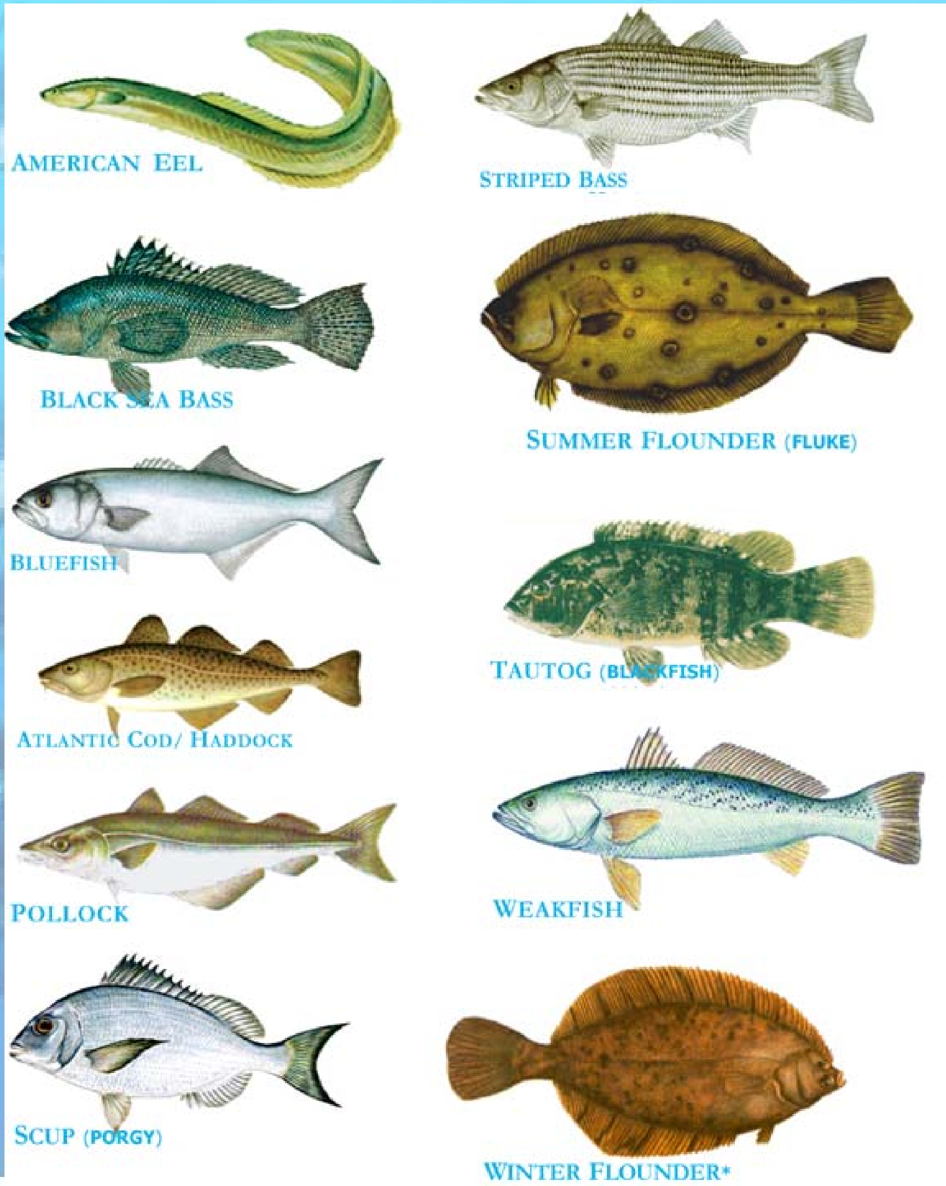
Study Design: Determining Consumption

Risk Interviews

- Risk interviews—34 questions, conducted in English
  - 30 participants—9 Hmong, 13 Laotians, 8 Cambodians
    - Contacted through local organizations: (SEDC, HUARI, LARI, CSRI)
  - Conducted at picnics, religious festivals, and ceremonies.
  - Conducted during summer 2006
  - Participants given a $10 stipend for their time
- Only criteria for participation in the study was a statement by the respondent that they ate fish that were caught in local waters.

Study Design (cont)

- The interview asked about:
  - Demographic information
  - Consumption rates
  - Source of fish
  - Parts of fish eaten
  - Fishing locations
  - Motivations for eating fish
  - Awareness of risk



Study Design: Determining PCB Concentrations

Sample Collection: Fish species

- Scup, striped bass, and tautog
- All fish caught in Rhode Island waters
- 10 scup (August), 6 striped bass (Sept), 7 tautog (Nov)

Study Design (cont)

Sample Preparation

•Fish frozen immediately after collection

•Weighed, filleted, and freeze dried

•0.5g of each sample was then separated out, along with a blank and a standard reference material (SRM 1946)

•Internal standard added—50μL of 1.00 ng/μL PCB 198

Study Design (cont)

Sample Preparation

•Extracted with the Accelerated Solvent Extraction machine

•Hexane (solvent) evaporated

•Samples re-dissolved in 1 mL hexane, then cleaned up with 1:1 (v/v) sulfuric acid/water solution

Study Design (cont)

Sample Analysis (pending)

•The samples were analyzed with a gas chromatography machine, with an electron capture detector (GC/ECD)

•The GC volatizes the sample (turns it into a gas) then runs it through a long column to separate out the compounds

•The ECD then detects the concentration of the compounds as they come out of the column.

•Each sample was tested for the following congeners: 1, 8, 18, 28, 29, 44, 50, 52, 66, 77, 87, 104, 105, 118, 126, 128, 138, 153, 154, 170, 180, 187, 188, 195, 201, 206, and 209

•Analysis still underway

Interview Results

Demographic Data

All : Hmong (9), Laotian (13), Cambodian (8)= 30					
	Average	**Minimum**	**Maximum**	**25th Percentile**	**75th Percentile**
Gender: Male	29				
Gender: Female	1				
Born in US	1				
Not born in US	29				
Age (yrs)	42.5 yrs	17 yrs	72 yrs	33.5	53 yrs
Years in US	23.67 yrs	15 yrs	32 yrs	19 yrs	27 yrs
Years in City	17.63 yrs	2 yrs	30 yrs	8.5 yrs	25 yrs
Weight (lbs)	155.23 lbs	120 lbs	200 lbs	142.5 lbs	167.5 lbs
# of Family Members	4.27	0	10	3	5.5
Has a spouse	26				
Doesn't have a spouse	4				
Spouse Age	40.04 yrs	18 yrs	75 yrs	30.5 yrs	48 yrs
Spouse Weight (lbs)	140.65 lbs	100 lbs	200 lbs	120 lbs	157.5 lbs
# of Children	2.7	0	7	0.5	5

Results (cont)

Fish Consumption

	Hmong = 9	Laotian = 13	Cambodian = 8	Total = 30
Scup	8 (88.9%)	13 (100%)	8 (100%)	29 (96.7%)
Striped Bass	9 (100%)	12 (92.3%)	8 (100%)	29 (96.7%)
Tautog	7 (77.8%)	11 (84.6%)	7 (87.5%)	25 (83.3%)
Bluefish	4 (44.4%)	9 (69.2%)	6 (75.0%)	19 (63.3%)
Summer Flounder	2 (22.2%)	10 (76.9%)	6 (75.0%)	18 (60.0%)
Black Sea Bass	2 (22.2%)	5 (38.5%)	6 (75.0%)	13 (43.3%)
Winter Flounder	2 (22.2%)	4 (44.4%)	5 (62.5%)	11 (36.7%)
Haddock	0 (0%)	3 (23.1%)	2 (25.0%)	5 (16.7%)
American Eel	0 (0%)	1 (7.7%)	2 (25.0%)	3 (10.0%)
Talapia	0 (0%)	3 (23.1%)	0 (0%)	3 (10.0%)
Trout	0 (0%)	2 (15.4%)	1 (12.5%)	3 (10.0%)
Salmon	0 (0%)	0 (0%)	3 (37.5%)	3 (10.0%)
Pollock	0 (0%)	0 (0%)	2 (25.0%)	2 (6.7%)
Weakfish	0 (0%)	0 (0%)	2 (25.0%)	2 (6.7%)
White Perch	2 (22.2%)	0 (0%)	0 (0%)	2 (6.7%)
Freshwater Bass	1 (11.1%)	0 (0%)	0 (0%)	1 (3.3%)
Tuna	0 (0%)	1 (7.7%)	0 (0%)	1 (3.3%)

Results (cont)

Fish Consumption

		Average	Min	Max	25th %	75th %
# meals of fish/week, summer	All	3.47	1	7	2.5	4.5
# meals of fish/week, winter	All	2.82	0	7	0.8	4.0
# meals of fish/week, annual avg	Hmong	2.54	1	7	1	5.8
	Laotian	2.76	1.4	5.5	1.6	3.4
	Cambodian	4.11	1.3	7	2.5	7
	All	3.06	0.6	7	1.4	3.5
Ounces of fish/meal	Hmong	15.33	7	21	11	21
	Laotian	14.85	5	24	7.3	22
	Cambodian	20.38	8	24	8	20
	All	16.47	5	64	8.5	21
Ounces of fish/week	Hmong	42.7	7	147	8.8	84.7
	Laotian	34.76	10	110	21.3	49.7
	Cambodian	103.31	20	168	40	56
	All	58.86	7	448	19.3	58

Results (cont)

Sources of Fish

All: Hmong, Lao., Camb. = 30				
	Local Water	**Supermarket**	**Fish market**	**Restaurant**
Scup	29	3	1	0
Striped Bass	27	6	0	1
Tautog	22	5	1	0
Bluefish	17	1	2	0
Summer Flounder	17	5	1	0
Black Sea Bass	11	4	0	1
Winter Flounder	10	3	0	1
Haddock	4	4	0	0
Other fish	3	3	2	0
Weakfish	2	1	0	0
American Eel	1	1	1	0
Pollock	1	2	0	0
Total	144	38	8	3

Results (cont)

Meals/Month, Local Waters

		Average	Minimum	Maximum	25th Percentile	75th Percentile
Black Sea Bass	Hmong	0.33	0	2	0	0.75
	Laotian	0.27	0	1	0	0.5
	Cambodian	3.88	0	10	0	10
	All	1.25	0	10	0	1
Scup	Hmong	7.72	0	30	2.5	15.5
	Laotian	3.96	1	10	1.38	5.5
	Cambodian	10	2.5	30	7	10
	All	6.7	0	30	2.5	9
Striped Bass	Hmong	3.94	1	10	1	8.5
	Laotian	3.92	0	10	1.38	5.5
	Cambodian	3.56	1	10	1	8
	All	3.83	0	10	1	5
Tautog	Hmong	7.17	0	30	0.5	14.5
	Laotian	2.32	0	6	0.25	4
	Cambodian	6.81	0	30	1	10
	All	4.97	0	30	0.75	4

Results (cont)

Reasons for eating fish

	Inexpensive	Tradition	Healthy	Tastes good	Like to go fishing
Hmong = 9	1	5	8	8	8
Laotian = 13	3	12	11	11	10
Cambodian = 8	0	5	7	7	5
All = 30	4 (13%)	22 (73%)	26 (87%)	26 (87%)	23 (77%)

Parts of fish eaten

- 56.9% of fish skins were eaten
- 47.5% of fish heads and other organs were eaten

Results (cont)

Fishing locations

•28 out of 30 fished

•14 fished in only saltwater

•0 fished in only freshwater

•14 fished in both saltwater and freshwater

	Narra-gansett	Newport	James-town	N.Kingston	Bristol	New Bedford	Seekonk
Hmong = 9	7	9	7	3	2	1	1
Laotian = 12	7	10	10	3	1	2	0
Cambodian = 7	7	5	6	1	0	0	0
All = 28	21	24	23	7	3	3	1

Results (cont)

Education

	Heard of bans/warnings?	Change habits?
Hmong = 9	6 (67%)	4 (67%)
Laotian = 13	9 (69%)	7 (78%)
Cambodian = 8	3 (38%)	3 (100%)
All = 30	18 (60%)	14 (78%)

	Heard of mercury/PCB in fish?	How much do you believe it?			
		Completely believe	**Believe**	**Somewhat believe**	**Don't believe**
Hmong = 9	5	3	1	0	1
Laotian = 13	9	6	0	3	0
Cambodian = 8	2	0	0	2	0
All = 30	53%	56%	6%	31%	6%

Results (cont)

Fish Consumption Rate

- Consumption rate:

$$\frac{(\#\text{ meals per month}) \times (\text{portion size g})}{(30\text{ days per month}) \times (\text{bodyweight kg})} = \text{g/kg/day}$$

- Calculation done for all fish, and for scup, striped bass, and tautog

Results (cont)

All fish (g/kg/day)					
	Average	Minimum	Maximum	25th Percentile	75th Percentile
Hmong	2.52	0.35	9.38	0.47	4.43
Laotian	2.4	0.6	6.04	1.33	2.94
Cambodian	6.03	1.15	24.24	1.19	12
All	3.65	0.35	24.24	1.06	3.15

Scup (g/kg/day)					
	Average	Minimum	Maximum	25th Percentile	75th Percentile
Hmong	1.87	0	9.38	0.23	2.65
Laotian	0.76	0.10	1.88	0.24	0.91
Cambodian	4.16	0.05	24.24	0.65	2.8
All	2.26	0	24.24	0.36	1.79

Results (cont)

Striped Bass (g/kg/day)					
	Average	**Minimum**	**Maximum**	**25th Percentile**	**75th Percentile**
Hmong	0.89	0.08	3.13	0.23	1.45
Laotian	0.74	0	1.88	0.23	1
Cambodian	1.47	0.11	8.08	0.13	1.6
All	1.03	0	8.08	0.22	0.97

Tautog (g/kg/day)					
	Average	**Minimum**	**Maximum**	**25th Percentile**	**75th Percentile**
Hmong	1.78	0	9.4	0.07	2.53
Laotian	0.55	0	1.88	0.02	0.89
Cambodian	3.58	0	24.24	0.20	1.85
All	1.97	0	24.24	0.13	0.96

Results (cont)

- "all fish" consumption rate often less than sum of 3 species

$C_{total,\ adjusted}$ =

$$C_{total,\ reported} – [(C_{total,\ reported}) - (C_{scup}+C_{striped\ bass}+C_{tautog,})] / 2$$

All Fish, adjusted (g/kg/day)	
Hmong	3.53
Laotian	2.225
Cambodian	7.62
All	4.455

Results (cont)

- Each species' consumption rate was then adjusted as a percentage of the new adjusted total
- $\% \ C_{scup} = C_{scup} \ / \ (C_{scup} + C_{striped\ bass} + C_{tautog})$
- $C_{scup} = (\% \ C_{scup})^*(C_{total,\ adjusted})$

	Scup (g/kg/day)	Striped Bass (g/kg/day)	Tautog (g/kg/day)	All, adjusted (g/kg/day)
Hmong	1.5	0.7	1.4	3.5
Laotian	0.8	0.8	0.6	2.2
Cambodian	3.4	1.2	3.0	7.6
All	1.9	0.9	1.6	4.5

Preliminary Results

- This study found an average of 4.5 g/kg/day consumption rate
- Other studies have found 0.325 µg/g of PCBs in fish tissue in the New England coast basin (Chalmers 2002)

- LADD: converting g/kg/day of fish to mg/kg/day of PCBs…

Exposure = (4.5 g fish/kg/day) (0.325 µg/g) (1 mg /1000 µg)

= 0.00146 mg/kg/day PCBs

Preliminary Results

- Exposure = 0.00146 mg/kg/day PCBs
- **Cancer risk** = (0.00146 mg/kg/day)(2 per mg/kg-day)

  = **.00292, or nearly 3 in 1000**

  → this is greater than 0.00001, so there is cancer risk

- **Non-cancer risk**:

Hazard Index = (0.00146 mg/kg/day)/(0.0002 mg/kg/day) = **7.3**

→ this is greater than 1, so there is non-cancer risk

Study limitations/uncertainties

- Lack of body burden data
- Small study size, biased study population
- Fish organs/skin not sampled, cooking not accounted for
- General uncertainties—
  - Validity of toxicity values
  - Reporting bias
  - Assumption that chemical effects are additive, not synergistic or antagonistic
- Supporting the study results— A 1999 EPA study on Asian and Pacific Islanders found a mean fish consumption rate of 1.891 g/kg/day, compared to our 4.5 g/kg/day

Remediation

Long term Remediation

- Goal—permanently reduce the levels of PCBs in the water and soil, permanently reducing exposure of humans to PCBs
  - Dredging
  - Bioremediation

Immediate Remediation

- Goal—reduce exposure of humans to PCBs instantly, to avoid any further harmful exposures
  - Fencing and capping
  - Posting warning signs
  - Educational campaign

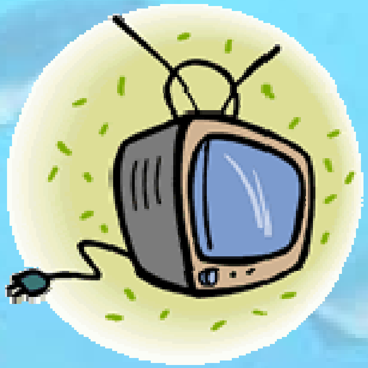
Long term remediation

- First major step has already been taken—PCB production has stopped
- Dredging—possible, but has many difficulties
  - Large impact on ecosystem
  - Problem of where to dispose of contaminated soil
- Bioremediation—degradation of PCBs by bacteria
  - Anaerobic: multichlorinated → 1-2 chlorines
  - Aerobic: degrade PCBs with 1-2 chlorines
  - Very slow, needs more research

Immediate Remediation

- Fencing and capping
- Posting warning signs
  - Location is key—newspapers, tide charts, bait and tackle shops, stores that sell fish

Immediate Remediation (cont)



- Educational campaign
  - Source of information is important—doctors & scientists most trusted (Zarcadoolas)
  - Method of communication—newsletters most preferred (75%), then TV (65%), and word of mouth (60%)
  - educational campaign should recommend monitoring and moderation

Working with the community

- Important to include the affected populations when looking to make policy decisions
- Environmental justice and community based participatory action
  - Community knowledge is essential for creating contextually relevant interventions
  - A dialogue should be set up between the government and community participants

Future Work

- Toxicity levels for each individual congener is needed to improve the precision of PCB studies
- More consistent coherent **national policy** is needed on risk assessment and management of contaminated seafood from the federal government
    - FDA and EPA should work together to provide a consistent approach across the states, to standardize risk assessment protocol, issuing advisories, and risk communication
- National seafood inspection program coordinated by both agencies

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Friends and Family

Thank you for your attention!