

# Seals as Sentinels

## Assessing Toxic Contaminants in Northwestern Atlantic Coast Seals

**Final Project Report**  
to the National Oceanographic and  
Atmospheric Administration  
(NOAA)

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## Table of Contents

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<b>Overview</b>	1
<b>Project Timeline</b>	1
<b>Deliverables</b>	1
<b>PROGRESS REPORT: Accomplishing Project Objectives</b>	2
1. Building Research Capacity	2
2. Staff Training	3
3. Collection of Marine Mammal Tissues and Tissue Banking	3
4. Database Management/Development	4
5. Contaminant Analysis	4
6. Statistical Analyses	5
7. Scientific Publications	6
8. Summary of Presentations	7
9. Outreach/Information Dissemination	8
10. Summary of Findings/Toxicological Implications	9
11. Continuing Work/Future Research	10

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### **APPENDIX A: Research Staff Biographies**

### **APPENDIX B: Summary of Analytical Results**

### **APPENDIX C: *Seals As Sentinels* Web Site Pages**

### **APPENDIX D: MERI Five-Year Research Plan**

### **APPENDIX E: Application for a Permit for Scientific Research under the Marine Mammal Protection Act of 1972**

### **APPENDIX F: Standard Operating Procedures for the *Seals as Sentinels* Capture-Release Project**

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## **PUBLICATIONS**

Shaw, S.D. (2007). Chapter 7. How are seals, as top predators, impacted by toxic contaminants in Casco Bay and the Gulf of Maine? In: *Toxic Pollution in Casco Bay: Sources and Impacts*. Casco Bay Estuary Partnership (<http://www.cascobay.usm.maine.edu>) (in press).

Susan D. Shaw and Bjorn Munro Jenssen (2006). Dioxin 2006 Session Summary: Levels and Effects in Marine Mammals. In: Thomsen, C. and Becher, G. (eds), *Plenary Lecture Abstracts and Session Summaries*, 26th International Symposium on Halogenated Persistent Organic Pollutants, Oslo, Norway, p. 51-54.

Shaw, S.D., Berger, M.L., Brenner, D., Fang, F., Hong, C-S., Storm, R., and O'Keefe, P. (2006a). Polybrominated diphenyl ethers (PBDEs) in harbor seals (*Phoca vitulina concolor*) from the northwestern Atlantic. *Organohalogen Compounds* 68:600-603.

*continued*

Shaw, S.D., Berger, M.L., Brenner, D., and Kannan, K. (2006b). Perfluorooctane sulfonate and related perfluorinated hydrocarbons in harbor seals (*Phoca vitulina concolor*) from the northwest Atlantic. *Organohalogen Compounds* 68:2042-2046.

Shaw, S.D., Berger, M.L., Brenner, D., Chu, M.D., Matherly, C.K., Chu, A.C., and Clark, G.C. (2006c). Application of the CALUX bioassay for the determination of PCDD/Fs and dioxin-like PCBs in tissues of harbor seals. *Organohalogen Compounds* 68:587-591.

## **POSTERS**

Shaw, S.D., Brenner, D., Bourakovsky, A., Mahaffey, C.A., and Perkins, C.R. (2005). Polychlorinated biphenyls and chlorinated pesticides in harbor seals (*Phoca vitulina concolor*) from the northwestern Atlantic coast.

Shaw, S.D., Berger, M.L., Brenner, D., and Kannan, K. (2006). Perfluorooctane sulfonate and related perfluorinated hydrocarbons in harbor seals (*Phoca vitulina concolor*) from the northwest Atlantic.

Berger, M.L., Brenner, D., Chu, M.D., Matherly, C.K., Chu, A.C., Clark, G.C., and Shaw, S.D. (2006). Application of the CALUX bioassay for the determination of PCDD/Fs and dioxin-like PCBs in tissues of harbor seals.

## **PRESS ARTICLES**

"Marine Toxicologist's Study Adds to the Body of Evidence on Flame Retardants in the Food Chain", Dateline: Montreal, Canada, November 9, 2006

"MERI Plans Expansion of Harbor Seal Research", *The Ellsworth American*, May 18, 2006

"Flame Retardants Pose Potential Health Risk", *Penobscot Bay Press*, February 17, 2005

"Group of Flame Retardants Banned", *Bangor Daily News*, April 16, 2004

## Overview

This is the Final Project Report on *Seals As Sentinels: Assessing Toxic Contaminants in Northwestern Atlantic Coast Seals* detailing ecosystem research provided by the Marine Environmental Research Institute to the Northeast Regional Office (NERO) of NOAA Fisheries to assist the agency in its effort to understand and manage marine ecosystems. Because marine ecosystems are extremely complex and difficult to study, NOAA Fisheries is exploring the possibility of using indicators that are relatively easily monitored as a proxy measure of the health of the overall ecosystem. The purpose of this contract was to implement a long-term investigation beginning in fall 2005 utilizing harbor seals as a mammalian sentinel species for ecosystem contamination and associated health risks. The contract was intended to continue to expand the research capacity of the Marine Environmental Research Institute in order to (1) broaden the spectrum of toxic contaminants analyzed in northwestern Atlantic coast seals; (2) assess temporal and spatial trends in the concentrations of contaminants in seal tissues; and (3) examine the trophic transfer of contaminants in the marine food chain by analyzing contaminants in selected prey fishes of seals.

## Project Timeline

October 1, 2005 – September 30, 2006 (Phase II)

## Deliverables

1. Interim Project Status Report, to be submitted on or about April 30, 2006
2. Final Project Status report, to be submitted on or about October 15, 2006

Project status reports will detail progress made in accomplishing the project objectives, and may include specific products such as tables with the analytical results, publications and reports, and a summary of presentations made using funds from this contract.

## PROGRESS REPORT: Accomplishing Project Objectives

During Phase II of the *Seals as Sentinels* project, the Marine Environmental Research Institute (MERI) has accomplished all the primary project objectives including building institutional research capacity, analyzing contaminant loads in seal tissues, performing statistical analysis of the data, publishing results, presenting findings to resource managers and scientists at regional and international meetings, and developing an understanding of the utility of seals as an indicator species for marine ecosystem health. Specific accomplishments are detailed below.

### Specific Accomplishments

Work performed to date includes:

#### 1. Building Research Capacity

MERI has substantially increased its research capacity by filling key professional research staff positions to implement the *Seals As Sentinels* project, hiring an experienced Science Communications Coordinator to broaden information dissemination and outreach, and providing ongoing training for the staff in field-work, labwork, tissue banking, database management, statistical analyses, and other aspects of this research.

Since April 2006, the Director/ Principal Investigator has committed 50% of her time to the *Seals As Sentinels* project. With more than 17 years of experience in the field of marine mammal toxicology, Dr. Shaw has served as MERI's Senior Scientist/Principal Investigator on multidisciplinary investigations examining levels and effects of environmental pollutants in marine mammals along the US Pacific and Atlantic coasts since 1989. She has authored numerous publications on the health effects of environmental pollutants and lectures frequently at international conferences. Dr. Shaw regularly chairs the Special Session *Persistent Organic Pollutants in Marine Mammals: Levels and Effects* at the annual International Dioxin Symposia held around the world. She currently serves on the Environmental Quality Monitoring Committee of the Gulf of Maine Council representing the New England states (Massachusetts, New Hampshire, and Maine) and Atlantic Canada (New Brunswick and Nova Scotia), and is a faculty member of the Institute for Health and the Environment, University at Albany. Dr. Shaw holds a doctoral degree in Public Health/Environmental Health Sciences from Columbia University.

In 2005-2006, MERI filled two professional research positions to help implement the long-term *Seals as Sentinels* project. Michelle Berger, a database expert, was hired as full-time Senior Research Assistant in summer 2005 to assist with database management, quality assurance/quality control, statistical analysis, data interpretation, and preparation of scientific publications and presentations. Prior to joining MERI, Berger worked at the Smithsonian Environmental Research Center (SERC) in Edgewater, MD as the head research technician in the Forest Ecology laboratory and SERC's Database Manager. Berger holds a Master's degree from Binghamton University, New York, in the field of Behavioral Ecology and a Bachelor of Science degree from the University of Maryland in Biology. In summer 2006 we hired a second Research Assistant/GIS Coordinator, Meggan Dwyer, who spends approximately one-half of her time working on the project. Dwyer has strong GIS skills, field and veterinary experience, database software proficiency, and writing and editing skills. She holds a Bachelor of Science degree in Wildlife Biology from the University of Rhode Island and a Master's degree in Conservation Biology from Columbia University, New York, NY.

In fall 2006, MERI hired Veronica Young as a Science Communications Coordinator to broaden public outreach for the *Seals As Sentinels* project and implement the dissemination of complex scientific information to diverse audiences. An experienced producer, writer, and director of television documentaries with a specialization in science and medicine, Young brings to the project strong skills in global communications, public relations, grant-writing, and the development of promotional materials. Prior to joining MERI's staff, Young served as producer/director/writer for the award-winning PBS science series NOVA, and previously was the Director of Information Programming at Time-Life Video and Associate Director for New Business Development (Video Group) at Time, Inc. in New York. A native of the United Kingdom, Young holds a Bachelor of Arts degree and Masters of Social Work equivalent from the University of Melbourne in Australia.

Four other MERI staff are currently working on the *Seals As Sentinels* project, including a Field and Lab Technician who coordinates our seal stranding response team, a Data Technician, a Senior Scientist/Consulting Epidemiologist, and a Community Outreach Coordinator (see Appendix A: Research Staff Biographies).

## **2. Staff Training**

In 2005-2006, members of MERI's research staff were extensively trained in field work techniques and sample collection/preparation methods using proper procedures and equipment according to approved, written protocols. In addition, training was provided in the use of new field and laboratory equipment, and on database management and statistical analysis methods. Training in the use of GIS software, spatial analysis, and mapping techniques is ongoing. Throughout the year, all staff were trained in marine mammal stranding response and necropsy procedures by stranding coordinators from the College of the Atlantic.

## **3. Collection of Marine Mammal Tissues and Tissue Banking**

During Phase II, MERI has coordinated the collection and banking of tissues from stranded marine mammals (live and postmortem) through the NMFS Northeast Region Stranding Network at locations throughout the Gulf of Maine and along the mid-Atlantic coast. Sample collection and processing, data acquisition and entry, and tissue banking procedures are conducted by several members of the research team including the Senior Research Assistant, Field and Lab Technician, Data Technician, and second Research Assistant. All samples (with the exception of whole blood) are frozen and stored in the MERI Tissue Bank at -80° C. until analysis. In conjunction with the collection and banking of marine mammal tissues, MERI's field research team directly assists the College of the Atlantic/Allied Whale and the Northeast Region Stranding Network in the response to stranded marine mammals along the Maine coast.

Under the term of this contract, MERI collected tissues *postmortem* for contaminant analysis from four pinniped and three cetacean species that stranded in this region (detailed below). These tissues will be used in future studies examining contaminant loads in animals occupying different ecological niches in the northwest Atlantic food web.

Animals Collected in 2006		Total in MERI Tissue Bank
15	Harbor seals ( <i>Phoca vitulina concolor</i> )	264
16	Harp seals ( <i>Pagophilus groenlandica</i> )	22
1	Hooded seal ( <i>Christophora cristata</i> )	5
4	Gray seals ( <i>Halichoerus grypus</i> )	24
8	Common dolphins ( <i>Delphinus delphis</i> )	8
7	White-sided dolphins ( <i>Lagenorhynchus acutus</i> )	7
2	Pilot whales ( <i>Globicephala melas</i> )	4
3	Harbor porpoises ( <i>Phocoena phocoena</i> )	3

In spring and summer 2006, MERI collected marine fishes from the Gulf of Maine for a food chain study investigating contaminant loads in selected prey of harbor seals. The following samples (whole fish, 10-20 per species) were collected through the state's trawl survey program:

Silver hake (*Merluccius bilinearis*)  
 White hake (*Urophycis tenuis*)  
 Atlantic herring (*Clupea harengus*)  
 Atlantic mackerel (*Scomber scombrus*)  
 Alewife (*Alosa pseudoharengus*)  
 Winter flounder (*Pleuronectes americanus*)  
 American plaice (dab) (*Hippoglossoides platessoides*)

#### 4. Database Management/Development

MERI's Senior Research Assistant, a database expert, has directed a recent upgrade of our sample chain-of-custody and data management system using FileMaker Pro (Version 8.0) software. Over the term of this contract, the database was substantially improved and is currently in use. We anticipate that the database will require continued development and refinement as the project evolves.

#### 5. Contaminant Analysis

We have completed the analysis of persistent organic pollutants (POPs) and metals in harbor seal tissues for several studies as detailed below. Contaminant analysis is underway for a new study examining contaminant loads in harbor seal prey.

##### Analysis completed (current projects):

- **Polybrominated Diphenyl Ethers (PBDEs) in NW Atlantic Coast Harbor Seals.** This project measured PBDEs in blubber samples collected from 28 harbor seals over the period 1991 to 2005. Analysis of 36 PBDE congeners in 28 seal blubber samples was completed in May 2006. Contract lab: Wadsworth Lab, NYS Department of Health, Albany, NY.
- **Perfluorooctane Sulfonate (PFOS) and Related Perfluorinated Hydrocarbons in NW Atlantic Coast Harbor Seals.** This project measured PFOS and related PFCs in 25 harbor seal liver samples. Analysis was completed in May 2006. Contract lab: Wadsworth Lab, NYS Department of Health, Albany, NY.

- **PCBs, Dioxins and Furans in Free-Ranging and Stranded Harbor Seals: Comparison of Results by CALUX and GC-MS.** This study applied two analytic methods, the CALUX bioassay and GC-MS, to assess body burdens of dioxin-like compounds (dioxin-like PCBs, dioxins and furans) in tissues obtained from 10 stranded harbor seals and 9 live stranded, rehabilitated pups. We also analyzed dioxins in blubber biopsies obtained from 4 live-captured pups under a research permit held by our UNE collaborators. This is the first study to examine correlations between the two methods in seal tissues. Analysis was completed in June 2006. Contract labs: Xenobiotic Detection Systems and Alta Analytical Labs, Durham, NC.
- **Heavy Metals and Trace Elements in NW Atlantic Coast Harbor Seals.** This project measured a suite of heavy metals and trace elements in 36 liver samples and mercury and cadmium in 30 kidney samples of stranded harbor seals from the Gulf of Maine and the mid-Atlantic region. This is the first region-wide study of its kind. Analysis was completed April 2005. Contract lab: Environmental Research Institute/University of Connecticut, Storrs, CT.

#### Analysis underway:

- **Higher Brominated Diphenyl Ethers (Hepta and Deca BDEs), PCBs, Dioxin-like PCBs, Dioxins and Furans (PCDD/Fs), and Chlorinated Pesticides in NW Atlantic Coast Harbor Seals.** This study previously measured 36 PBDE congeners in blubber samples collected from 28 harbor seals over the period 1991 to 2005. Analysis of hepta- through deca-BDEs and a suite of OCs in 42 harbor seal blubber samples is ongoing and is expected to be completed in April 2007. Contract lab: Wadsworth Lab, NYS Department of Health, Albany, NY.
- **Food Chain Study: Analysis of Persistent Organic Pollutants and Mercury in Harbor Seal Prey Fish.** This study measures a broad range of persistent organic pollutants (POPs) including PBDEs and mercury in the fish diet of northwestern Atlantic harbor seals. The research objectives are (1) to determine contaminant levels in selected prey fishes of harbor seals and (2) to compare contaminant levels and isomer patterns in prey fish with those previously found in seals in order to gain an understanding of the trophic transfer of persistent compounds through the marine food web. The study has implications for human health since most harbor seal prey fish (hake, herring, mackerel, flounder) are also commonly consumed by people. Contaminant analysis is being performed at ERGO, a specialized laboratory located in Hamburg, Germany.

## 6. Statistical Analyses

Phase II of the *Seals as Sentinels* project has generated several large datasets on contaminant levels in northwestern Atlantic harbor seals over the period 1991 to 2005 (see *Appendix B: Summary of Analytical Results*). We are engaged in ongoing statistical analyses and interpretation of the data, and are preparing and submitting manuscripts for publication in peer-reviewed journals. This activity has involved a large time commitment from members of the research staff including the PI, Senior Scientist/Environmental Epidemiologist, Senior Research Assistant, and second Research Assistant/GIS Specialist, and will continue to require a considerable amount of staff time in the future.



## 7. Scientific Publications

During Phase II, three peer-reviewed publications have resulted from the *Seals as Sentinels* project and six publications are in various stages of preparation (see below and attached). The new findings indicate that harbor seals from this region carry relatively high body burdens of a complex mixture of POPs in their tissues, including the brominated flame retardants (PBDEs) and perfluorinated compounds. Unlike the legacy POPs such as PCBs and DDT which were banned in the 1970s, these compounds of emerging concern are currently in production and use in the US. This study represents the first report of these current-use compounds in marine mammals from the northwestern Atlantic.

Findings from the *Seals as Sentinels* project, Phase II, have received widespread attention in recent publications and press articles, as highlighted below:

- The *Seals As Sentinels* results are featured in a chapter of an EPA-sponsored report entitled *Toxic Pollution in Casco Bay: Sources and Impacts* to be released in February 2007. In conjunction with this report, the PI will give a presentation of the results at a seminar/press conference to be held at the University of Southern Maine in late February 2007.
- In November 2006, three papers resulting from the project were presented at the Annual Meeting of the Society of Toxicology and Chemistry held in Montreal, Canada
- In August 2006, three new papers were presented at the international Dioxin Symposium held in Oslo, Norway.
- In May 2006, the study was profiled in a press article entitled "MERI Plans Expansion of Harbor Seal Research" in the Ellsworth American, a newspaper distributed throughout the mid-Maine coastal region.

### Publications completed to date:

Shaw, S.D. (2007). Chapter 7. How are seals, as top predators, impacted by toxic contaminants in Casco Bay and the Gulf of Maine? In: *Toxic Pollution in Casco Bay: Sources and Impacts*. Diane M. Gould, (ed.), Casco Bay Estuary Project, Casco Bay, Maine (in press).

Susan D. Shaw and Bjorn Munro Jenssen (2006). Dioxin 2006 Session Summary: Levels and Effects in Marine Mammals. In: Thomsen, C. and Becher, G. (eds), *Plenary Lecture Abstracts and Session Summaries*, 26th International Symposium on Halogenated Persistent Organic Pollutants, Oslo, Norway, p. 51-54.

Shaw, S.D., Berger, M.L., Brenner, D., Fang, F., Hong, C-S., Storm, R., and O'Keefe, P. (2006a). Polybrominated diphenyl ethers (PBDEs) in harbor seals (*Phoca vitulina concolor*) from the northwestern Atlantic. *Organohalogen Compounds* 68:600-603.

Shaw, S.D., Berger, M.L., Brenner, D., and Kannan, K. (2006b). Perfluorooctane sulfonate and related perfluorinated hydrocarbons in harbor seals (*Phoca vitulina concolor*) from the northwest Atlantic. *Organohalogen Compounds* 68:2042-2046.

Shaw, S.D., Berger, M.L., Brenner, D., Chu, M.D., Matherly, C.K., Chu, A.C., and Clark, G.C. (2006c). Application of the CALUX bioassay for the determination of PCDD/Fs and dioxin-like PCBs in tissues of harbor seals. *Organohalogen Compounds* 68:587-591.

### **Publications in preparation:**

Shaw, S.D., Berger, M.L., Brenner, D., and Kannan, K. (2007). Perfluorooctane sulfonate and related perfluorinated hydrocarbons in harbor seals (*Phoca vitulina concolor*) from the northwest Atlantic. For *Environmental Science & Technology*.

Shaw S.D., Berger, M.L., Brenner, D., Fang, F., Hong, C-S., Storm, R., and O'Keefe, P. (2007). Polybrominated diphenyl ethers (PBDEs), PCBs, and dioxin-like compounds in harbor seals (*Phoca vitulina concolor*) from the northwestern Atlantic. For *Environmental Science & Technology*.

Shaw, S.D., Berger, M.L., Brenner, D., Chu, M.D., Matherly, C.K., Chu, A.C., and Clark, G.C. (2007). Application of the CALUX bioassay for the determination of PCDD/Fs and dioxin-like PCBs in tissues of harbor seals. For *Environmental Science & Technology*.

Shaw, S.D., Brenner, D., Perkins, C.R., and Waring, G.T. (2007). Accumulation of heavy metals and trace elements in tissues of harbor seals (*Phoca vitulina concolor*) from the northwestern Atlantic. For: *Marine Pollution Bulletin*.

Shaw, S.D., Brenner, D., Berger, M.L., De Guise, S., Perkins, C.R., Clark, G.C., and Waring, G.T. (2007). Exposure to dioxin-like compounds and enhanced immune responses in free-ranging harbor seals (*Phoca vitulina concolor*). For *Environmental Health Perspectives*.

### **Previous Publications:**

Shaw, S.D., Brenner, D., Bourakovsky, A., Mahaffey, C.A., and Perkins, C.R. (2005). Polychlorinated biphenyls and chlorinated pesticides in harbor seals (*Phoca vitulina concolor*) from the northwestern Atlantic coast. *Marine Pollution Bulletin* 50:1069-1084.

Shaw, S.D., Brenner, D., Bourakovsky, A., Mahaffey, C.A., and Perkins, C.R. (2004). Persistent organic pollutants (POPs) in harbor seals (*Phoca vitulina concolor*) from the northwestern Atlantic coast. *Organohalogen Compounds* 66: 1581-1586.

## **8. Summary of Presentations**

MERI Director/Principal Investigator made presentations of the research findings generated by the *Seals as Sentinels* project at six major conferences and meetings using funds from this contract (detailed below). Numerous informal presentations were also made to colleagues and resource managers throughout the term of the contract.

### **■ Society for Environmental Toxicology and Chemistry (SETAC) 22nd Annual Meeting, Montreal, Canada, November 5-9, 2006**

MERI's Director/PI, the Senior Research Assistant, and the GIS Coordinator/Research Assistant, attended this international conference and presented three new papers from the *Seals as Sentinels* project:

“Polybrominated Diphenyl Ethers (PBDEs) in Harbor Seals (*Phoca vitulina concolor*) from the Northwestern Atlantic”

“Application of the CALUX Bioassay for the Determination of PCDD/Fs and Dioxin-Like PCBs in Tissues of Harbor Seals”

“Perfluorooctane Sulfonate And Related Perfluorinated Hydrocarbons In Harbor Seals (*Phoca vitulina concolor*) from the Northwestern Atlantic”

■ **Dioxin 2006, 26th International Symposium on Halogenated Environmental Organic Pollutants and Persistent Organic Pollutants (POPs), Oslo, Norway, August 21-25, 2006**

At the Dioxin Symposium in Oslo, Dr. Shaw chaired the Special Session: “POPs in Marine Mammals: Levels and Effects” (see Session Summary attached) and presented three new papers from the *Seals as Sentinels* project to the international scientific community.

“Polybrominated Diphenyl Ethers (PBDEs) in Harbor Seals (*Phoca vitulina concolor*) from the Northwestern Atlantic”

“Perfluorooctane Sulfonate And Related Perfluorinated Hydrocarbons In Harbor Seals (*Phoca vitulina concolor*) from the Northwestern Atlantic”

“Application of the CALUX Bioassay for the Determination of PCDD/Fs and Dioxin-Like PCBs in Tissues of Harbor Seals”

■ **Marine Environmental Research Institute, Annual Meeting of the Board of Directors, Blue Hill, Maine August 12, 2006**

Dr. Shaw presented an update on the *Seals As Sentinels* project to the MERI Board of Directors at the Annual Meeting of the Board in Maine. Her talk focused on the importance of MERI’s new studies on levels and trends of chemicals of emerging concern such as the brominated flame retardants (PBDEs) and perfluorinated compounds in northwestern Atlantic coast harbor seals.

■ **Eighth Annual Workshop on Brominated Flame Retardants, Toronto, Canada, June 27-29, 2006**

The PI gave a presentation titled “Polybrominated Diphenyl Ethers (PBDEs) in Harbor Seals (*Phoca vitulina concolor*) from the Northwestern Atlantic” at this international meeting. This was the first time that PBDEs had been reported in harbor seals from the region.

■ **NOAA/NMFS Northeast Region Stranding Conference, Ocean City, MD, March 24-26, 2006**

An update on the results of the *Seals as Sentinels* project entitled “Persistent Organic Pollutants in Northwestern Atlantic Harbor Seals” was presented to members of the NMFS Northeast Region Stranding Network, many of whom had assisted the project by providing tissues from stranded seals for contaminant analysis.

■ **State of the Bay Conference, Casco Bay Estuary Project, Portland, Maine, November 3, 2005**

Dr. Shaw gave a 30-minute power point slide talk in the Contaminants Session of this region-wide conference entitled “Impacts of Toxic Pollutants on Northwestern Atlantic Harbor Seals: Implications for Casco Bay.”

## 9. Outreach/Information Dissemination

MERI has implemented ongoing outreach activities to ensure that information generated by the *Seals As Sentinels* project is readily available to appropriate data-users including resource managers and policymakers in the form of hard copies and web available reports and through meetings with key managers/agencies and presentations at conferences. The outreach plan includes a new section of the MERI website’s research pages (see attached) featuring studies completed under the *Seals As Sentinels* project with links to federal and regional networks and available resources ([www.meriresearch.org](http://www.meriresearch.org)). The research pages will be available on-line in early 2007.

In addition to the Outreach Coordinator who devotes 25% of his time to the project, we recently hired an experienced Science Communications Coordinator to broaden public outreach for the *Seals As Sentinels* project and to disseminate the scientific findings to the global research community and diverse audiences (see *Appendix A: Research Staff Biographies* and attached press articles)

## 10. Summary of Findings/Toxicological Implications

The *Seals as Sentinels* project has generated the first extensive data in 25 years on levels and trends of toxic contaminants in harbor seals from the northwestern Atlantic coast. Although banned in the late 1970s, legacy pollutants such as PCBs and DDT are extremely persistent in the ocean environment and we are still detecting these compounds at significant levels in tissues of marine mammals. Previously, this research demonstrated that the levels of PCBs and chlorinated pesticides in northwestern Atlantic harbor seals are similar to those reported in seals from polluted areas of Europe and Asia and ten-fold higher than the levels in seals from the US Pacific coast (Shaw et al. 2005). PCB burdens found in our adult male, pup, and yearling harbor seals exceed the estimated threshold level of 17 $\mu$ g PCB/g lw in blubber for adverse effects on immune function in harbor seals, and fall within the estimated threshold level of 25-77  $\mu$ g PCB/g lw for reproductive effects in marine mammals. These observations, together with reports of a series of viral epizootics resulting in mass mortalities among these seals since the late 1970s, suggest that the population is currently at risk for adverse health effects, including effects on reproduction and immune and endocrine function.

The most recent mass mortality occurred in fall 2006 among harbor seals widely distributed throughout the northwestern Atlantic. Although the causal agent is unknown, it can be speculated that immunotoxic contaminants (e.g., PCBs) may have contributed to the event, by altering normal immune resilience in these seals. To examine this possibility, MERI researchers have collected tissues from affected animals for future contaminant analysis.

In Phase II of the *Seals as Sentinels* project, a major objective was to broaden the analysis to measure current-use chemicals such as the brominated flame retardants (PBDEs) and perfluorinated compounds that are of emerging concern in marine ecosystems and in humans, and to examine temporal and spatial trends in the accumulation of these compounds in seals and their prey. While some of this work is still underway, we have accomplished the following:

- For the first time, we reported the presence of the brominated flame retardants, PBDEs, in tissues of pinnipeds from the northwestern Atlantic (Shaw et al. 2006a). Our initial analysis of 36 PBDEs was performed on samples from 28 harbor seals and revealed that they are accumulating relatively high PBDE body burdens on a global scale.
- We have expanded the PBDE analysis to measure 40 congeners including the hepta through deca BDEs in a larger sample size (n=42). BDE 209 is the major component in the commercial DecaBDE mixture which comprises 80% of all PBDEs currently in production and use globally. The results of this analysis will help determine whether harbor seals are accumulating DecaBDE and/or metabolically debrominating BDE 209 to lower brominated and more toxic congeners, as has been shown in rats and fish. The data we have generated to date on a small subset of seals (n=4) provides the first evidence suggesting that metabolic debromination does occur in marine mammals.

- We have also detected perfluorooctane sulfonate (PFOS) and related perfluorinated hydrocarbons (PFCHs) in liver samples collected from 25 harbor seals (Shaw et al. 2006b). This is the first report of the occurrence of perfluorochemical compounds in marine mammals from the US northwestern Atlantic region. On a global scale, mean PFOS concentrations in these seals are similar to those found in harbor seals from industrialized areas of Europe including the Dutch Wadden Sea and the North Sea.
- We have analyzed dioxins and furans (PCDD/Fs) and dioxin-like PCBs in tissues of stranded and free-ranging harbor seals using two analytic methods (GC-MS and the CALUX bioassay), and for the first time, reported comparative results of the two methods in pinniped tissues (Shaw et al. 2006c).
- The *Seals as Sentinels* project has generated long-term data over the period 1991 – 2005 for the analysis of temporal trends for a broad range of contaminants detected in tissues of harbor seals. To date, we have found no significant temporal trends in the concentrations of persistent contaminants in seals from this region, although the congener patterns of certain compounds have shifted over time.
- No significant spatial trends were found in the concentrations or patterns of persistent contaminants in harbor seals from the northwestern Atlantic. However, it should be noted that although the data are region-wide, their heterogeneity with regard to age and gender of the animals was a limiting factor in the analysis. Future studies using larger sample sizes and homogenous datasets are needed to support meaningful analysis of spatial trends.
- We have begun a new study examining the trophic transfer of contaminants through the food chain by analyzing a broad suite of legacy and novel compounds in selected prey fish of harbor seals that are also frequently consumed by humans.

As top predators in the marine food chain, seals represent an important niche in the ecosystem and data generated from the *Seals as Sentinels* project is the first critical body of baseline information on the extent of toxic contamination in marine mammals inhabiting this region. However, the identification of cause and effect relationships between elevated concentrations and observed health impacts remains a challenging task. While the data from these studies indicate that current levels of POPs and mercury are high enough to pose health risks to harbor seals in this region, evaluation of harbor seals as an indicator species for ecosystem health is a complex process that requires further data collection and analysis.

The analysis of persistent pollutants in stranded animals can provide valuable information about body burdens, spatial and temporal trends, and factors influencing levels that is useful when comparing results with findings on stranded seals from other marine regions. However, such studies are limited in that the data are biased toward compromised individuals. Further work is needed to examine contaminant levels and biomarkers of effect including immune system and endocrine function markers in free-ranging seals, in order to identify possible relationships between tissue burdens and adverse health outcomes. Although more costly and invasive, biomarker studies using free-ranging seals are essential to the assessment of population- or species-level impacts.

## 11. Continuing Work/Future Research

At present, large data gaps exist that will be addressed as part of the continuing *Seals as Sentinels* project. Over the next five years, research objectives include but are not limited to the following:

- Complete the food chain study to elucidate the trophic transfer of contaminants from selected prey to harbor seals

- Complete the PBDE analysis to determine whether harbor seals are accumulating the DecaBDE mixture and/or metabolically debrominating BDE 209 to lower brominated and more toxic congeners
- Develop homogenous datasets for the analysis of spatial trends in contaminant distribution across the migratory range
- Continue to generate long-term data for analysis of temporal trends regarding the accumulation of persistent contaminants in seals
- Measure toxic contaminant loads in harbor seals that died in the 2006 mass mortality in order to gain an understanding as to whether immunotoxic chemicals may have played a role in this event
- Measure a broad range of contaminants in marine mammal species inhabiting this region (pinnipeds and cetaceans) in order to examine differences in accumulation among predators occupying different ecologic niches in the ocean food web
- Examine relationships between contaminant burdens and biomarkers of effects, including immune and endocrine function markers, in free-ranging seals
- Determine threshold levels of contaminant-related health effects in free-ranging seals

MERI has made substantial progress in planning for the next implementation phase of the *Seals as Sentinels* project. A 5-year research plan has been developed (see *Appendix D: MERI Research Plan*). We have invested considerable effort in expanding our network of collaborators and participating institutions, evaluating permitting needs and obtaining necessary permits, and identifying and training field team personnel. Since 2001, MERI has been an active participant in live capture studies under the permits of other institutions. In 2006 we completed an application for a NOAA NMFS Scientific Research permit to enable us to conduct research on free-ranging seals (see *Appendix E: Application for a Permit for Scientific Research under the Marine Mammal Protection Act of 1972*). Notice of the application was published in the Federal Register in March 2006 and we are in the process of responding to reviewers' comments. In order to incorporate organizational changes since that time, we plan to submit a revised application in 2007. In conjunction with the permit application, MERI has developed comprehensive Standard Operating Procedures manual for the field team (see *Appendix F: MERI Standard Operating Procedures for the Seals as Sentinels Capture-Release Project*).

The *Seals as Sentinels* project is the first long-term, region-wide research effort assessing harbor seals as wildlife sentinels of contaminant-related health effects. Results of this project will contribute to ecosystem-based management and natural resource policy and decision-making by: 1) providing evidence of linkages between exposure and effects in a mammalian sentinel species that will inform ecological and human health risk assessment; 2) contributing to the hazard assessment of POPs of emerging concern such as the brominated flame retardant chemicals that are increasing in marine food webs; 3) helping to identify relatively more polluted areas of the ecosystem that may need regulatory attention and/or remediation; and 4) guiding future research and monitoring efforts.



## APPENDIX A: RESEARCH STAFF BIOGRAPHIES

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### **Susan D. Shaw, Dr. P.H., Executive Director/ Principal Investigator**

An environmental toxicologist and public health expert, Dr. Shaw founded MERI in 1990 and serves as its Executive Director, supervising a 15-person staff as well as graduate students, interns, and volunteers. She is President/ CEO of MERI's Board of Directors and international Advisory Board. MERI serves a broad constituency in mid-coast Maine, while its research and policy initiatives affect the regulation of toxins and oceans management along the Eastern seaboard and internationally. For the past 17 years, Dr. Shaw has served as MERI's Senior Scientist/Principal Investigator on a series of ecotoxicological investigations examining levels and effects of environmental pollutants in marine mammals along the US Pacific and Atlantic coasts. She has directed the *Seals As Sentinels* project since its inception and is responsible for its overall implementation and development. Under her direction, the project has broadened to include analyses of pollutants of emerging concern such as the brominated flame retardants, PBDEs, and perfluorinated compounds in tissues of northwestern Atlantic harbor seals and their prey fish. Over the next five years, the *Seals As Sentinels* project will undertake a series of biomarker studies in order to examine relationships between contaminant loads and health effects in free-ranging seals. Dr. Shaw has authored numerous publications on the health effects of environmental pollutants and lectures frequently at international conferences. She regularly chairs the Special Session *Persistent Organic Pollutants in Marine Mammals* at the International Dioxin Symposia held around the world. Dr. Shaw currently serves on the Environmental Quality Monitoring Committee of the Gulf of Maine Council representing the New England states (Massachusetts, New Hampshire, and Maine) and Atlantic Canada (New Brunswick and Nova Scotia), and is a faculty member of the Institute for Health and the Environment, University at Albany. Dr. Shaw holds a doctoral degree in Public Health/ Environmental Health Sciences from Columbia University.

### **Diane Brenner, Dr. P.H., Senior Scientist/ Environmental Epidemiologist**

An environmental epidemiologist, Dr. Brenner specializes in research study design, study management, statistical analyses and interpretation of data related to health effects following exposure to environmental contaminants. Her responsibilities include assisting in the development of MERI's long-term research plan for the *Seals as Sentinels* project, obtaining necessary permits, and recruiting the research field team. Since 1990 she has provided policy evaluation, planning, publication, and editorial services to the Marine Environmental Research Institute, and currently assists the Director in the development and implementation of MERI's expanding research programs. Dr. Brenner holds a doctoral degree in Public Health/ Environmental Health Sciences from Columbia University.

### **Michelle Berger, M.S., Senior Research Assistant**

Berger is responsible for *Seals As Sentinels* database and data management, statistical analysis and interpretation, literature reviews, and preparation of scientific publications and presentations. Berger was formerly employed at the Smithsonian Environmental Research Center (SERC) in Edgewater, MD where she worked as SERC's database and metadata manager for 1.5 years and as the head research technician in the Forest Ecology laboratory for the last 4 years. Her primary research interest is the assessment of human impacts on ecosystems. Previously, she ran a primate lab in

Atlanta, GA, for two years. Her strengths in database organization, quality assurance, statistical analysis, data interpretation, and preparation of scientific publications and presentations are valuable assets in the management and analysis of our increasing number of datasets and in the preparation of scientific journal articles and reports for peer-reviewed journals and the presentation of findings at regional, national and international meetings. Berger also has strong skills in GIS, web page design and management, and experience in educating the public about ecological research and stewardship, which strengthen our outreach and information dissemination efforts. Berger holds a Master's degree from Binghamton University, New York, in the field of Behavioral Ecology and a Bachelor of Science degree in Biology from the University of Maryland.

#### **Simone Cromwell, Data Technician**

Cromwell serves as the manager of MERI's Marine Laboratories. She assists with sample collection and lab work, data management, results reporting, budgeting, organizing staff, and supervising research interns. In addition to her work on the *Seals as Sentinels* project, Cromwell also serves as coordinator of MERI's *Blue Hill Bay Watershed Monitoring* Project. Prior to joining MERI, Cromwell gained extensive lab experience working as a lab technician for the Eleanor Roosevelt Institute for Cancer Research where her responsibilities included tissue culture, gel electrophoresis, Western blotting and DNA extraction. She helped design and implement an experiment measuring the effects of ultrasound on ovarian mouse cells. Cromwell holds a Bachelor of Science degree in Biology from Antioch College, Ohio.

#### **Meggan Dwyer, M.S., GIS Specialist/ Research Assistant**

Dwyer is responsible for GIS mapping and spatial analysis on the *Seals As Sentinels* project. She performs field and labwork, and assists with the response to stranded seals, necropsies and tissue collection. She also assists with results reporting, scientific publications, and presentations. Dwyer has strong GIS skills, field and veterinary experience, data management, database software proficiency, and writing and editing skills. Her responsibilities include integrating GIS into the *Seals as Sentinels* project to look more closely at spatial trends in contaminant occurrence and to develop data layers that attempt to address the causal agents behind environmental contamination. Previously, she worked as a GIS analyst on the Millennium Village Project at Columbia University's Earth Institute. Dwyer's interest in the conservation of biodiversity led her to work on projects ranging from sustainable butterfly farming in Ecuador to monitoring oyster disease in Rhode Island to ecotourism in the Caribbean. Dwyer holds a Bachelor of Science degree in Wildlife Biology from the University of Rhode Island and a Master's degree in Conservation Biology from Columbia University, New York, NY.

#### **Kirk Trabant, Field and Lab Technician**

Working in conjunction with College of the Atlantic/Allied Whale and the NMFS Northeast Region Stranding Network, Trabant coordinates MERI's response to stranded, injured, and abandoned seals in the downeast Maine region. She conducts health assessments on stranded seals, performs necropsies, collects tissue samples for analysis and tissue banking, and assists with chain-of-custody, sample preparation, and shipping of samples to laboratories. Trabant also performs sample collection, processing, and data entry. Trabant holds a Bachelor of Arts degree in Education from the University of Vermont.



**Greg Williams, Community Outreach Coordinator**

Williams is responsible for disseminating information generated by the *Seals As Sentinels* project to a broad audience in order to bring to bear MERI's findings on public discourse and policymaking. Williams manages media relations, generates press releases and publicity, outreach meetings and programs, synthesizes public information in the form of fact sheets, flyers, newsletters and website updates, and represents MERI at local, regional, and national meetings and conferences. Previously, Williams worked as a news reporter for several Maine publications, including the *Ellsworth American* and the Penobscot Bay Press publications, as well as an English teacher in Nicaragua and Maryland. He holds a Bachelor of Arts degree in Geology from Denison University, Ohio.

**Veronica L. Young, Science Communications Coordinator**

An experienced producer, writer, and director of television documentaries with a specialization in science and medicine, Young brings to the *Seals As Sentinels* project strong skills in public relations, grant-writing, developing promotional materials, and explaining complex scientific issues to diverse audiences. Prior to joining MERI's staff in September 2006, Young has been an independent filmmaker and international business consultant. After working for BBC TV in London and New York, she served as producer/director/writer for four programs of the award-winning PBS science series *NOVA*. Young previously served as Director of Information Programming at Time-Life Video and Associate Director for New Business Development (Video Group) at Time, Inc. and Executive Producer of several TV documentary series. A native of the United Kingdom, Young holds a B.A. degree and Masters of Social Work equivalent from the University of Melbourne in Australia.

Revised 12-20-06



## Appendix B: Summary of Analytical Results

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**Table 1.** Concentrations of 35 PBDEs (ng/g lipid wt) by congener in blubber of harbor seals from the northwest Atlantic (N=42).

**Table 2.** Concentrations of 113 detected PCBs (ng/g lipid wt) by congener in blubber of harbor seals from the northwest Atlantic (N=42).

**Table 3.** Total PBDE concentration and total PCB concentration (ng/g lipid wt) by age class in blubber of harbor seals from the northwest Atlantic.

**Table 4.** Concentrations of four coplanar PCBs (pg/g lipid wt) by congener in blubber of harbor seals from the northwest Atlantic (N=42).

**Table 5.** Mean, standard deviation and median concentrations of perfluorinated compounds (ng/g wet wt) in liver of stranded harbor seals from the northwest Atlantic (N = 25).

Table 1. Concentrations of 35 PBDEs (ng/g lipid wt) by congener in blubber of harbor seals from the NW Atlantic (N=42).

BDE	Mean $\pm$ SD <sup>a</sup> (Min - Max)	% Detected	BDE	Mean $\pm$ SD <sup>a</sup> (Min - Max)	% Detected
1	ND	0	47	1684 $\pm$ 3963 (45 - 21842)	100
2	ND	0	49+71	7.0 $\pm$ 10 (ND - 48)	64
3	ND	0	66	ND	0
<b>Sum Mono</b>	ND	0	75	26 $\pm$ 34 (ND - 50)	5
7	ND	0	77	0.70 $\pm$ 1.0 (ND - 2.6)	12
8	ND	0	<b>Sum Tetra</b>	1690 $\pm$ 3975 (45 - 21926)	100
10	ND	0	85	8.0 $\pm$ 6.7 (ND - 21)	24
11	ND	0	99	238 $\pm$ 501 (16 - 2547)	100
12	ND	0	100	98 $\pm$ 203 (3.8 - 1026)	100
13	ND	0	116	1.0 $\pm$ 0.82 (ND - 2.0)	7
15	1.1 $\pm$ 1.4 (ND - 3.5)	12	118	2.4 $\pm$ 3.0 (ND - 11)	52
<b>Sum Di</b>	1.1 $\pm$ 1.4 (ND - 3.5)	12	119	2.1 $\pm$ 2.7 (ND - 12)	45
17	5.0 $\pm$ 5.7 (ND - 13)	14	126	0.51 $\pm$ 0.31 (ND - 0.90)	7
25	1.4 $\pm$ 0.63 (ND - 1.8)	5	<b>Sum Penta</b>	341 $\pm$ 704 (24 - 3373)	100
28	9.5 $\pm$ 20 (ND - 111)	88	138	ND	0
30	8.5 $\pm$ 18 (ND - 68)	33	153	268 $\pm$ 946 (ND - 6093)	98
32	ND	0	154	55 $\pm$ 131 (ND - 613)	93
33	ND	0	155	52 $\pm$ 134 (ND - 805)	88
35	0.21 (ND - 0.21)	2	166	ND	0
37	0.75 (ND - 0.75)	2	<b>Sum Hexa</b>	367 $\pm$ 1159 (ND - 7407)	98
<b>Sum Tri</b>	13 $\pm$ 33 (ND - 195)	90	<b>Sum PBDE</b>	2403 $\pm$ 5406 (80 - 25720)	100

<sup>a</sup>Mean and standard deviation were calculated only with samples above the limit of detection.

ND = not detected.

Table 2. Concentrations of 113 detected<sup>a</sup> PCBs (ng/g lipid wt) by congener in blubber of harbor seals from the NW Atlantic (N=42).

CB	Mean ± SD <sup>b</sup> (Min - Max)	% Detected	CB	Mean ± SD <sup>b</sup> (Min - Max)	% Detected
6	3.4 ± 2.0 (ND - 5.2)	7	46	3.7 ± 1.7 (ND - 5.6)	7
8	21 ± 20 (ND - 50)	19	47	512 ± 1098 (4.8 - 5953)	100
15	18 (ND - 18)	2	48	12 ± 11 (ND - 29)	19
<b>Sum DiCB</b>	25 ± 23 (ND - 56)	19	49	261 ± 505 (3.8 - 2392)	100
16	11 ± 9.6 (ND - 24)	19	51	2.5 ± 0.92 (ND - 3.6)	7
17	6.2 ± 8.6 (ND - 23)	31	52	782 ± 1550 (11 - 7065)	100
18	15 ± 25 (ND - 81)	60	53	4.9 ± 3.9 (ND - 9.5)	12
19	3.7 ± 2.8 (ND - 7.5)	12	56	8.8 ± 15 (ND - 70)	45
20+33	4.6 ± 7.3 (ND - 22)	48	60	3.3 ± 3.4 (ND - 13)	40
22	6.2 ± 4.5 (ND - 12)	12	63	0.91 ± 0.19 (ND - 1.2)	10
25	2.0 ± 0.19 (ND - 2.1)	5	64	11 ± 21 (ND - 110)	98
26	3.4 ± 2.2 (ND - 6.5)	17	66	23 ± 42 (ND - 198)	98
27	2.1 ± 1.1 (ND - 3.3)	10	70	20 ± 32 (3.5 - 146)	100
28	29 ± 41 (2.0 - 187)	100	71	4.3 ± 6.7 (ND - 33)	57
31	13 ± 18 (ND - 87)	98	73	1.5 ± 0.12 (ND - 2.7)	5
32	8.1 ± 8.0 (ND - 21)	21	74	200 ± 412 (6.3 - 2126)	100
<b>Sum TriCB</b>	62 ± 84 (3.7 - 275)	100	75	4.6 ± 4.5 (ND - 18)	43
40	1.9 ± 0.65 (ND - 2.4)	7	<b>Sum TetraCB</b>	1840 ± 3634 (40 - 17697)	100
41	2.0 ± 0.64 (ND - 2.7)	7	82	2.0 ± 3.0 (ND - 8.7)	17
42+59	3.1 ± 1.9 (ND - 6.3)	26	83+119	65 ± 131 (2.0 - 634)	100
44	18 ± 31 (1.1 - 151)	100	84+92	253 ± 550 (5.3 - 2720)	100
45	5.2 ± 4.1 (ND - 10.1)	12	85	700 ± 1465 (9.6 - 7665)	100

Table 2. Continued

CB	Mean $\pm$ SD <sup>b</sup> (Min - Max)	% Detected	CB	Mean $\pm$ SD <sup>b</sup> (Min - Max)	% Detected
87	133 $\pm$ 315 (ND - 1668)	98	135	74 $\pm$ 144 (ND - 696)	98
90+101	1750 $\pm$ 3860 (27 - 18947)	100	136	12 $\pm$ 23 (ND - 108)	98
91	63 $\pm$ 126 (1.2 - 680)	100	137	170 $\pm$ 360 (3.8 - 2019)	100
95	173 $\pm$ 360 (3.1 - 1787)	100	138	5255 $\pm$ 10132 (60 - 53786)	100
97	46 $\pm$ 97 (3.6 - 495)	100	141	88 $\pm$ 200 (2.7 - 1119)	100
99	3088 $\pm$ 6144 (23 - 30949)	100	144	41 $\pm$ 84 (ND - 423)	90
100	7.7 $\pm$ 9.8 (ND - 36)	43	146	1759 $\pm$ 3351 (17 - 17370)	100
103	11 $\pm$ 14 (ND - 49)	52	147	57 $\pm$ 101 (ND - 483)	86
104	0.98 $\pm$ 0.53 (ND - 1.4)	5	149	906 $\pm$ 1919 (9.7 - 10190)	100
105	251 $\pm$ 539 (10 - 2700)	100	151	211 $\pm$ 444 (1.9 - 2301)	100
109+123	21 $\pm$ 38 (2.1 - 213)	100	153	10363 $\pm$ 19188 (105 - 98930)	100
110	151 $\pm$ 332 (9.4 - 1734)	100	154	107 $\pm$ 186 (ND - 799)	98
114	2.6 $\pm$ 3.0 (ND - 6.1)	7	156	319 $\pm$ 631 (5.2 - 3128)	100
117	15 $\pm$ 32 (ND - 175)	88	157	105 $\pm$ 212 (1.3 - 988)	100
118	684 $\pm$ 1445 (25 - 7101)	100	158	164 $\pm$ 325 (ND - 1661)	95
122	4.4 $\pm$ 1.2 (ND - 5.3)	5	164	15 $\pm$ 31 (ND - 148)	85
124	1.3 $\pm$ 0.39 (ND - 1.9)	17	165	172 $\pm$ 185 (ND - 350)	10
<b>Sum PentaCB</b>	7399 $\pm$ 15349 (132 - 77468)	100	167	2.4 $\pm$ 3.2 (ND - 7.1)	10
128	1689 $\pm$ 3285 (11 - 15272)	100	<b>Sum Hexa CB</b>	23900 $\pm$ 45314 (289 - 236757)	100
129+163	1992 $\pm$ 3979 (25 - 22043)	100	170	1261 $\pm$ 2491 (14 - 13658)	100
130	314 $\pm$ 647 (4.9 - 3517)	100	171	221 $\pm$ 404 (3.0 - 2057)	100
132	269 $\pm$ 671 (6.3 $\pm$ 3890)	100	172	259 $\pm$ 522 (3.5 - 2932)	100
134	23 $\pm$ 26 (ND - 41)	5	173	64 (ND - 64)	2

Table 2. Continued

CB	Mean $\pm$ SD <sup>b</sup> (Min - Max)	% Detected	CB	Mean $\pm$ SD <sup>b</sup> (Min - Max)	% Detected
174	160 $\pm$ 431 (ND - 2553)	98	194	430 $\pm$ 746 (3.8 - 4430)	100
175	35 $\pm$ 54 (ND - 242)	88	195	114 $\pm$ 210 (1.2 - 1227)	100
176	3.6 $\pm$ 5.0 (ND - 20)	52	196	565 $\pm$ 972 (6.7 - 5648)	100
177	525 $\pm$ 1011 (7.2 - 5155)	100	197	45 $\pm$ 68 (ND - 294)	83
178	440 $\pm$ 806 (5.9 - 4445)	100	199	829 $\pm$ 1401 (8.3 - 7932)	100
179	9.4 $\pm$ 14 (ND - 71)	88	200	5.2 $\pm$ 2.9 (ND - 10)	12
180	3129 $\pm$ 5689 (32 - 29063)	100	201	5.9 $\pm$ 8.1 (ND - 20)	17
183	754 $\pm$ 1339 (ND - 7381)	98	202	531 $\pm$ 820 (3.2 - 4129)	100
185	15 $\pm$ 29 (ND - 146)	86	203	1000 $\pm$ 1679 (7.4 - 8883)	100
187	2039 $\pm$ 3529 (22 - 18971)	100	205	24 $\pm$ 43 (ND - 247)	86
189	13 $\pm$ 23 (ND - 106)	71	<b>Sum OctaCB</b>	3528 $\pm$ 5883 (31 - 32789)	100
190	176 $\pm$ 355 (2.3 - 2019)	100	206	262 $\pm$ 506 (1.1 - 3141)	100
191	45 $\pm$ 78 (ND - 379)	81	207	40 $\pm$ 60 (ND - 299)	88
193	212 $\pm$ 359 (3.2 - 1785)	100	208	141 $\pm$ 244 (0.82 - 1435)	100
<b>Sum HeptaCB</b>	9248 $\pm$ 16700 (124 - 89455)	100	<b>Sum NonaCB</b>	439 $\pm$ 802 (2.0 - 4874)	100
			209	107 $\pm$ 210 (ND - 1269)	95
			<b>Sum PCB</b>	46520 $\pm$ 86597 (629 - 460570)	100

<sup>a</sup> 21 PCB congeners were not detected in any sample: 1, 2, 3, 4+10, 5, 7, 9, 12, 13, 14, 24, 29, 34, 35, 37, 54, 67, 69, 93, 115, 131.

<sup>b</sup> Mean and standard deviation were calculated only with samples above the limit of detection.  
ND = not detected.

Table 3. Total PBDE concentration<sup>a</sup> and total PCB concentration<sup>b</sup> (ng/g lipid wt) by age class in blubber of harbor seals from the NW Atlantic.

Age	N	Sum PBDE ng/g lw		Sum PCB ng/g lw	
		Mean ± SD	Median	Mean ± SD	Median
Adult Male	7	1385 ± 1265	690	36685 ± 29545	34145
Adult Female	8	326 ± 193	249	14087 ± 14707	5933
Yearling	14	2945 ± 5995	1130	60479 ± 118284	19457
Pup	13	3645 ± 7388	658	56799 ± 93847	19490
All	42	2403 ± 5406	674	46538 ± 86605	18339

<sup>a</sup>Sum of 35 PBDE congeners.

<sup>b</sup>Sum of 113 PCB congeners.

Table 4. Concentrations of four coplanar PCBs (pg/g lipid wt) by congener in blubber of harbor seals from the NW Atlantic (N=42).

<b>CoPCB</b>	<b>Mean <math>\pm</math> SD<sup>a</sup> (Min - Max)</b>	<b>% Detected</b>
<b>77</b>	131 $\pm$ 146 (ND - 596)	74
<b>81</b>	91 $\pm$ 99 (ND - 359)	24
<b>126</b>	689 $\pm$ 1030 (38 - 5243)	100
<b>169</b>	177 $\pm$ 191 (ND - 774)	67
<b>Sum CoPCB</b>	925 $\pm$ 1275 (38 - 5900)	100

<sup>a</sup> Mean and standard deviation were calculated only with samples above the limit of detection.

ND = not detected.



Table 5. Mean, standard deviation and median concentrations of perfluorinated compounds (ng/g ww) in liver of stranded harbor seals from the northwest Atlantic (N = 25).

<b>Compound</b>	<b>Mean <math>\pm</math> SD<sup>a</sup> (Min - Max)</b>	<b>Median<sup>a</sup></b>	<b>% Detected</b>
<b>PFHpA</b>	1.6 $\pm$ 0.01 (ND - 1.6)	1.6	8
<b>PFOA</b>	6.7 (ND - 6.7)	6.7	4
<b>PFNA</b>	11 $\pm$ 7.0 (ND - 27)	7.8	40
<b>PFDA</b>	5.2 $\pm$ 1.1 (ND - 7.1)	5.0	28
<b>PFUnDA</b>	9.2 $\pm$ 4.8 (ND - 18)	8.2	96
<b>PFDoDA</b>	4.6 $\pm$ 0.6 (ND - 5.3)	4.4	12
<b>Sum PFCAs</b>	23 $\pm$ 12 (ND - 54)	18	96
<b>PFHS</b>	1.3 $\pm$ 0.5 (ND - 1.7)	1.4	16
<b>PFOS</b>	162 $\pm$ 179 (8.0 - 869)	100	100
<b>PFDS</b>	2.6 $\pm$ 1.3 (ND - 4.8)	2.3	24
<b>PFOSA</b>	5.0 $\pm$ 2.8 (ND - 8.8)	5.0	20
<b>Sum PFSs</b>	286 $\pm$ 181 (10-876)	112	100

<sup>a</sup> Mean, standard deviation, and median values were calculated only with samples above the limit of detection.

ND = not detected.



**APPENDIX C: *Seals as Sentinels* Website Pages**

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MERI Research: Current and Completed Projects

*Seals as Sentinels*

Free-Ranging Seals

Stranded Seals

Toxic Pollutants in Wild and Farmed Salmon

Pacific Seal Study

MERI Research: *Seals as Sentinels*: Assessing Toxic Contaminants in Northwestern Atlantic Coast Seals

*Seals as Sentinels*: Toxic Contaminants in Stranded Seals

Polychlorinated biphenyls (PCBs) and Organochlorine (OC) Pesticides

Dioxins, Furans, and Dioxin-Like PCBs

Brominated Flame Retardants (PBDEs)

Perfluorinated Compounds (PFCs)

Metals and Trace Elements

*Seals as Sentinels*: Toxic Contaminants in Free-Ranging Seals

*Seals as Sentinels*: Toxic Contaminants in Seal Prey Species

Food Habits Study 2000: Summary of harbor seal food habits in Mid-Coast Maine

Food Chain Study 2006: Toxic Contaminants in Harbor Seal Prey

Marine Mammal Tissue Bank

Marine Mammal Stranding Response

# MERI Research

Current and Completed Projects



## Research Topics

Seals as Sentinels  
Free-ranging  
Stranded

Toxic Pollutants in Wild  
and Farmed Salmon

Pacific Seal Study

MERI was founded in 1990 in response to mounting concerns about mass mortalities occurring among marine mammals and a possible contributing role of environmental chemicals (e.g., PCBs), in these events. To advance knowledge about ocean pollutants and their impact on the health of marine mammals, MERI's research has focused on examining levels and effects of persistent pollutants in marine mammals and their food sources along the US Pacific and Atlantic coasts.

# MERI Research

## Seals as Sentinels: Assessing Toxic Contaminants in Stranded Northwestern Atlantic Harbor Seals

### Research Topics

Toxic Contaminants in Stranded Seals

Toxic Contaminants in Free-Ranging Seals

Toxic Contaminants in Prey Species

Marine Mammal Tissue Bank

Stranding Response



Seals as Sentinels is an ongoing series of studies examining biomarkers of exposure and effects of toxic contaminants (organohalogenes and metals) on harbor seals (*Phoca vitulina concolor*) and gray seals (*Halichoerus grypus*) from the Northwestern Atlantic coast. This research has been partially funded by grants from the National Oceanic and Atmospheric Administration (NOAA), the Maine Department Environmental Protection's Toxic Monitoring Program and the Stroud Water Research Trust.

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# Seals as Sentinels

## Toxic Contaminants in Stranded Seals



### Toxic Contaminants

PCBs & OC  
Pesticides

Dioxins & Furans

PBDEs

PFCs

Heavy Metals &  
Trace Elements

Since the 1970's, ecotoxicological studies have linked an array of harmful effects in marine mammals including reproductive impairment, endocrine disruption, immune suppression, and disease outbreaks with their burdens of endocrine-disrupting pollutants, notably PCBs, DDT and mercury, but also novel compounds such as fluorinated and brominated substances. Ecotoxicological studies on marine mammals can also have predictive value for human health because humans and marine mammals exhibit similar biologic and toxic responses. The *Seals as Sentinels* Project at MERI, in accordance with the Marine Mammal Protection Act, uses samples collected from stranding networks on the Atlantic coast. Since 2001, MERI has archived approximately 600 tissue samples which can be used for future analysis. In the sidebar are the compounds that MERI has analyzed and continues to monitor in stranded seals.

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[Links](#)

# Seals as Sentinels

Polychlorinated biphenyls (PCBs) & OC  
Pesticides

## Downloadable Publications

[Journal Articles](#)

[Reports](#)

[Posters](#)



Lipophilic persistent organic pollutants (POPs) such as PCBs and other organochlorines (OCs) build up in fatty tissues like blubber and have been shown to cause immune and endocrine system disruption in seals and other marine wildlife. Evidence amassed over three decades suggests that immunotoxic chemicals such as PCBs have played a role in the recurring distemper virus outbreaks and mass mortalities reported among seals since the 1980s, by altering the animals' normal immune resistance to disease. Since 1999, MERI has collected seal blubber, liver, and kidney samples from seals stranded along the Northern Atlantic coast from Mount Desert Island, ME to Long Island, NY. Though PCBs were banned in the United States in the late 1970s, they were the predominant organic compound found in harbor seal tissues, reflecting the extreme persistence of these substances in the marine food chain.

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# Seals as Sentinels

## Mercury, Metals & Trace Elements



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There has been very little information reported about the levels or toxicological significance of metals and trace elements in seals from the Gulf of Maine. Since 2001, MERI has collected hair,

kidney and liver samples from harbor and gray seals in regions of the Gulf of Maine and tested for mercury and selenium. Seal liver and kidney samples were also tested for arsenic, cadmium, chromium, lead, silver, copper and zinc, but these metals were not detected at levels of concern. Total mercury concentrations in liver of the adult seals exceeded the threshold level of 60 ppm for liver damage in mammals. Elevated mercury levels are known to be common in livers of marine mammals, and seals have evolved mechanisms involving selenium to detoxify mercury. However, this ability may not be present in newborn and young seals following exposure to the mother's burden in utero and while nursing. Therefore, young and developing seals may be at risk for mercury toxicoses.

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# Seals as Sentinels

## Brominated Flame Retardants (PBDEs)



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Brominated flame retardants, especially polybrominated diphenyl ethers (PBDEs), are persistent organic pollutants that biomagnify and are associated with endocrine disruption and neurodevelopmental effects in animals. As a result of their lipophilicity, and widespread use as flame retardants in upholstery, furniture foam, consumer electronics, wire insulation and small appliances, PBDEs are now ubiquitous and have been found in the tissues of humans and animals even in remote locations. Since 2004, MERI has been monitoring PBDEs in Northwestern Atlantic harbor seals as part of the *Seals as Sentinels* Project. Our findings show that, on a global scale, PBDE concentrations in our samples are approximately at the middle of the contamination spectrum.

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# Seals as Sentinels

## Perfluorinated Compounds (PFCs)



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Perfluorooctane sulfonate (PFOS) and related perfluorinated organic compounds (PFCs) are used in coatings for carpets, apparel, nonstick cookware, paper, insecticides and surfactants for fire-fighting foams. Recently, they have been found widely distributed in the environment, humans and wildlife. PFCs are persistent and bioaccumulative although, unlike PCBs, they accumulate not in the blubber but in the blood plasma and liver. High concentrations of PFOS have been found in marine mammals, with higher concentrations occurring in animals near urban and industrial areas. PFCs have also been detected in marine mammals in remote areas, suggesting transport in the atmosphere and/or ocean currents. In 2006, MERI reported, for the first time, the occurrence of PFOS in harbor seals of the northwestern Atlantic and will continue to monitor these compounds in the future as part of the Seals as Sentinels Project.

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[Contact Us](#)

# Seals as Sentinels

## Dioxins & Dioxin-like Compounds (DLCs)



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Reports

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Dioxins and dioxin-like compounds are released from the incineration of wastes and the production of paper, pulp, PVC plastics and chlorinated pesticides. Dioxins are lipophilic and biomagnify in marine mammals. Furthermore they have been confirmed to be carcinogenic by the US EPA. Like other persistent organic chemicals, they are thought cause immune suppression and reproductive impairment in mammals. In 2006, MERI analyzed dioxins and furans (PCDD/fs) and dioxin-like PCBs in tissues of stranded and free-ranging harbor seals using two analytic methods (GC-MS and the CALUX bioassay), and for the first time, reported comparative results of the two methods in pinniped tissues

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# Seals as Sentinels

## Toxic Contaminants in Free-Ranging Seals

In 2004, MERI along with the University of New England, undertook a live capture study to examine seal pups in the downeast region of Maine. MERI collected tissues to analyze for a broad range of contaminants and to archive in the Center's tissue bank. While the analysis of persistent pollutants in stranded animals can provide valuable information when comparing results with findings on stranded seals from other marine regions, such studies are limited in that the data are biased toward compromised individuals. Further work

is needed to examine contaminant levels and biomarkers of effect in free-ranging seals, including immune system and endocrine function markers, in order to identify possible relationships between tissue burdens and adverse health outcomes. Therefore, in the 2007 field season, MERI will begin a live capture study that will extend over 5 years. This study will focus on harbor seal pups and will examine a wide range of parameters including concentrations of persistent organic chemicals and novel compounds, genetic variability, immune and endocrine function and overall health.



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# Seals as Sentinels

## Toxic Contaminants in Prey Species



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[Food Habits Study](#)

[Food Chain Study](#)

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The Food Habits study was the first attempt to establish the most important prey species of harbor seals in Mid-coast Maine haul-out sites. In June through August of 2000, 167 harbor seal scat samples were collected at several sites in Blue Hill Bay, Penobscot Bay and Mount Desert Rock. Silver hake (*Merluccius bilinearis*), red and white hake (*Urophycis spp.*) and redfish (*Sebastes mentella*) were the most dominant species in the harbor seal diet during the summer season. We are currently conducting a Food Chain study examining contaminants in harbor seal prey. In 2006, MERI gathered seven species of fish in the harbor seal diet for analysis of contaminant levels. The results, available in 2007, will provide a good basis for analyzing the causal sources of contamination in harbor seals.

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[Contact Us](#)

# Seals as Sentinels

## Marine Mammal Stranding Response



MERI's assistance with the National Marine Fisheries Northeast Stranding Network provides a critical link in this region's stranding response. MERI provides direct support by assisting College of the Atlantic/Allied Whale in response to strandings in downeast and midcoast Maine. Tissue samples obtained from stranded animals are collected at the center's necropsy lab and used in MERI's ongoing research. With more than 3,500 marine mammal strandings every year, MERI's help is crucial. The stranding specialists at MERI are trained to assist the standing network in responding to animals in trouble and can help determine what action, if any, is needed. If the animal needs to be sent to a rehabilitation facility, MERI can help recover the animal and ensure that it arrives safely. Click **here** to find out what to do if you find a stranded seal or carcass.

[MERI Home](#)

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# Seals as Sentinels

## Marine Mammal Tissue Bank



MERI, working closely with the Northeast Region Stranding Network, archives blubber, liver, skin, hair and other tissues of marine mammals inhabiting the northwest Atlantic. Species include harp seal, harbor seal, grey seal, common dolphin, white-sided dolphin and harbor porpoise. Tissue samples are collected in the Center's Necropsy Lab and used in MERI's ongoing research.



The Center's Tissue Bank houses -80 and -40 degree Celsius freezers, which hold both archived samples from previous studies and samples being prepared for future analysis. Currently, the tissue archive consists of over 600 tissue samples, compiled from over 10 years of research.

[MERI Home](#)

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